HVAC

EQUATIONS, DATA, AND RULES OF THUMB

THIRD EDITION

ARTHUR A. BELL, JR., P.E. • W. LARSEN ANGEL, P.E., LEED AP

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PART 1

Foreword

1.01

The heating, ventilation, and air conditioning (HVAC) equations, data, rules of thumb, and other information contained within this reference manual were assembled to aid the beginning engineer and designer in the design of HVAC systems. In addition, the experienced engineer or designer may find this manual useful as a quick design reference guide and teaching tool. The following pages compile information from various reference sources listed in Part 2 of this manual, from college HVAC class notes, from continuing education design seminars and classes, from engineers, and from personnel experience. This document was put together as an encyclopedic type reference in contract specification outline format where information could be looked up quickly, in lieu of searching through volumes of text books, reference books and manuals, periodicals, trade articles, and product catalogs.

1.02

Rules of thumb listed herein should be used considering the following:

A. Building loads are based on building gross square footage.

B. Building loads generally include ventilation and make-up air requirements.

C. Building loads should be calculated using the *ASHRAE Handbook of Fundamentals* or similar computational procedure in lieu of using these rules of thumb for final designs. When calculating heating and cooling loads, actual occupancy, lighting, and equipment information should be obtained from the Owner, Architect, Electrical engineer, other design team members, or from technical publications such as ASHRAE. These rules of thumb may be used to estimate system loads during the preliminary design stages of a project.

1.03

Code items contained herein were included more for comparison purposes than for use during design. All code items (i.e., BOCA, SBCCI, UBC, NFPA) are subject to change, and federal, state, and local codes should be consulted for applicable regulations and requirements. The following codes were used unless otherwise noted:

A. 1990 Building Officials and Code Administrators International, Inc., (BOCA) The Basic/National Building Codes

B. 1993 Building Officials and Code Administrators International, Inc., (BOCA) The Basic/National Building Codes

C. 1988 Southern Building Code Congress International, Inc., (SBCCI) The Standard/Southern Building Codes

D. 1988 International Conference of Building Officials, (ICBO) The Uniform Building Codes

E. 1991 National Fire Protection Association (NFPA) Codes

1.04

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C. The engineers at Henry Adams, Inc., in Baltimore, MD.

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PART 2

References and Design Manuals

2.01 References and Design Manuals

A. The references listed in the paragraphs to follow form the basis for most of the information contained in this manual. In addition, these references are excellent HVAC design manuals and will provide expanded explanations of the information contained within this text. These references are recommended for all HVAC engineers' libraries.

B. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbooks, Standards, and Manuals

ASHRAE. *ASHRAE Handbook, 1998 Refrigeration Volume, Inch-Pound Edition.* Atlanta, GA.: ASHRAE, 1998.

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PART 3

Definitions

3.01 General

A. *Furnish.* Except as otherwise defined in greater detail, the term *furnish* is used to mean "supply and deliver to the project site, ready for unloading, unpacking, assembly, installation, and similar operations" as applicable to each instance.

B. *Install.* Except as otherwise defined in greater detail, the term *install* is used to describe operations at the project site including actual "unloading, unpacking, assembly, erection, placing, anchoring, connecting, applying, working to dimension, finishing, curing, protecting, testing to demonstrate satisfactory operation, cleaning and similar operations" as applicable in each instance.

C. *Provide.* Except as otherwise defined in greater detail, the term *provide* means to furnish and install, complete and ready for intended use and successfully tested to demonstrate satisfactory operation as applicable in each instance.

D. *Remove.* Except as otherwise defined in greater detail, the term *remove* means to disassemble, dismantle, and/or cut into pieces in order to remove the equipment from the site and to properly dispose of the removed equipment and pay for all associated costs incurred.

E. *Replace.* Except as otherwise defined in greater detail, the term *replace* means to remove the existing equipment and to provide new equipment of the same size, capacity, electrical characteristics, function, etc., as the existing equipment.

F. *Relocate.* Except as otherwise defined in greater detail, the term *relocate* means to carefully remove without damaging item and to install where shown on the contract documents and/or as directed by the Engineer and/or Owner.

G. *Shall. Shall* indicates action which is mandatory on the part of the Contractor.

H. *Will. Will* indicates action which is probable on the part of the Contractor.

I. *Should. Should* indicates action which is probable on the part of the Contractor.

J. *May. May* indicates action which is permissible on the part of the Contractor.

K. *Indicated.* The term *indicated* is a cross-reference to graphic representations, details, notes, or schedules on the drawings; to other paragraphs or schedules in the specifications; and to similar means of recording requirements in the Contract Documents. Where terms such as *shown, noted, scheduled,* and *specified* are used in lieu of *indicated,* it is for the purpose of helping the reader locate the cross-reference, and no limitation is intended except as specifically noted.

L. *Shown.* The term *shown* is a cross-reference to graphic representations, details, notes, or schedules on the Contract Drawings and to similar means of recording requirements in the Contract Documents.

M. *Detailed.* The term *detailed* is a cross-reference to graphic representations, details, notes, or schedules on the Contract Drawings and to similar means of recording requirements in the Contract Documents.

N. *Specified.* The term *specified* is a cross-reference to paragraphs or schedules in the specifications and to similar means of recording requirements in the Contract

Documents. The specifications include the General Provisions, Special Provisions, and the Technical Specifications for the project.

O. *Including,* Such as. The terms *including* and *such as* shall always be taken in the most inclusive sense, namely "including, but not limited to" and "such as, but not limited to."

P. *Supply, Procurement.* The terms *supply* and *procurement* shall mean to purchase, procure, acquire, and deliver complete with related accessories.

Q. *At no additional cost.* The phrase "at no additional cost" shall mean at no additional cost to the Owner and at no additional cost to the Engineer or Construction Manager.

R. *Approved, Accepted.* Where used in conjunction with the Engineer's response to submittals, requests, applications, inquiries, reports, and claims by the Contractor, the meaning of the terms *approved* and *accepted* shall be held to the limitations of the Engineer's responsibilities to fulfill requirements of the Contract Documents. The terms *approved* and *accepted* shall also mean to permit the use of material, equipment, or methods conditional upon compliance with the Contract Documents.

S. *Approved Equal, Approved Equivalent.* The terms *approved equal* and *approved equivalent* shall mean possessing the same performance qualities and characteristics and fulfilling the same utilitarian function and approved by the Engineer.

T. *Directed, Requested, Required, etc.* Where not otherwise explained, terms such as *directed, requested, required, authorized, selected, approved, accepted, designated, prescribed, ordered,* and *permitted* mean "directed by the Engineer," "requested by the Engineer," "required by the Engineer," and similar phrases. However, no such implied meaning will be interpreted to expand the Engineer's responsibility into the Contractor's area of construction supervision.

U. *Review.* The term *review* shall mean limited observation or checking to ascertain general conformance with design concept of the Work and with information given in the Contract Documents. Such action does not constitute a waiver or alteration of the Contract Document requirements.

V. *Suitable, Reasonable, Proper, Correct, and Necessary.* Such terms shall mean as suitable, reasonable, proper, correct, or necessary for the purpose intended as required by the Contract Documents, subject to the judgement of the Engineer or the Construction Manager.

W. *Option.* The term *option* shall mean a choice from the specified products, manufacturers, or procedures which shall be made by the Contractor. The choice is not "whether" the Work is to be performed, but "which" product, "which" manufacturer, or "which" procedure is to be used. The product or procedure chosen by the Contractor shall be provided at no increase or additional cost to the Owner, Engineer, or Construction Manager and with no lessening of the Contractor's responsibility for its performance.

X. *Similar.* The term *similar* shall mean generally the same but not necessarily identical; details shall be worked out in relation to other parts of the work.

Y. ***Submit.*** **The term** ***submit*** **shall mean, unless otherwise defined in greater detail, transmit to the Engineer for approval, information, and record.**

Z. ***Project Site, Work Site.*** **The term** ***project site*** **shall be defined as the space available to the Contractor for performance of the Work, either exclusively or in conjunction with others performing other Work as part of the project or another project. The extent of the project site is shown on the drawings or specified and may or may not be identical with the land upon which the project is to be built. The project site boundaries may include public streets, highways, roads, interstates, etc., public easements, and property under ownership of someone other than the Client and are not available for performance of Work.**

AA. ***Testing Laboratories.*** **The term** ***testing laboratories*** **shall be defined as an independent entity engaged to perform specific inspections or tests of the Work, either at the project site or elsewhere, and to report and, if required, interpret the results of those inspections or tests.**

BB. ***Herein.*** **The term** ***herein*** **shall mean the contents of a particular section where this term appears.**

CC. ***Singular Number.*** **In all cases where a device or part of equipment or system is herein referred to in the singular number (such as fan, pump, cooling system, heating system, etc.) it is intended that such reference shall apply to as many such items as are required by the Contract Documents and to complete the installation.**

DD. ***No Exception Taken.*** **The term** ***no exception taken*** **shall mean the same as approved.**

EE. ***Approved as Noted, Make Corrections Noted, or Revise–No Resubmittal Required.*** **The terms** ***approved as noted, make corrections noted,*** **and** ***revise–no resubmittal required*** **shall mean the submittal essentially complies with the Contract Documents except for a few minor discrepancies that have been annotated directly on the submittal that will have to be corrected on the submittal and the Work correctly installed in the field by the Contractor.**

FF. ***Revise and Resubmit.*** **The term** ***revise and resubmit*** **shall mean the Contractor shall revise the submittal to conform with the Contract Documents by correcting moderate errors, omissions, and/or deviations from the Contract Documents and resubmit it for review prior to approval and before any material and/or equipment can be fabricated, purchased, or installed by the Contractor.**

GG. ***Disapproved/Resubmit.*** **The term** ***disapproved/resubmit*** **shall mean the Contractor shall revise the submittal to conform with the Contract Documents by correcting serious errors, omissions, and/or deviations from the Contract Documents and resubmit it for review prior to approval and before any material and/or equipment can be fabricated, purchased, or installed by the Contractor.**

HH. ***Disapproved or Rejected.*** **The terms** ***disapproved*** **and** ***rejected*** **shall mean the Contractor shall discard and replace the submittal because the submittal did not comply with the Contract Documents in a major way.**

II. ***Submit Specified Item.*** **The term** ***submit specified item*** **shall mean the Contractor shall discard and replace the submittal with a submittal containing the specified items because the submittal contained improper manufacturer, model number, material, etc.**

JJ. ***Acceptance.*** **The formal acceptance by the Owner or Engineer of the Work, as evidenced by the issuance of the Acceptance Certificate.**

KK. ***Contract Item, Pay Item, Contract Fixed Price Item.*** **A specifically described item of Work which is priced in the Contract Documents.**

LL. ***Contract Time, Time of Completion.*** **The number of Calendar Days (not working days) set forth in the Contract Documents for completion of the Work.**

MM. ***Failure.*** **Any detected inability of material or equipment, or any portion thereof, to function or perform in accordance with the Contract Documents.**

NN. ***Substantial Completion. Substantial completion*** **shall be defined as the sufficient completion and accomplishment by the Contractor of all Work or designated portions thereof essential to fulfillment of the purpose of the Contract, so the Owner can occupy or utilize the Work or designated portions thereof for the use for which it is intended.**

OO. ***Final Completion, Final Acceptance.*** **Final completion or final acceptance shall be defined as completion and accomplishment by the Contractor of all Work including contractual administrative demobilization Work, all punch list items, and all other Contract requirements essential to fulfillment of the purpose of the Contract, so the Owner can occupy or utilize the Work for the use for which it is intended.**

PP. ***Pre-Final Inspection or Observation.*** **The term** ***pre-final inspection or observation*** **shall be held to the limitations of the Engineer's responsibilities to fulfill the requirements of the Contract Documents and shall not relieve the Contractor from Contract obligations. The term** ***pre-final inspection*** **shall also mean all inspections conducted prior to the final inspection by the Owner, the Engineer, or both, verifying that all the Work, with the exception of required contractual administrative demobilization work, inconsequential punch list items, and guarantees, has been satisfactorily completed in accordance with the Contract Documents.**

QQ. ***Final Inspection or Observation.*** **The term** ***final inspection or observation*** **shall be held to the limitations of the Engineer's responsibilities to fulfill the requirements of the Contract Documents and shall not relieve the Contractor from Contract obligations. The term** ***final inspection*** **shall also mean the inspection conducted by the Owner, the Engineer, or both, verifying that all the Work, with the exception of required contractual administrative demobilization work, inconsequential punch list items, and guarantees, has been satisfactorily completed in accordance with the Contract Documents.**

RR. ***Reliability.*** **The probability that a system will perform its intended functions without failure and within design parameters under specified operating conditions for which it is designed and for a specified period of time.**

SS. ***Testing.*** **The term** ***testing*** **may be described as the inspection, investigation, analysis, and diagnosis of all systems and components to assure that the systems are operable, meet the requirements of the Contract Documents, and are ready for operation. Included are such items as:**

1. Verification that the system is filled with water and is not air bound.
2. Verification that expansion tanks of the proper size are connected at the correct locations and that they are not water logged.

3. Verification that all system components are in proper working order and properly installed. Check for proper flow directions.
4. Checking of all voltages for each motor in the system.
5. Checking that all motors rotate in the correct direction and at the correct speed.
6. Checking all motors for possible overload (excess amperage draw) on initial start-up.
7. Checking of each pump for proper alignment.
8. Checking all systems for leaks, etc.
9. Checking all systems and components to assure that they meet the Contract Document requirements as far as capacity, system operation, control function, and other items required by the Contract Documents.

TT. *Adjusting.* The term *adjusting* may be described as the final setting of balancing devices such as dampers and valves, in addition to automatic control devices, such as thermostats and pressure/temperature controllers to achieve maximum system performance and efficiency during normal operation. Adjusting also includes final adjustments for pumps by regulation of motor speed, partial close-down of pump discharge valve or impeller trim (preferred over the partial close-down of pump discharge valve).

UU. *Balancing.* The term *balancing* is the methodical regulation of system fluid flow-rates (air and water) through the use of workable and industry accepted procedures as specified to achieve the desired or specified flow quantities (CFM or GPM) in each segment (main, branch, or sub-circuit) of the system.

VV. *Commissioning.* The term *commissioning* is the methodical procedures and methods for documenting and verifying the performance of HVAC systems so that the systems operate in conformity with the design intent. Commissioning will include testing; adjusting; balancing; documentation of occupancy requirements and design assumptions; documentation of design intent for use by contractors, owners, and operators; functional performance testing and documentation necessary for evaluating the HVAC systems for acceptance; adjusting the HVAC systems to meet actual occupancy needs within the capability of the systems. Commissioning does not include system energy efficiency testing or testing of other building systems such as envelope, structure, electrical, lighting, plumbing, fire protection, and life safety. The purpose of commissioning of HVAC systems is to achieve the end result of a fully functional, fine-tuned HVAC system.

WW. *Functional Performance Testing.* The term *functional performance testing* shall mean the full range of checks and tests carried out to determine if all components, sub-systems, systems, and interfaces between systems function in accordance with the contract documents. In this context, *function* includes all modes and sequences of control operation, all interlocks and conditional control responses, and all specified responses to abnormal emergency conditions.

XX. *Confined Spaces. Confined spaces* (according to OSHA Regulations) are spaces which must have these three characteristics:

1. The space must be large enough and configured to permit personnel to enter and work.
2. The space is not designed for continuous human occupancy.
3. The space has limited or restricted means of entry and exit.

There are two categories of confined spaces:

1. *Non-Permit Required Confined Spaces (NRCS).* Spaces which contain no physical hazards that could cause death or series physical harm, and there is no possibility that it contains any atmospheric hazards.
2. *Permit Required Confined Spaces (PRCS).* Spaces which contain or may contain a hazardous atmosphere (atmospheric hazards—oxygen deficiency or enrichment 19.5% acceptable minimum and 23.5% acceptable maximum; flammable contaminants; and toxic contaminants—product, process, or reactivity); a liquid or finely divided solid material such as grain, pulverized coal, etc., that could surround or engulf a person; or some other recognized serious safety or health hazard such as temperature extremes or mechanical or electrical hazards (boilers, open transformers, tanks, vaults, sewers, manholes, pits, machinery enclosures, vats, silos, storage bins, rail tank cars, process or reactor vessels).

YY. Hazardous Location Classifications

1. Hazardous locations are those areas where a potential for explosion and fire exist because of flammable gases, vapors, or dust in the atmosphere, or because of the presence of easily ignitable fibers or flyings in accordance with the National Electric Code (*NEC—NFPA 70*).
2. *Class I Locations.* Class I locations are those locations in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures.
   a. *Class I, Division 1 Locations.* These are Class I locations where the hazardous atmosphere is expected to be present during normal operations. It may be present continuously, intermittently, periodically, or during normal repair or maintenance operations. Division 1 locations are also those locations where a breakdown in the operation of processing equipment results in the release of hazardous vapors while providing a source of ignition with the simultaneous failure of electrical equipment.
   b. *Class I, Division 2 Locations.* These are Class I locations in which volatile flammable liquids or gases are handled, processed, or used, but in which they can escape only in the case of accidental rupture or breakdown of the containers or systems. The hazardous conditions will occur only under abnormal conditions.
3. *Class II Locations.* Class II locations are those locations that are hazardous because of the presence of combustible dust.
   a. *Class II, Division 2 Locations.* These are Class II locations where combustible dust may be in suspension in the air under normal conditions in sufficient quantities to produce explosive or ignitable mixtures. This may occur continuously, intermittently, or periodically. Division 1 locations also exist where failure or malfunction of machinery or equipment might cause a hazardous location to exist while providing a source of ignition with the simultaneous failure of electrical equipment. Included also are locations in which combustible dust of an electrically conductive nature may be present.
   b. *Class II, Division 2 Locations.* These are Class II locations in which combustible dust will not normally be in suspension in the air and normal operations will not put the dust in suspension, but where accumulation of the dust may interfere with the safe dissipation of heat from electrical equipment or where accumulations near electrical equipment may be ignited by arcs, sparks, or burning material from the equipment.
4. *Class III Locations.* Class III locations are those locations that are hazardous because of the presence of easily ignitable fibers or flyings, but in which the fibers or flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures.

a. *Class III, Division 1 Locations.* These are locations in which easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.
b. *Class III, Division 2 Locations.* These locations are where easily ignitable fibers are stored or handled.

3.02 Systems

A. *Mechanical Systems.* The term *mechanical systems* shall mean for the purposes of these Contract Documents all heating, ventilating, and air conditioning systems and all piping systems as specified and as shown on the Mechanical Drawings and all services and appurtenances incidental thereto.

B. *Plumbing Systems.* The term *plumbing systems* shall mean for the purposes of these Contract Documents all plumbing fixtures, plumbing systems, piping systems, and all fire protection systems as specified and as shown on the Plumbing and/or Fire Protection Drawings and all services and appurtenances incidental thereto.

C. *Ductwork.* The term *ductwork* shall include ducts, fittings, flanges, dampers, insulation, hangers, supports, access doors, housings, and all other appurtenances comprising a complete and operable system.

1. *Supply Air Ductwork.* The term *supply air ductwork* shall mean for the purposes of these Contract Documents all ductwork carrying air from a fan or air handling unit to the room, space, or area to which it is introduced. The air may be conditioned or unconditioned. Supply air ductwork extends from the fan or air handling unit to all the diffusers, registers, and grilles.
2. *Return Air Ductwork.* The term *return air ductwork* shall mean for the purposes of these Contract Documents all ductwork carrying air from a room, space, or area to a fan or air handling unit. Return air ductwork extends from the registers, grilles, or other return openings to the return fan (if used) and the air handling unit.
3. *Exhaust Air Ductwork.* The term *exhaust air ductwork* shall mean for the purposes of these Contract Documents all ductwork carrying air from a room, space, area, or equipment to a fan and then discharged to the outdoors. Exhaust air ductwork extends from the registers, grilles, equipment, or other exhaust openings to the fan and from the fan to the outdoor discharge point.
4. *Relief Air Ductwork.* The term *relief air ductwork* shall mean for the purposes of these Contract Documents all ductwork carrying air from a room, space, or area without the use of a fan or with the use of a return fan to be discharged to the outdoors. Relief air ductwork extends from the registers, grilles, or other relief openings to the outdoor discharge point or from the return fan discharge to the outdoor discharge point.
5. *Outside Air Ductwork.* The term *outside air ductwork* shall mean for the purposes of these Contract Documents all ductwork carrying un-conditioned air from the outside to a fan or air handling unit. Outdoor air ductwork extends from the intake point or louver to the fan, air handling unit, or connection to the return air ductwork.
6. *Mixed Air Ductwork.* The term *mixed air ductwork* shall mean for the purposes of these Contract Documents all ductwork carrying a mixture of return air and outdoor air. Mixed air ductwork extends from the point of connection of the return air and outdoor air ductwork to the fan or air handling unit.
7. *Supply Air Plenum.* The term *supply air plenum* shall mean for the purposes of these Contract Documents all ductwork in which the discharges of multiple fans or air handling units connect forming a common supply header or all ductwork or ceiling con-

struction forming a common supply box where supply air ductwork discharges into the box at limited locations for air distribution to supply diffusers which are directly connected to the plenum.

8. *Return Air Plenum.* The term *return air plenum* shall mean for the purposes of these Contract Documents all ductwork in which the suctions of multiple return fans or the discharges of multiple return fans connect forming a common suction or discharge return header or the space above the architectural ceiling and below the floor or roof structure used as return air ductwork.
9. *Exhaust Air Plenum.* The term *exhaust air plenum* shall mean for the purposes of these Contract Documents all ductwork in which the suctions of multiple exhaust fans or the discharges of multiple exhaust fans connect forming a common suction or discharge exhaust header or the ductwork formed around single or multiple exhaust air discharge openings or louvers to create a connection point for exhaust air ductwork.
10. *Relief Air Plenum.* The term *relief air plenum* shall mean for the purposes of these Contract Documents all ductwork in which multiple relief air ductwork connections are made forming a common relief air header.
11. *Outdoor Air Plenum.* The term *outdoor air plenum* shall mean for the purposes of these Contract Documents all ductwork in which the suctions of multiple fans or air handling units connect to form a common outside air header or the ductwork formed around single or multiple outside air openings or louvers to create a connection point for outside air ductwork.
12. *Mixed Air Plenum.* The term *mixed air plenum* shall mean for the purposes of these Contract Documents all ductwork in which multiple return air and multiple outdoor air ductwork connections are made forming a common mixed air header.
13. *Vents, Flues, Stacks, and Breeching.* The terms *vents, flues, stacks, and breeching* shall mean for the purposes of these Contract Documents ductwork conveying the products of combustion to atmosphere for safe discharge.

D. *Piping.* The term *piping* shall include pipe, fittings, valves, flanges, unions, traps, drains, strainers, insulation, hangers, supports, and all other appurtenances comprising a complete and operable system.

E. *Wiring.* The term *wiring* shall include wire, conduit, raceways, fittings, junction and outlet boxes, switches, cutouts, receptacles, and all other appurtenances comprising a complete and operable system.

F. *Product.* The term *product* shall include materials, equipment, and systems for a complete and operable system.

G. *Motor Controllers.* The term *motor controllers* shall be manual or magnetic starters (with or without switches), individual push buttons, or hand-off-automatic (HOA) switches controlling the operation of motors.

H. *Control Devices.* The term *control devices* shall be automatic sensing and switching devices such as thermostats, float and electro-pneumatic switches controlling the operations of mechanical and electrical equipment.

I. *Work, Project.* The terms *work* and *project* shall mean labor, operations, materials, supervision, services, machinery, equipment, tools, supplies, and facilities to be performed or provided including Work normally done at the location of the project to accomplish the requirements of the Contract including all alterations, amendments, or extensions to the Contract made by Change Order.

J. *Extra Work.* The term *extra work* shall be any item of Work not provided for in the awarded Contract as previously modified by change order (change bulletin) or supplemental agreement, but which is either requested by the Owner or found by the Engineer to be necessary to complete the Work within the intended scope of the Contract as previously modified.

K. *Concealed.* The term *concealed* shall mean hidden from normal sight; includes Work in crawl spaces, above ceilings, in chases, and in building shafts.

L. *Exposed.* The term *exposed* shall mean not concealed.

M. *Below Ground.* The term *below ground* shall mean installed under ground, buried in the earth, or buried below the ground floor slab.

N. *Above Ground.* The term *above ground* shall mean not installed under ground, not buried in the earth, and not buried below the ground floor slab.

O. *Conditioned.* The term *Conditioned* shall mean for the purposes of these Contract Documents rooms, spaces, or areas that are provided with mechanical heating and cooling.

P. *Un-Conditioned and Non-Conditioned.* The terms *un-conditioned* and *non-conditioned* shall mean for the purposes of these Contract Documents rooms, spaces, or areas that are not provided with mechanical heating or cooling.

Q. *Heated.* The term *heated* shall mean for the purposes of these Contract Documents rooms, spaces, or areas that are provided with mechanical heating only.

R. *Air Conditioned.* The term *air conditioned* shall mean for the purposes of these Contract Documents rooms, spaces, or areas that are provided with mechanical cooling only.

S. *Unheated.* The term *unheated* shall mean for the purposes of these Contract Documents rooms, spaces, or areas that are not provided with mechanical heating.

T. *Ventilated Spaces.* The term *ventilated spaces* shall mean for the purposes of these Contract Documents rooms, spaces, or areas supplied with outdoor air on a continuous or intermittent basis. The outdoor air may be conditioned or unconditioned.

U. *Indoor.* The term *indoor* shall mean for the purposes of these Contract Documents items or devices contained within the confines of a building, structure, or facility and items or devices which are not exposed to weather. The term *indoor* shall generally reference ductwork, piping, or equipment location (indoor ductwork, indoor piping, indoor equipment).

V. *Outdoor.* The term *outdoor* shall mean for the purposes of these Contract Documents items or devices not contained within the confines of a building, structure, or facility and items or devices which are exposed to weather. The term *outdoor* shall generally reference to ductwork, piping, or equipment (outdoor ductwork, outdoor piping, outdoor equipment).

W. *Hot.* The term *hot* shall mean for the purposes of these Contract Documents the temperature of conveyed solids, liquids, or gases which are above the surrounding ambient temperature or above 100°F. (hot supply air ductwork, heating water piping).

X. *Cold.* The term *cold* shall mean for the purposes of these Contract Documents the temperature of conveyed solids, liquids, or gases which are below the surrounding ambient temperature or below 60°F. (cold supply air ductwork, chilled water piping).

Y. *Warm.* The term *warm* shall mean for the purposes of these Contract Documents the temperature of conveyed solids, liquids, or gases which are at the surrounding ambient temperature or between 60°F. and 100°F. (condenser water piping).

Z. *Hot/Cold.* The term *hot/cold* shall mean for the purposes of these Contract Documents the temperature of conveyed solids, liquids, or gases that can be either hot or cold depending on the season of the year (heating and air conditioning supply air ductwork, dual temperature piping systems).

AA. *Removable.* The term *removable* shall mean detachable from the structure or system without physical alteration or disassembly of the materials or equipment or disturbance to other construction.

BB. *Temporary Work.* Work provided by the Contractor for use during the performance of the Work, but which is to be removed prior to Final Acceptance.

CC. *Normally Closed (NC).* The term *normally closed* shall mean the valve, damper, or other control device shall remain in or go to the closed position when the control air pressure, the control power or the control signal is removed. The position the device will assume when the control signal is removed.

DD. *Normally Open (NO).* The term *normally open* shall mean that the valve, damper, or other control device shall remain in, or go to, the open position when the control air pressure, the control power, or the control signal is removed. The position the device will assume when the control signal is removed.

EE. *Traffic Level or Personnel Level.* The term *traffic level or personnel level* shall mean for the purposes of these Contract Documents all areas, including process areas, equipment rooms, boiler rooms, chiller rooms, fan rooms, air handling unit rooms, and other areas where insulation may be damaged by normal activity and local personnel traffic. The area extends vertically from the walking surface to 8′-0″ above walking surface and extends horizontally 5′-0″ beyond the edge of walking surface. The walking surface shall include floors, walkways, platforms, catwalks, ladders, and stairs.

3.03 Contract Documents

A. *Contract Drawings.* The terms *contract drawings* and *drawings* shall mean all drawings or reproductions of drawings pertaining to the construction or plans, sections, elevations, profiles, and details of the Work contemplated and its appurtenances.

B. *Contract Specifications.* The terms *contract specifications* and *specifications* shall mean the description, provisions, and other requirements pertaining to the method and manner of performing the Work and to the quantities and qualities of materials to be furnished under the Contract. The specifications shall include the general provisions, the special provisions, and the technical specifications.

C. *Contract Documents.* The term *contract documents* shall include Contract Drawings, Contract Specifications, Addendums, Change Orders, shop drawings, coordination drawings, General Provisions, Special Provisions, the executed Agreement and other items required or pertaining to the Contract including the executed Contract.

D. *Addendums.* Addendums are issued as changes, amendments, or clarifications to the original or previously issued Contract Documents. Addendums are issued in written and/or drawing form prior to acceptance or signing of the Construction Contract.

E. *Change Orders (Change Bulletins).* Change orders (change bulletins) are issued changes or amendments to the Contract Documents. Change orders are issued in written and/or drawing form after acceptance or signing of the Contract.

F. *Shop Drawings.* The term *shop drawings* shall include drawings, diagrams, schedules, performance characteristics, charts, brochures, catalog cuts, calculations, certified drawings, and other materials prepared by the Contractor, Sub-Contractor, Manufacturer, or Distributor which illustrates some portion of the Work as per the requirements of the Contract Documents used by the Contractor to order, fabricate and install mechanical and electrical equipment and systems in a building.

The corrections or comments annotated on a shop drawing during the Engineer's review do not relieve the Contractor from full compliance with the Contract Documents regarding the Work. The Engineer's check is only a review of the shop drawing's general compliance with the information shown in the Contract Documents. The Contractor remains responsible for continuing the correlation of all material and component quantities and dimensions, coordination of the Contractor's Work with that of other trades, selection of suitable fabrication and installation techniques, and performance of Work in a safe and satisfactory manner.

G. *Product Data.* Illustrations, standard schedules, performance charts, instructions, brochures, diagrams, and other information furnished by the Contractor to illustrate a material, product, or system for some portion of the Work.

H. *Samples.* Physical examples which illustrate material, equipment, or workmanship and establish standards to which the Work will be judged.

I. *Coordination Drawings.* The terms *coordination drawings* and *composite drawings* are drawings created by the respective Contractors showing Work of all Contractors superimposed on the sepia or mylar of the basic shop drawing of one of the Contractors to coordinate and verify that all Work in a congested area will fit in an acceptable manner.

J. *Contract.* A set of documents issued by the Owner for the Work, which may include the Contract Documents, the Advertisement, Form of Proposal, Free Competitive Bidding Affidavit, Affidavit as to Taxes, Certification of Bidder, Buy America Requirements, Disadvantaged Business Enterprise Forms, Bid Bond, Agreement, Waiver of Right to File Mechanics Lien, Performance Bond, Labor and Materialman's Bond, Maintenance Bond(s), Certification Regarding Lobbying, Disclosure Form to Report Lobbying, and other forms that form part of the Contract as required by the Owner and the Contract Documents.

K. ***Labor and Materialman's Bond.*** **The approved form of security furnished by the Contractor and its Surety as a guaranty to pay promptly, or cause to be paid promptly, in full, such items as may be due for all material furnished, labor supplied or performed, rental of equipment used, and services rendered in connection with the Work.**

L. ***Maintenance Bond.*** **The approved form of security furnished by the Contractor and its Surety as a guaranty on the part of the Contractor to remedy, without cost to the Owner, any defects in the Work which may develop during a period of twelve (12) months from the date of Substantial Completion.**

M. ***Performance Bond.*** **The approved form of security furnished by the Contractor and its Surety as a guaranty on the part of the Contractor to execute the Work.**

N. ***Working Drawings.*** **Drawings and calculations which are prepared by the Contractor, Sub-Contractor, Supplier, Distributor, etc., and which illustrate Work required for the construction of, but which will not become an integral part of, the Work. These shall include, but are not limited to, drawings showing Contractor's plans for Temporary Work such as decking, temporary bulkheads, support of excavation, support of utilities, groundwater control systems, forming and false-work, erection plans, and underpinning.**

O. ***Construction Drawings.*** **Detailed drawings which are prepared by the Contractor, Sub-Contractor, Supplier, Distributor, etc., and which illustrate in exact and intricate detail, Work required for the construction Contract. These drawings often show hanger locations, vibration isolators, ductwork and pipe fittings, sections, dimensions of ducts and pipes, and other items required to construct the Work.**

P. ***Project Record Documents.*** **A copy of all Contract Drawings, Shop Drawings, Working Drawings, Addendum, Change Orders, Contract Documents, and other data maintained by the Contractor during the Work. The Contractor's recording, on a set of prints, of accurate information and sketches regarding exact detail and location of the Work as actually installed, recording such information as exact location of all underground utilities, Contract changes, and Contract deviations. The Contractor's information is then transferred to the original Contract Documents by the Engineer for the Owner's permanent record unless otherwise directed or specified.**

Q. ***Proposal Guaranty.*** **Cashier's check, certified check, or Bid Bond accompanying the Proposal submitted by the Bidder as a guaranty that the Bidder will enter into a Contract with the Owner for the performance of the Work indicated and file acceptable bonds and insurance if the Contract is awarded to it.**

R. ***Project Schedule.*** **The schedule for the Work as prepared and maintained by the Contractor in accordance with the Contract Documents.**

S. ***Certificate of Substantial Completion.*** **Certificate issued by the Owner or Engineer certifying that a substantial portion of the Work has been completed in accordance with the Contract Documents with the exception of contractual administrative demobilization work, inconsequential punch list items, and guarantees. The Certificate of Substantial Completion shall establish the Date of Substantial Completion, shall state the responsibilities of the Owner and the Contractor for security,**

maintenance, heat, utilities, damage to the Work, and insurance, and shall fix the time within which the Contractor shall complete the items listed therein. Warranties required by the Contract Documents shall commence on the Date of Substantial Completion of the Work or designated portion thereof unless otherwise provided in the Certificate of Substantial Completion or the Contract Documents.

T. *Certificate of Final Completion (Final Acceptance).* Certificate issued by the Owner or Engineer certifying that all of the Work has been completed in accordance with the Contract Documents to the best of the Owner's or Engineer's knowledge, information, and belief, and on the basis of that person's observations and inspections including contractual administrative demobilization work and all punch list items. The Certificate of Final Completion shall establish the Date of Owner acceptance. Warranties required by the Contract Documents shall commence on the Date of Final Completion of the Work unless otherwise provided in the Certificate of Substantial Completion or the Contract Documents.

U. *Acceptance Certificate.* Certificate to be issued by the Owner or Engineer certifying that all the Work has been completed in accordance with the Contract Documents.

V. *Award.* The acceptance by the Owner of the Bid from the responsible Bidder (sometimes the lowest responsible Bidder) as evidenced by the written Notice to Award to the Bidder tendering said bid.

W. *Bid (Proposal).* The Proposal of the Bidder for the Work, submitted on the prescribed Bid Form, properly signed, dated, and guaranteed, including Alternates, the Unit Price Schedule, Bonds, and other bidding requirements as applicable.

X. *Certificate of Compliance.* Certificate issued by the Supplier certifying that the material or equipment furnished is in compliance with the Contract Documents.

Y. *Agreement.* The instrument executed by the Owner and the Contractor in conformance with the Contract Documents for the performance of the Work.

Z. *Field Order.* A notice issued to the Contractor by the Engineer specifying an action required of the Contractor.

AA. *Request for Information (RFI).* A notice issued to the Engineer or Owner requesting a clarification of the Contract Documents.

BB. *Notice to Proceed.* A written notice from the Owner to the Contractor or Engineer directing the Contractor or Engineer to proceed with the work.

CC. *Advertisement, Invitation to Bid.* The public or private announcement, as required by law or the Owner, inviting Bids for the Work to be performed, material to be furnished, or both.

3.04 Contractors/Manufacturers/Authorities

A. *Contractor.* The term *contractor* shall mean the individual, firm, partnership, corporation, joint venture, or any combination thereof or their duly authorized representatives who have executed a Contract with the client for the proposed Work.

B. *Sub-Contractor or Trade Contractor.* The terms *sub-contractor* and *trade contractor* shall mean all the lower tier contractors, material suppliers, and distributors which have executed a contract with the Contractor for the proposed Work.

C. *Furnisher, Supplier.* The terms *furnisher* and *supplier* shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the Contractor, its Sub-Contractor, or Sub-Sub-Contractor, to furnish a particular unit of material or equipment to the project site. It shall be a requirement that the furnisher or supplier be experienced in the manufacture of the material or equipment they are to furnish.

D. *Installer.* The term *installer* shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the Contractor, its Sub-Contractor, or Sub-Sub-Contractor to install a particular unit of Work at the project site, including installation, erection, application, and similar required operations. It shall be a requirement that the installer be experienced in the operations they are engaged to perform.

E. *Provider.* The term *provider* shall be defined as the "entity" (individual, partnership, firm, corporation, joint venture, or any combination thereof) engaged by the Contractor, its Sub-Contractor, or Sub-Sub-Contractor to provide a particular unit of material or equipment at the project site. It shall be a requirement that the provider be experienced in the operations they are engaged to perform.

F. *Bidder.* An individual, firm, partnership, corporation, joint venture, or any combination thereof submitting a Bid for the Work as a single business entity and acting directly or through a duly authorized representative.

G. *Authority Having Jurisdiction.* The term *authority having jurisdiction* shall mean federal, state, and/or local authorities or agencies thereof having jurisdiction over Work to which reference is made and authorities responsible for "approving" equipment, installation, and/or procedures.

H. *Surety.* The corporate body which is bound with and for the Contractor for the satisfactory performance of the Work by the Contractor, and the prompt payment in full for materials, labor, equipment, rentals, and services, as provided in the bonds.

I. *Acceptable Manufacturers.* The term *acceptable manufacturers* shall mean the specified list of manufacturers considered acceptable to bid the project for a specific piece of equipment. Only the equipment specified has been checked for spatial compatibility. If the Contractor elects to use an optional manufacturer from the acceptable manufacturers list in the specifications, it shall be the Contractor's responsibility to determine and ensure the spatial compatibility of the manufacturers equipment selected.

PART 4

Professional Societies and Trade Organizations

4.01 Professional Societies and Trade Organizations

AABC	Associated Air Balance Council
AACC	American Automatic Control Council
ABMA	American Boiler Manufacturers' Association
ACCA	Air Conditioning Contractors of America
ACGIH	American Conference of Governmental and Industrial Hygienists
ACI	American Concrete Institute
ACS	American Ceramic Society
ACS	American Chemical Society
ACSM	American Congress on Surveying and Mapping
ADA	American with Disabilities Act
ADAAG	ADA Accessibility Guidelines for Buildings and Facilities
ADC	Air Diffusion Council
AEE	Association of Energy Engineers
AEI	Architectural Engineering Institute
AFBMA	American Fan and Bearing Manufacturers' Association
AFS	American Foundrymen's Society
AGA	American Gas Association
AGMA	American Gear Manufacturers Association
AIA	American Institute of Architects
AIA	American Insurance Association
AICE	American Institute of Consulting Engineers
AIChE	American Institute of Chemical Engineers
AIHA	American Industrial Hygiene Association
AIIE	American Institute of Industrial Engineers, Inc.
AIPE	American Institute of Plant Engineers
AISC	American Institute of Steel Construction
AISE	Association of Iron and Steel Engineers
AISI	American Iron and Steel Institute
AMCA	Air Movement and Control Association International, Inc.
ANSI	American National Standards Institute
APCA	Air Pollution Control Association
APFA	American Pipe and Fittings Association
APHA	American Public Health Association
API	American Petroleum Institute
APWA	American Public Works Association
ARI	Air-Conditioning and Refrigeration Institute
ASA	Acoustical Society of America
ASCE	American Society of Civil Engineers
ASCET	American Society of Certified Engineering Technicians
ASEE	American Society for Engineering Education
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASLE	American Society of Lubricating Engineers
ASME	American Society of Mechanical Engineers International
ASNT	American Society for Non-Destructive Testing
ASPE	American Society of Plumbing Engineers
ASQC	American Society of Quality Control, Inc.

ASSE	American Society of Safety Engineers; American Society of Sanitary Engineers
ASTM	American Society for Testing and Materials
ATBCB	Architectural and Transportation Barrier Compliance Board
AWS	American Welding Society
AWWA	American Water Works Association, Inc.
BCMC	Board for the Coordination of Model Codes (a Board of CABO)
BEPS	Building Energy Performance Standards
BOCA	Building Officials and Code Administrators Basic/National Building, Mechanical, Plumbing, and Fire Codes
BRI	Building Research Institute
BSI	British Standards Institute
CABO	Council of American Building Officials
CAGI	Compressed Air and Gas Institute
CANENA	North American Electro/Technical Standards Harmonization Council
CEC	Consulting Engineers Council of the United States
CEN	European Standards Organization
CENELEC	European Committee for Electro/Technical Standardization
CGA	Compressed Gas Association, Inc.
CISPI	Cast Iron Soil Pipe Institute
CSA	Canadian Standards Association
CSI	Construction Specifications Institute
CTI	Cooling Tower Institute
DER	Department of Environmental Resources
DOE	Department of Energy
ECPD	Engineers' Council for Professional Development
EF	Engineering Foundation
EJC	Engineers' Joint Council
EJMA	Expansion Joint Manufacturers' Association
EPA	Environmental Protection Agency
ETL	ETL Testing Laboratories
FM	Factory Mutual System
FPS	Fluid Power Society
HEI	Heat Exchange Institute
HI	Hydraulic Institute
HTFMI	Heat Transfer and Fluid Mechanics Institute
HYDI	Hydronics Institute
IAPMO	International Association of Plumbing and Mechanical Officials
IBR	Institute of Boiler and Radiator Manufacturers'
ICBO	International Conference of Building Officials Uniform Building, Mechanical, Plumbing, and Fire Codes
ICC	International Code Council (BOCA, CABO, ICBO, and SBCCI combined) International Mechanical and Plumbing Codes
ICET	Institute for the Certification of Engineering technicians
IEC	International Electro/Technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IFCI	International Fire Code Institute
IFI	Industrial Fasteners Institute

IIAR	International Institute of Ammonia Refrigeration
IRI	HSB Industrial Risk Insurers; Industrial Research Institute, Inc.
ISA	Instrument Society of America
ISO	International Organization for Standardization
MCAA	Mechanical Contractors Association of America
MSS	Manufacturers' Standardization Society of the Valve and Fittings Industry
NACE	National Association of Corrosion Engineers
NAE	National Academy of Engineering
NAIMA	North American Insulation Manufacturers Association
NAPE	National Association of Power Engineers, Inc.
NAPHCC	National Association of Plumbing-Heating-Cooling Contractors
NAS	National Academy of Sciences
NBFU	National Board of Fire Underwriters
NBS	National Bureau of Standards
NCEE	National Council of Engineering Examiners
NCPWB	National Certified Pipe Welding Bureau
NCSBCS	National Conference of States on Building Codes and Standards
NEBB	National Environmental Balancing Bureau
NEC	National Electric Code
NEMA	National Electrical Manufacturers' Association
NEMI	National Energy Management Institute
NFPA	National Fire Protection Association
NFSA	National Fire Sprinkler Association
NICE	National Institute of Ceramic Engineers
NICET	National Institute of Certified Engineering Technicians
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NRC	National Research Council
NRCA	National Roofing Contractors' Association
NRCC	National Research Council of Canada
NSAE	National Society of Architectural Engineers
NSF	National Sanitation Foundation International
NSPE	National Society of Professional Engineers
NUSIG	National Uniform Seismic Installation Guidelines
OSHA	Occupational Safety and Health Administration
PADER	Pennsylvania Department of Environmental Resources
PDI	Plumbing and Drainage Institute
PFI	Pipe Fabrication Institute
RESA	Scientific Research Society of America
SAE	Society of Automotive Engineers
SAME	Society of American Military Engineers
SAVE	Society of American Value Engineers
SBCCI	Southern Building Code Congress International; Southern/Standard Building, Mechanical, Plumbing, and Fire Codes
SES	Solar Energy Society
SFPE	Society of Fire Protection Engineers
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SPE	Society of Plastics Engineers, Inc.
SSPC	Structural Steel Painting Council
SSPMA	Sump and Sewage Pump Manufacturers' Association

SWE	Society of Women Engineers
TEMA	Tubular Exchanger Manufacturers Association
TIMA	Thermal Insulation Manufacturers' Association
UL	Underwriters' Laboratories, Inc.
WPCF	Water Pollution Control Federation

Equations

5.01 Cooling and Heating Equations

$$H_S = 1.08 \times CFM \times \Delta T$$

$$H_S = 1.1 \times CFM \times \Delta T$$

$$H_L = 0.68 \times CFM \times \Delta W_{GR.}$$

$$H_L = 4840 \times CFM \times \Delta W_{LB.}$$

$$H_T = 4.5 \times CFM \times \Delta h$$

$$H_T = H_S + H_L$$

$$H = U \times A \times \Delta T$$

$$SHR = \frac{H_S}{H_T} = \frac{H_S}{H_S + H_L}$$

$$LB.\ STM/HR = \frac{BTU/HR}{H_{FG}}$$

H_S = Sensible Heat (Btu/Hr.)
H_L = Latent Heat (Btu/Hr.)
H_T = Total Heat (Btu/Hr.)

ΔT = Temperature Difference (°F.)

$\Delta W_{GR.}$ = Humidity Ratio Difference (Gr.H_2O/Lb.DA)
$\Delta W_{LB.}$ = Humidity Ratio Difference (Lb.H_2O/Lb.DA)

Δh = Enthalpy Difference (Btu/Lb.DA)

CFM = Air Flow Rate (Cubic Feet per Minute)
U = U-Value (Btu/Hr. Sq. Ft. °F.)

A = Area (Sq. Ft.)
SHR = Sensible Heat Ratio

H_{FG} = Latent Heat of Vaporization at Design Pressure (*1989 ASHRAE Fundamentals*)

5.02 R-Values/U-Values

$$R = \frac{1}{C} = \frac{1}{K} \times Thickness$$

$$U = \frac{1}{\Sigma R}$$

R = R-Value (Hr. Sq. Ft. °F./Btu.)
U = U-Value (Btu./Hr. Sq. Ft. °F.)
C = Conductance (Btu./Hr. Sq. Ft. °F.)
K = Conductivity (Btu. In./Hr. Sq. Ft. °F.)
ΣR = Sum of the Individual R-Values

5.03 Water System Equations

$$H = 500 \times GPM \times \Delta T$$

$$GPM_{EVAP.} = \frac{TONS \times 24}{\Delta T}$$

$$GPM_{COND.} = \frac{TONS \times 30}{\Delta T}$$

H	=	Total Heat (Btu/Hr.)
GPM	=	Water Flow Rate (Gallons per Minute)
ΔT	=	Temperature Difference (°F.)
TONS	=	Air Conditioning Load (Tons)
$GPM_{EVAP.}$	=	Evaporator Water Flow Rate (Gallons per Minute)
$GPM_{COND.}$	=	Condenser Water Flow Rate (Gallons per Minute)

5.04 Air Change Rate Equations

$$\frac{AC}{HR} = \frac{CFM \times 60}{VOLUME}$$

$$CFM = \frac{\frac{AC}{HR} \times VOLUME}{60}$$

AC/HR.	=	Air Change Rate per Hour
CFM	=	Air Flow Rate (Cubic Feet per Minute)
VOLUME	=	Space Volume (Cubic Feet)

5.05 Mixed Air Temperature

$$T_{MA} = \left(T_{ROOM} \times \frac{CFM_{RA}}{CFM_{SA}}\right) + \left(T_{OA} \times \frac{CFM_{OA}}{CFM_{SA}}\right)$$

$$T_{MA} = \left(T_{RA} \times \frac{CFM_{RA}}{CFM_{SA}}\right) + \left(T_{OA} \times \frac{CFM_{OA}}{CFM_{SA}}\right)$$

CFM_{SA}	=	Supply Air (CFM)
CFM_{RA}	=	Return Air (CFM)
CFM_{OA}	=	Outside Air (CFM)
T_{MA}	=	Mixed Air Temperature (°F)
T_{ROOM}	=	Room Design Temperature (°F)
T_{RA}	=	Return Air Temperature (°F)
T_{OA}	=	Outside Air Temperature (°F)

5.06 Ductwork Equations

$$TP = SP + VP$$

$$VP = \left[\frac{V}{4005}\right]^2 = \frac{(V)^2}{(4005)^2}$$

$$V = \frac{Q}{A} = \frac{Q \times 144}{W \times H}$$

$$D_{EQ} = \frac{1.3 \times (A \times B)^{0.625}}{(A + B)^{0.25}}$$

TP = Total Pressure
SP = Static Pressure, Friction Losses
VP = Velocity Pressure, Dynamic Losses
V = Velocity, Ft./Min.
Q = Flow through Duct (CFM)
A = Area of Duct (Sq. Ft.)
W = Width of Duct (Inches)
H = Height of Duct (Inches)
D_{EQ} = Equivalent Round Duct Size for Rectangular Duct (Inches)
A = One Dimension of Rectangular Duct (Inches)
B = Adjacent Side of Rectangular Duct (Inches)

5.07 Fan Laws

$$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$$

$$\frac{SP_2}{SP_1} = \left[\frac{CFM_2}{CFM_1}\right]^2 = \left[\frac{RPM_2}{RPM_1}\right]^2$$

$$\frac{BHP_2}{BHP_1} = \left[\frac{CFM_2}{CFM_1}\right]^3 = \left[\frac{RPM_2}{RPM_1}\right]^3 = \left[\frac{SP_2}{SP_1}\right]^{1.5}$$

$$BHP = \frac{CFM \times SP \times SP.GR.}{6356 \times FAN_{EFF.}}$$

$$MHP = \frac{BHP}{M/D_{EFF.}}$$

CFM = Cubic Feet/Minute
RPM = Revolutions/Minute
SP = In. W.G.
BHP = Break Horsepower

Fan Size = Constant
Air Density = Constant

SP.GR. (Air) = 1.0

$FAN_{EFF.}$ = 65–85%
$M/D_{EFF.}$ = 80–95%
M/D = Motor/Drive

5.08 Pump Laws

$$\frac{GPM_2}{GPM_1} = \frac{RPM_2}{RPM_1}$$

$$\frac{HD_2}{HD_1} = \left[\frac{GPM_2}{GPM_1}\right]^2 = \left[\frac{RPM_2}{RPM_1}\right]^2$$

$$\frac{BHP_2}{BHP_1} = \left[\frac{GPM_2}{GPM_1}\right]^3 = \left[\frac{RPM_2}{RPM_1}\right]^3 = \left[\frac{HD_2}{HD_1}\right]^{1.5}$$

$$BHP = \frac{GPM \times HD \times SP.GR.}{3960 \times PUMP_{EFF.}}$$

$$MHP = \frac{BHP}{M/D_{EFF.}}$$

$$VH = \frac{V^2}{2g}$$

$$HD = \frac{P \times 2.31}{SP.GR.}$$

GPM	=	Gallons/Minute
RPM	=	Revolutions/Minute
HD	=	Ft. H_2O
BHP	=	Break Horsepower
Pump Size	=	Constant
Water Density	=	Constant
SP.GR.	=	Specific Gravity of Liquid with Respect to Water
SP.GR. (Water)	=	1.0
$PUMP_{EFF.}$	=	60–80%
$M/D_{EFF.}$	=	85–95%
M/D	=	Motor/Drive
P	=	Pressure in Psi
VH	=	Velocity Head in Ft.
V	=	Velocity in Ft./Sec.
g	=	Acceleration due to Gravity (32.16 Ft./Sec^2)

5.09 Pump Net Positive Suction Head (NPSH) Calculations

$$NPSH_{AVAIL} > NPSH_{REQ'D}$$

$$NPSH_{AVAIL} = H_A \pm H_S - H_F - H_{VP}$$

$NPSH_{AVAIL}$	=	Net Positive Suction Available at Pump (Feet)
$NPSH_{REQ'D}$	=	Net Positive Suction Required at Pump (Feet)
H_A	=	Pressure at Liquid Surface (Feet—34 Feet for Water at Atmospheric Pressure)
H_S	=	Height of Liquid Surface Above (+) or Below (–) Pump (Feet)
H_F	=	Friction Loss between Pump and Source (Feet)
H_{VP}	=	Absolute Pressure of Water Vapor at Liquid Temperature (Feet—1989 ASHRAE Fundamentals)

5.10 Air Conditioning Condensate

$$GPM_{AC\ COND} = \frac{CFM \times \Delta W_{LB.}}{SpV \times 8.33}$$

$$GPM_{AC\ COND} = \frac{CFM \times \Delta W_{GR.}}{SpV \times 8.33 \times 7000}$$

$GPM_{AC\ COND}$ = Air Conditioning Condensate Flow (Gallons/Minute)

CFM = Air Flow Rate (Cu.Ft./Minute)
SpV = Specific Volume of Air (Cu.Ft./Lb.DA)

$\Delta W_{LB.}$ = Specific Humidity (Lb.H_2O/Lb.DA)
$\Delta W_{GR.}$ = Specific Humidity (Gr.H_2O/Lb.DA)

5.11 Humidification

$$GRAINS_{REQ'D} = \left(\frac{W_{GR.}}{SpV}\right)_{ROOM\ AIR} - \left(\frac{W_{GR.}}{SpV}\right)_{SUPPLY\ AIR}$$

$$POUNDS_{REQ'D} = \left(\frac{W_{LB.}}{SpV}\right)_{ROOM\ AIR} - \left(\frac{W_{LB.}}{SpV}\right)_{SUPPLY\ AIR}$$

$$LB.\ STM/HR = \frac{CFM \times GRAINS_{REQ'D} \times 60}{7000} = CFM \times POUNDS_{REQ'D} \times 60$$

$GRAINS_{REQ'D}$ = Grains of Moisture Required (Gr.H_2O/Cu.Ft.)
$POUNDS_{REQ'D}$ = Pounds of Moisture Required (Lb.H_2O/Cu.Ft.)

CFM = Air Flow Rate (Cu.Ft./Minute)
SpV = Specific Volume of Air (Cu.Ft./Lb.DA)

$W_{GR.}$ = Specific Humidity (Gr.H_2O/Lb.DA)
$W_{LB.}$ = Specific Humidity (Lb.H_2O/Lb.DA)

5.12 Humidifier Sensible Heat Gain

$$H_S = (0.244 \times Q \times \Delta T) + (L \times 380)$$

H_S = Sensible Heat Gain (Btu/Hr.)
Q = Steam Flow (Lb.Steam/Hr.)
ΔT = Steam Temperature – Supply Air Temperature (F.)
L = Length of Humidifier Manifold (Ft.)

5.13 Expansion Tanks

$$CLOSED\quad V_T = V_S \times \frac{\left[\left(\frac{\nu_2}{\nu_1}\right) - 1\right] - 3\alpha\Delta T}{\left[\frac{P_A}{P_1} - \frac{P_A}{P_2}\right]}$$

$$OPEN\quad V_T = 2 \times \left\{\left(V_S \times \left[\left(\frac{\nu_2}{\nu_1}\right) - 1\right]\right) - 3\alpha\Delta T\right\}$$

$$DIAPHRAGM\quad V_T = V_S \times \frac{\left[\left(\frac{\nu_2}{\nu_1}\right) - 1\right] - 3\alpha\Delta T}{1 - \left(\frac{P_1}{P_2}\right)}$$

V_T = Volume of Expansion Tank (Gallons)
V_S = Volume of Water in Piping System (Gallons)

ΔT = $T_2 - T_1$ (°F)
T_1 = Lower System Temperature (°F)

Heating Water	T_1 =	45–50°F Temperature at Fill Condition
Chilled Water	T_1 =	Supply Water Temperature
Dual Temperature	T_1 =	Chilled Water Supply Temperature

T_2 = Higher System Temperature (°F)

Heating Water	T_2 =	Supply Water Temperature
Chilled Water	T_2 =	95°F Ambient Temperature (Design Weather Data)
Dual Temperature	T_2 =	Heating Water Supply Temperature

P_A = Atmospheric Pressure (14.7 Psia)
P_1 = System Fill Pressure/Minimum System Pressure (Psia)
P_2 = System Operating Pressure/Maximum Operating Pressure (Psia)
V_1 = SpV of H_2O at T_1 (Cu. Ft./Lb.H_2O) *1989 ASHRAE Fundamentals,* Chapter 2, Table 25 or Part 27, Properties of Air and Water
V_2 = SpV of H_2O at T_2 (Cu. Ft./Lb.H_2O) *1989 ASHRAE Fundamentals,* Chapter 2, Table 26 or Part 27, Properties of Air and Water
α = Linear Coefficient of Expansion
$\alpha_{STEEL} = 6.5 \times 10^{-6}$
$\alpha_{COPPER} = 9.5 \times 10^{-6}$

System Volume Estimate:
12 Gal./Ton
35 Gal./BHP

System Fill Pressure/Minimum System Pressure Estimate:
Height of System +5 to 10 Psi OR 5–10 Psi, whichever is greater.

System Operating Pressure/Maximum Operating Pressure Estimate:

150 Lb. Systems	45–125 Psi
250 Lb. Systems	125–225 Psi

5.14 Air Balance Equations

SA = Supply Air
RA = Return Air
OA = Outside Air
EA = Exhaust Air
RFA = Relief Air

$SA = RA + OA = RA + EA + RFA$

If minimum OA (ventilation air) is greater than EA, then

$OA = EA + RFA$

If EA is greater than minimum OA (ventilation air), then

$OA = EA \qquad RFA = 0$

For Economizer Cycle

$OA = SA = EA + RFA \qquad RA = 0$

5.15 Efficiencies

$$COP = \frac{BTU\ OUTPUT}{BTU\ INPUT} = \frac{EER}{3.413}$$

$$EER = \frac{BTU\ OUTPUT}{WATTS\ INPUT}$$

Turndown Ratio = Maximum Firing Rate: Minimum Firing Rate
(i.e., 5:1, 10:1, 25:1)

$$OVERALL\ THERMAL\ EFF. = \frac{GROSS\ BTU\ OUTPUT}{GROSS\ BTU\ INPUT} \times 100\%$$

$$COMBUSTION\ EFF. = \frac{BTU\ INPUT - BTU\ STACK\ LOSS}{BTU\ INPUT} \times 100\%$$

Overall Thermal Efficiency Range 75%–90%
Combustion Efficiency Range 85%–95%

5.16 Cooling Towers and Heat Exchangers

$$APPROACH_{CT'S} = LWT - AWB$$

$$\text{APPROACH}_{\text{HE'S}} = \text{EWT}_{\text{HS}} - \text{LWT}_{\text{CS}}$$

RANGE = EWT − LWT

EWT = Entering Water Temperature (°F)
LWT = Leaving Water Temperature (°F)
AWB = Ambient Wet Bulb Temperature (Design WB, °F)
HS = Hot Side
CS = Cold Side

5.17 Moisture Condensation on Glass

$$T_{GLASS} = T_{ROOM} - \left[\frac{R_{IA}}{R_{GLASS}} \times (T_{ROOM} - T_{OA})\right]$$

$$T_{GLASS} = T_{ROOM} - \left[\frac{U_{GLASS}}{U_{IA}} \times (T_{ROOM} - T_{OA})\right]$$

If $T_{GLASS} < DP_{ROOM}$ Condensation Occurs

T = Temperature (°F.)
R = R-Value (Hr. Sq.Ft. °F./Btu.)
U = U-Value (Btu./Hr. Sq.Ft. °F.)
IA = Inside Airfilm
OA = Design Outside Air Temperature
DP = Dew Point

5.18 Electricity

$$KVA = KW + KVAR$$

KVA = Total Power (Kilovolt Amps)

KW	=	Real Power, Electrical Energy (Kilowatts)
KVAR	=	Reactive Power or "Imaginary" Power (Kilovolt Amps Reactive)
V	=	Voltage (Volts)
A	=	Current (Amps)
PF	=	Power Factor (0.75–0.95)
BHP	=	Break Horsepower
MHP	=	Motor Horsepower
EFF	=	Efficiency
M/D	=	Motor Drive

A. Single Phase Power:

$$KW_{1\phi} = \frac{V \times A \times PF}{1000}$$

$$KVA_{1\phi} = \frac{V \times A}{1000}$$

$$BHP_{1\phi} = \frac{V \times A \times PF \times DEVICE_{EFF.}}{746}$$

$$MHP_{1\phi} = \frac{BHP_{1\phi}}{M/D_{EFF.}}$$

B. 3-Phase Power:

$$KW_{3\phi} = \frac{\sqrt{3} \times V \times A \times PF}{1000}$$

$$KVA_{3\phi} = \frac{\sqrt{3} \times V \times A}{1000}$$

$$BHP_{3\phi} = \frac{\sqrt{3} \times V \times A \times PF \times DEVICE_{EFF.}}{746}$$

$$MHP_{3\phi} = \frac{BHP_{3\phi}}{M/D_{EFF.}}$$

5.19 Calculating Heating Loads for Loading Docks, Heavily Used Vestibules and Similar Spaces.

A. Find volume of space to be heated (Cu.Ft.).

B. Determine acceptable warm-up time for space (Min.).

C. Divide volume by time (CFM).

D. Determine inside and outside design temperatures–assume inside space temperature has dropped to the outside design temperature because doors have been open for an extended period of time.

E. Use sensible heat equation to determine heating requirement using CFM and inside and outside design temperatures determined above.

5.20 Ventilation of Mechanical Rooms with Refrigeration Equipment

A. For a more detailed description of ventilation requirements for mechanical rooms with refrigeration equipment see ASHRAE Standard 15 and Part 9, Ventilation Rules of Thumb.

B. Completely Enclosed Equipment Rooms:

$$CFM = 100 \times G^{0.5}$$

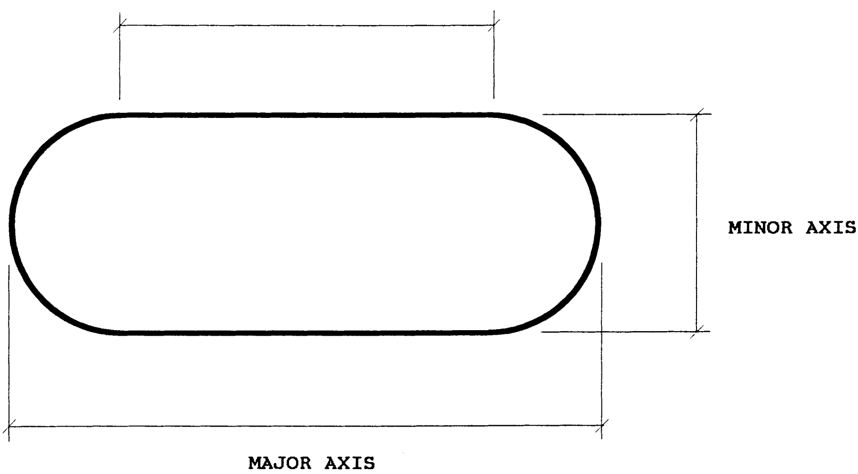
CFM = Exhaust Air Flow Rate Required (Cu.Ft./Minute)
G = Mass of Refrigerant of Largest System (Pounds)

C. Partially Enclosed Equipment Rooms:

$$FA = G^{0.5}$$

FA = Ventilation Free Opening Area (Sq.Ft.)
G = Mass of Refrigerant of Largest System (Pounds)

5.21 Equations for Flat Oval Ductwork



$$FS = MAJOR - MINOR$$

$$A = \frac{(FS \times MINOR) + \dfrac{(\pi \times MINOR^2)}{4}}{144}$$

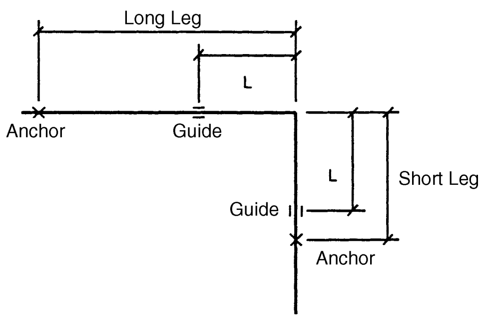
$$P = \frac{(\pi \times MINOR) + (2 \times FS)}{12}$$

$$D_{EQ} = \frac{1.55 \times (A)^{0.625}}{(P)^{0.25}}$$

FS	=	Flat Span Dimension (Inches)
MAJOR	=	Major Axis Dimension [Inches (Larger Dimension)]
MINOR	=	Minor Axis Dimension [Inches (Smaller Dimension)]
A	=	Cross-Sectional Area (Square Feet)
P	=	Perimeter or Surface Area (Square Feet per Lineal Feet)
D_{EQ}	=	Equivalent Round Duct Diameter

5.22 Pipe Expansion Equations

A. L-Bends:



L-Bends

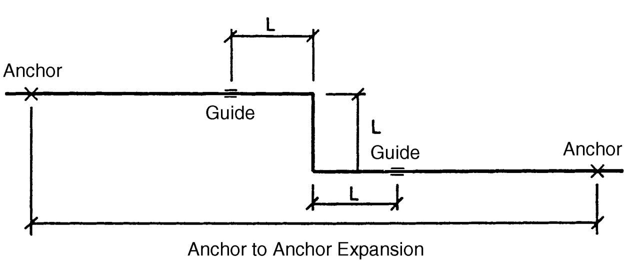
$$L = 6.225 \times \sqrt{\Delta D}$$

$$F = 500\ LB./PIPE\ DIA. \times PIPE\ DIA.$$

L	=	Length of Leg Required to Accommodate Thermal Expansion or Contraction (Feet)
Δ	=	Thermal Expansion or Contraction of Long Leg (Inches)
D	=	Pipe Outside Diameter (Inches)
F	=	Force Exerted by Pipe Expansion or Contraction on Anchors and Supports (Lbs.)

See Tables in Part 32, Appendix D

B. Z-Bends:



Z-Bends

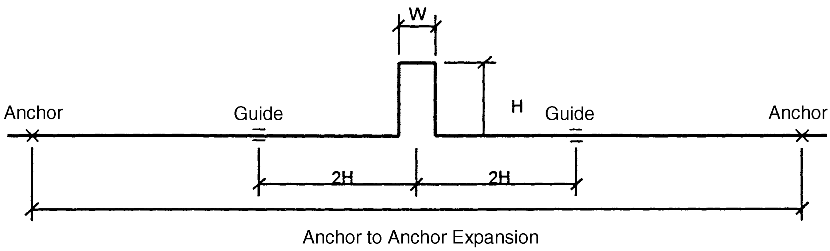
$$L = 4 \times \sqrt{\Delta D}$$

$$F = 200 - 500\ LB./PIPE\ DIA. \times PIPE\ DIA.$$

L = Length of Offset Leg Required to Accommodate Thermal Expansion or Contraction (Feet)
Δ = Anchor to Anchor Expansion or Contraction (Inches)
D = Pipe Outside Diameter (Inches)
F = Force Exerted by Pipe Expansion or Contraction on Anchors and Supports (Lbs.)

See Tables in Part 32, Appendix D.

C. U-Bends or Expansion Loops:



U-Bends or Loops

$L = 6.225 \times \sqrt{\Delta D}$

$F = 200\ LB./PIPE\ DIA. \times PIPE\ DIA.$

$L = 2H + W$

$H = 2W$

$L = 5W$

L = Length of Loop Required to Accommodate Thermal Expansion or Contraction (Feet)
Δ = Anchor to Anchor Expansion or Contraction (Inches)
D = Pipe Outside Diameter (Inches)
F = Force Exerted by Pipe Expansion or Contraction on Anchors and Supports (Lbs.)

See Tables in Part 32, Appendix D.

5.23 Steam and Condensate Equations

A. General:

$$LBS.\ STM./HR. = \frac{BTU/HR.}{960}$$

$$LB.\ STM.\ COND./HR. = \frac{EDR}{4}$$

$$EDR = \frac{BTU/HR.}{240}$$

$$LB.\ STM.\ COND./HR. = \frac{GPM \times 500 \times SP.GR. \times C_P \times \Delta T}{L}$$

$$LB.\ STM.\ COND./HR. = \frac{CFM \times 60 \times D \times C_P \times \Delta T}{L}$$

B. Approximating Condensate Loads:

$$LB.\ STM.\ COND./HR. = \frac{GPM(WATER) \times \Delta T}{2}$$

$$LB.\ STM.\ COND./HR. = \frac{GPM(FUEL\ OIL) \times \Delta T}{4}$$

$$LB.\ STM.\ COND./HR. = \frac{CFM(AIR) \times \Delta T}{900}$$

STM. = Steam
GPM = Quantity of Liquid (Gallons per Minute)
CFM = Quantity of Gas or Air (Cubic Feet per Minute)
SP.GR. = Specific Gravity
D = Density (Lbs./Cubic Feet)
C_P = Specific Heat of Gas or Liquid (Btu/Lb)
Air $C_P = 0.24$ Btu/Lb
Water $C_P = 1.00$ Btu/Lb
L = Latent Heat of Steam (Btu/Lb. at Steam Design Pressure)
ΔT = Final Temperature minus Initial Temperature
EDR = Equivalent Direct Radiation

5.24 Steam and Steam Condensate Pipe Sizing Equations

A. Steam Pipe Sizing Equations:

$$\Delta P = \frac{(0.01306) \times W^2 \times \left(1 + \frac{3.6}{ID}\right)}{3600 \times D \times ID^5}$$

$$W = 60 \times \sqrt{\frac{\Delta P \times D \times ID^5}{0.01306 \times \left(1 + \frac{3.6}{ID}\right)}}$$

$$W = 0.41667 \times V \times A_{INCHES} \times D = 60 \times V \times A_{FEET} \times D$$

$$V = \frac{2.4 \times W}{A_{INCHES} \times D} = \frac{W}{60 \times A_{FEET} \times D}$$

ΔP Pressure Drop per 100 Feet of Pipe (Psig/100 feet)
W Steam Flow Rate (Lbs./Hour)
ID Actual Inside Diameter of Pipe (Inches)
D Average Density of Steam at System Pressure (Lbs./Cu. Ft.)
V Velocity of Steam in Pipe (Feet/Minute)
A_{INCHES} Actual Cross Sectional Area of Pipe (Square Inches)
A_{FEET} Actual Cross Sectional Area of Pipe (Square Feet)

B. Steam Condensate Pipe Sizing Equations:

$$FS = \frac{H_{S_{SS}} - H_{S_{CR}}}{H_{L_{CR}}} \times 100$$

$$W_{CR} = \frac{FS}{100} \times W$$

FS	Flash Steam (Percentage %)
H_{SSS}	Sensible Heat at Steam Supply Pressure (Btu/Lb.)
H_{SCR}	Sensible Heat at Condensate Return Pressure (Btu/Lb.)
H_{LCR}	Latent Heat at Condensate Return Pressure (Btu/Lb.)
W	Steam Flow Rate (Lbs./Hr.)
W_{CR}	Condensate Flow based on percentage of Flash Steam created during condensing process (Lbs./Hr.). Use this flow rate in steam equations above to determine condensate return pipe size.

5.25 Psychrometric Equations

$$W = 0.622 \times \frac{P_W}{P - P_W}$$

$$RH = \frac{W_{ACTUAL}}{W_{SAT}} \times 100\%$$

$$RH = \frac{P_W}{P_{SAT}} \times 100\%$$

$$H_S = m \times c_P \times \Delta T$$

$$H_L = L_V \times m \times \Delta W$$

$$H_T = m \times \Delta h$$

$$W = \frac{(2501 - 2.381\ T_{WB})(W_{SAT\ WB}) - (T_{DB} - T_{WB})}{(2501 + 1.805\ T_{DB} - 4.186\ T_{WB})}$$

$$W = \frac{(1093 - 0.556\ T_{WB})(W_{SAT\ WB}) - (0.240)(T_{DB} - T_{WB})}{(1093 + 0.444\ T_{DB} - T_{WB})}$$

W	=	Specific Humidity (Lb.H_2O/Lb.DA or Gr.H_2O/Lb.DA)
W_{ACTUAL}	=	Actual Specific Humidity (Lb.H_2O/Lb.DA or Gr.H_2O/Lb.DA)
W_{SAT}	=	Saturation Specific Humidity at the Dry Bulb Temperature
$W_{SAT\ WB}$	=	Saturation Specific Humidity at the Wet Bulb Temperature
P_W	=	Partial Pressure of Water Vapor (Lb./Sq.Ft.)
P	=	Total Absolute Pressure of Air/Water Vapor Mixture (Lb./Sq.Ft.)
P_{SAT}	=	Saturation Partial Pressure of Water Vapor at the Dry Bulb Temperature (Lb./Sq.Ft.)
RH	=	Relative Humidity (%)
H_S	=	Sensible Heat (Btu/Hr.)
H_L	=	Latent Heat (Btu/Hr.)
H_T	=	Total Heat (Btu/Hr.)
m	=	Mass Flow Rate (Lb.DA/Hr. or Lb.H_2O/Hr.)
c_P	=	Specific Heat (Air: 0.24 Btu/Lb.DA, Water: 1.0 Btu/Lb.H_2O)
T_{DB}	=	Dry Bulb Temperature (°F.)
T_{WB}	=	Wet Bulb Temperature (°F.)
ΔT	=	Temperature Difference (°F.)
ΔW	=	Specific Humidity Difference (Lb.H_2O/Lb.DA or Gr.H_2O/Lb.DA)
Δh	=	Enthalpy Difference (Btu/Lb.DA)
L_V	=	Latent Heat of Vaporization (Btu/Lb.H_2O)

5.26 Swimming Pools

A. Sizing Outdoor Pool Heater:

1. Determine pool capacity in gallons. Obtain from Architect if available.
   Length × Width × Depth × 7.5 Gal/Cu.Ft. (If depth is not known assume an average depth 5.5 Feet)
2. Determine heat pick-up time in hours from Owner.
3. Determine pool water temperature in degrees F. from the Owner. If Owner does not specify assume 80°F.
4. Determine the average air temperature on the coldest month in which the pool will be used.
5. Determine the average wind velocity in miles per hour. For pools less than 900 square feet and where the pool is sheltered by nearby buildings, fences, shrubs, etc., from the prevailing wind an average wind velocity of less than 3.5 mph may be assumed. The surface heat loss factor of 5.5 Btu/Hr/Sq.Ft.°F. in the equation below assumes a wind velocity of 3.5 mph. If a wind velocity of less than 3.5 mph is used, multiply equation by 0.75; for 5.0 mph multiply equation by 1.25; and for 10 mph multiply equation by 2.0.
6. Pool Heater Equations:

$$H_{POOL\ HEATER} = H_{HEAT\text{-}UP} + H_{SURFACE\ LOSS}$$

$$H_{HEAT\text{-}UP} = \frac{GALS. \times 8.34\ LBS./GAL. \times \Delta T_{WATER} \times 1.0\ BTU/LB.°F.}{HEAT\ PICK\text{-}UP\ TIME}$$

$$H_{SURFACE\ LOSS} = 5.5\ BTU/HR.\ SQ.\ FT.\ °F. \times \Delta T_{WATER/AIR} \times POOL\ AREA$$

$$\Delta T_{WATER} = T_{FINAL} - T_{INITIAL}$$

$$T_{FINAL} = POOL\ WATER\ TEMPERATURE$$

$$T_{INITIAL} = 50\ °F$$

$$\Delta T_{WATER/AIR} = T_{FINAL} - T_{AVERAGE\ AIR}$$

H = Heating Capacity (Btu/Hr.)
ΔT = Temperature Difference (°F.)

5.27 Domestic Water Heater Sizing

$$H_{OUTPUT} = GPH \times 8.34\ LBS./GAL. \times \Delta T \times 1.0$$

$$H_{INPUT} = \frac{GPH \times 8.34\ LBS./GAL. \times \Delta T}{\%\ EFFICIENCY}$$

$$GPH = \frac{H_{INPUT} \times \%\ EFFICIENCY}{\Delta T \times 8.34\ LBS./GAL.} = \frac{KW \times 3413\ BTU/KW}{\Delta T \times 8.34\ LBS./GAL.}$$

$$\Delta T = \frac{H_{INPUT} \times \%\ EFFICIENCY}{GPH \times 8.34\ LBS./GAL.} = \frac{KW \times 3413\ BTU/KW}{GPH \times 8.34\ LBS./GAL.}$$

$$KW = \frac{GPH \times 8.34\ LBS./GAL. \times \Delta T \times 1.0}{3413\ BTU/KW}$$

$$\%\ COLD\ WATER = \frac{T_{HOT} - T_{MIX}}{T_{HOT} - T_{COLD}}$$

$$\%\ HOT\ WATER = \frac{T_{MIX} - T_{COLD}}{T_{HOT} - T_{COLD}}$$

H_{OUTPUT} = Heating Capacity, Output
H_{INPUT} = Heating Capacity, Input

GPH = Recovery Rate (Gallons per Hour)
ΔT = Temperature Rise (°F.)
KW = Kilowatts

T_{COLD} = Temperature, Cold Water (°F.)
T_{HOT} = Temperature, Hot Water (°F.)
T_{MIX} = Temperature, Mixed Water (°F.)

5.28 Domestic Hot Water Recirculation Pump/Supply Sizing

A. Determine the approximate total length of all hot water supply and return piping.

B. Multiply this total length by 30 Btu/Ft. for insulated pipe and 60 Btu/Ft. for uninsulated pipe to obtain the approximate heat loss.

C. Divide the total heat loss by 10,000 to obtain the total pump capacity in GPM.

D. Select a circulating pump to provide the total required GPM and obtain the head created at this flow.

E. Multiply the head by 100 and divide by the total length of the longest run of the hot water return piping to determine the allowable friction loss per 100 feet of pipe.

F. Determine the required GPM in each circulating loop and size the hot water return pipe based on this GPM and the allowable friction loss as determined above.

5.29 Relief Valve Vent Line Maximum Length

$$L = \frac{9 \times P_1^2 \times D^5}{C^2} = \frac{9 \times P_2^2 \times D^5}{16 \times C^2}$$

$$P_1 = 0.25 \times [(PRESSURE\ SETTING \times 1.1) + 14.7]$$

$$P_2 = [(PRESSURE\ SETTING \times 1.1) + 14.7]$$

L = Maximum Length of Relief Vent Line (Feet)
D = Inside Diameter of Pipe (Inches)
C = Minimum Discharge of Air (Lbs./Min.)

5.30 Relief Valve Sizing

A. Liquid System Relief Valves and Spring Style Relief Valves:

$$A = \frac{GPM \times \sqrt{G}}{28.14 \times K_B \times K_V \times \sqrt{\Delta P}}$$

B. Liquid System Relief Valves and Pilot Operated Relief Valves:

$$A = \frac{GPM \times \sqrt{G}}{36.81 \times K_V \times \sqrt{\Delta P}}$$

C. Steam System Relief Valves:

$$A = \frac{W}{51.5 \times K \times P \times K_{SH} \times K_N \times K_B}$$

D. Gas and Vapor System Relief Valves (Lb./Hr.):

$$A = \frac{W \times \sqrt{TZ}}{C \times K \times P \times K_B \times \sqrt{M}}$$

E. Gas and Vapor System Relief Valves (SCFM):

$$A = \frac{SCFM \times \sqrt{TGZ}}{1.175 \times C \times K \times P \times K_B}$$

F. Relief Valve Equation Definitions:

1. A = Minimum Required Effective Relief Valve Discharge Area (Square Inches)
2. GPM = Required Relieving Capacity at Flow Conditions (Gallons per Minute)
3. W = Required Relieving Capacity at Flow Conditions (Lbs./Hr.)
4. SCFM = Required Relieving Capacity at Flow Conditions (Standard Cubic Feet per Minute)
5. G = Specific Gravity of Liquid, Gas, or Vapor at Flow Conditions
   Water = 1.0 for most HVAC Applications
   Air = 1.0
6. C = Coefficient Determined from Expression of Ratio of Specific Heats
   C = 315 if Value is Unknown
7. K = Effective Coefficient of Discharge
   K = 0.975
8. K_B = Capacity Correction Factor Due to Back Pressure
   K_B = 1.0 for Atmospheric Discharge Systems
9. K_V = Flow Correction Factor Due to Viscosity
   K_V = 0.9 to 1.0 for most HVAC Applications with Water
10. K_N = Capacity Correction Factor for Dry Saturated Steam at Set Pressures above 1500 Psia and up to 3200 Psia
    K_N = 1.0 for most HVAC Applications
11. K_{SH} = Capacity Correction Factor Due to the Degree of Superheat
    K_{SH} = 1.0 for Saturated Steam
12. Z = Compressibility Factor
    Z = 1.0 If Value is Unknown
13. P = Relieving Pressure (Psia)
    P = Set Pressure (Psig) + Over Pressure (10% Psig) + Atmospheric Pressure (14.7 Psia)
14. ΔP = Differential Pressure (Psig)
    ΔP = Set Pressure (Psig) + Over Pressure (10% Psig) − Back Pressure (Psig)
15. T = Absolute Temperature (°R = °F. + 460)
16. M = Molecular Weight of the Gas or Vapor

G. Relief Valve Sizing Notes:

1. When multiple relief valves are used, one valve shall be set at or below the maximum allowable working pressure, and the remaining valves may be set up to 5 percent over the maximum allowable working pressure.

2. When sizing multiple relief valves, the total area required is calculated on an over-pressure of 16 percent or 4 Psi, whichever is greater.
3. For superheated steam, the correction factor values listed below may be used:
   a. Superheat up to 400 °F.: 0.97 (Range 0.979–0.998)
   b. Superheat up to 450 °F.: 0.95 (Range 0.957–0.977)
   c. Superheat up to 500 °F.: 0.93 (Range 0.930–0.968)

GAS OR VAPOR	MOLECULAR WEIGHT	RATIO OF SPECIFIC HEATS	COEFFICIENT C	SPECIFIC GRAVITY
Acetylene	26.04	1.25	342	0.899
Air	28.97	1.40	356	1.000
Ammonia (R-717)	17.03	1.30	347	0.588
Argon	39.94	1.66	377	1.379
Benzene	78.11	1.12	329	2.696
N-Butane	58.12	1.18	335	2.006
Iso-Butane	58.12	1.19	336	2.006
Carbon Dioxide	44.01	1.29	346	1.519
Carbon Disulphide	76.13	1.21	338	2.628
Carbon Monoxide	28.01	1.40	356	0.967
Chlorine	70.90	1.35	352	2.447
Cyclohexane	84.16	1.08	325	2.905
Ethane	30.07	1.19	336	1.038
Ethyl Alcohol	46.07	1.13	330	1.590
Ethyl Chloride	64.52	1.19	336	2.227
Ethylene	28.03	1.24	341	0.968
Helium	4.02	1.66	377	0.139
N-Heptane	100.20	1.05	321	3.459
Hexane	86.17	1.06	322	2.974
Hydrochloric Acid	36.47	1.41	357	1.259
Hydrogen	2.02	1.41	357	0.070
Hydrogen Chloride	36.47	1.41	357	1.259
Hydrogen Sulphide	34.08	1.32	349	1.176
Methane	16.04	1.31	348	0.554
Methyl Alcohol	32.04	1.20	337	1.106
Methyl Butane	72.15	1.08	325	2.491
Methyl Chloride	50.49	1.20	337	1.743
Natural Gas	19.00	1.27	344	0.656
Nitric Oxide	30.00	1.40	356	1.036
Nitrogen	28.02	1.40	356	0.967
Nitrous Oxide	44.02	1.31	348	1.520
N-Octane	114.22	1.05	321	3.943
Oxygen	32.00	1.40	356	1.105
N-Pentane	72.15	1.08	325	2.491
Iso-Pentane	72.15	1.08	325	2.491
Propane	44.09	1.13	330	1.522
R-11	137.37	1.14	331	4.742
R-12	120.92	1.14	331	4.174
R-22	86.48	1.18	335	2.985
R-114	170.93	1.09	326	5.900
R-123	152.93	1.10	327	5.279
R-134a	102.03	1.20	337	3.522
Sulfur Dioxide	64.04	1.27	344	2.211
Toluene	92.13	1.09	326	3.180

d. Superheat up to 550 °F.: 0.90 (Range 0.905–0.974)
e. Superheat up to 600 °F.: 0.88 (Range 0.882–0.993)
f. Superheat up to 650 °F.: 0.86 (Range 0.861–0.988)
g. Superheat up to 700 °F.: 0.84 (Range 0.841–0.963)
h. Superheat up to 750 °F.: 0.82 (Range 0.823–0.903)
i. Superheat up to 800 °F.: 0.80 (Range 0.805–0.863)
j. Superheat up to 850 °F.: 0.78 (Range 0.786–0.836)
k. Superheat up to 900 °F.: 0.75 (Range 0.753–0.813)
l. Superheat up to 950 °F.: 0.72 (Range 0.726–0.792)
m. Superheat up to 1000 °F.: 0.70 (Range 0.704–0.774)

4. Gas and Vapor Properties are shown in the table on the preceding page:

5.31 Steel Pipe Equations

$$A = 0.785 \times ID^2$$

$$W_P = 10.6802 \times T \times (OD - T)$$

$$W_W = 0.3405 \times ID^2$$

$$OSA = 0.2618 \times OD$$

$$ISA = 0.2618 \times ID$$

$$A_M = 0.785 \times (OD^2 - ID^2)$$

A = Cross-Sectional Area (Square Inches)
W_P = Weight of Pipe per Foot (Pounds)
W_W = Weight of Water per Foot (Pounds)
T = Pipe Wall Thickness (Inches)
ID = Inside Diameter (Inches)
OD = Outside Diameter (Inches)
OSA = Outside Surface Area per Foot (Square Feet)
ISA = Inside Surface Area per Foot (Square Feet)
A_M = Area of the Metal (Square Inches)

5.32 English/Metric Cooling and Heating Equations Comparison

$$H_S = 1.08 \frac{Btu\ Min}{Hr\ Ft^3\ °F} \times CFM \times \Delta T$$

$$H_{SM} = 72.42 \frac{KJ\ Min}{Hr\ M^3\ °C} \times CMM \times \Delta T_M$$

$$H_L = 0.68 \frac{Btu\ Min\ Lb\ DA}{Hr\ Ft^3\ Gr\ \mathrm{H_2O}} \times CFM \times \Delta W$$

$$H_{LM} = 177{,}734.8 \frac{KJ\ Min\ Kg\ DA}{Hr\ M^3\ Kg\ \mathrm{H_2O}} \times CMM \times \Delta W_M$$

$$H_T = 4.5 \frac{Lb\ Min}{Hr\ Ft^3} \times CFM \times \Delta h$$

$$H_{TM} = 72.09 \frac{Kg\ Min}{Hr\ M^3} \times CMM \times \Delta h_M$$

$$H_T = H_S + H_L$$

$$H_{TM} = H_{SM} + H_{LM}$$

$$H = 500 \frac{Btu\ Min}{Hr\ Gal\ °F} \times GPM \times \Delta T$$

$$H_M = 250.8 \frac{KJ\ Min}{Hr\ Liters\ °C} \times LPM \times \Delta T_M$$

$$\frac{AC}{HR} = \frac{CFM \times 60 \frac{Min}{Hr}}{VOLUME}$$

$$\frac{AC}{HR_M} = \frac{CMM \times 60 \frac{Min}{Hr}}{VOLUME_M}$$

$$°C = \frac{°F - 32}{1.8}$$

$$°F = 1.8\ °C + 32$$

H_S	=	Sensible Heat (Btu/Hr.)
H_{SM}	=	Sensible Heat (KJ/Hr.)
H_L	=	Latent Heat (Btu/Hr.)
H_{LM}	=	Latent Heat (KJ/Hr.)
H_T	=	Total Heat (Btu/Hr.)
H_{TM}	=	Total Heat (KJ/Hr.)
H	=	Total Heat (Btu/Hr.)
H_M	=	Total Heat (KJ/Hr.)
ΔT	=	Temperature Difference (°F.)
ΔT_M	=	Temperature Difference (°C.)
ΔW	=	Humidity Ratio Difference (Gr.H_2O/Lb.DA)
ΔW_M	=	Humidity Ratio Difference (Kg.H_2O/Kg.DA)
Δh	=	Enthalpy Difference (Btu/Lb.DA)
Δh	=	Enthalpy Difference (KJ/Lb.DA)
CFM	=	Air Flow Rate (Cubic Feet per Minute)
CMM	=	Air Flow Rate (Cubic Meters per Minute)
GPM	=	Water Flow Rate (Gallons per Minute)
LPM	=	Water Flow Rate (Liters per Minute)
AC/HR.	=	Air Change Rate per Hour, English
AC/HR.$_M$	=	Air Change Rate per Hour, Metric
AC/HR.	=	AC/HR.$_M$
VOLUME	=	Space Volume (Cubic Feet)
$VOLUME_M$	=	Space Volume (Cubic Meters)
KJ/Hr	=	Btu/Hr × 1.055
CMM	=	CFM × 0.02832
LPM	=	GPM × 3.785
KJ/Lb	=	Btu/Lb × 2.326
Meters	=	Feet × 0.3048
Sq. Meters	=	Sq. Feet × 0.0929
Cu. Meters	=	Cu. Feet × 0.02832
Kg	=	Pounds × 0.4536

1.0 GPM	=	500 Lb. Steam/Hr.
1.0 Lb.Stm. /Hr	=	0.002 GPM
1.0 Lb.H_2O/Hr	=	1.0 Lb.Steam/Hr.
Kg/Cu. Meter	=	Pounds/Cu. Feet × 16.017 (Density)
Cu. Meters/Kg	=	Cu. Feet/Pound × 0.0624 (Specific Volume)
Kg H_2O/Kg DA	=	Gr H_2O/Lb DA/7,000 = Lb. H_2O/Lb DA

5.33 Cooling Tower Equations

$$C = \frac{(E + D + B)}{(D + B)}$$

$$B = \frac{E - [(C - 1) \times D]}{(C - 1)}$$

$$E = GPM_{COND.} \times R \times 0.0008$$

$$D = GPM_{COND.} \times 0.0002$$

$$R = EWT - LWT$$

B	=	Blowdown (GPM)
C	=	Cycles of Concentration
D	=	Drift (GPM)
E	=	Evaporation (GPM)
EWT	=	Entering Water Temperature (°F.)
LWT	=	Leaving Water Temperature (°F.)
R	=	Range (°F.)

5.34 Motor Drive Formulas

$$D_{FP} \times RPM_{FP} = D_{MP} \times RPM_{MP}$$

$$BL = [(D_{FP} + D_{MP}) \times 1.5708] + (2 \times L)$$

D_{FP}	=	Fan Pulley Diameter
D_{MP}	=	Motor Pulley Diameter
RPM_{FP}	=	Fan Pulley RPM
RPM_{MP}	=	Motor Pulley RPM
BL	=	Belt Length
L	=	Center-to-Center Distance of Fan and Motor Pulleys

PART 6

Cooling Load Rules of Thumb

6.01 Offices, Commercial

A. General:

1. Total Heat	300–400 Sq.Ft./Ton;	(Range 230–520)
2. Total Heat	30–40 Btuh/Sq.Ft.;	(Range 23–52)
3. Room Sens. Heat	25–28 Btuh/Sq.Ft.;	(Range 19–37)
4. SHR	0.75–0.93	
5. Perimeter Spaces	1.0–3.0 CFM/Sq.Ft.	
6. Interior Spaces	0.5–1.5 CFM/Sq.Ft.	
7. Building Block CFM	1.0–1.5 CFM/Sq.Ft.	
8. Air Change Rate	4–10 AC/Hr.	

B. Large, Perimeter:

1. Total Heat 225–275 Sq.Ft./Ton
2. Total Heat 43–53 Btuh/Sq.Ft.

C. Large, Interior:

1. Total Heat 300–350 Sq.Ft./Ton
2. Total Heat 34–40 Btuh/Sq.Ft.

D. Small:

1. Total Heat 325–375 Sq.Ft./Ton
2. Total Heat 32–37 Btuh/Sq.Ft.

6.02 Banks, Court Houses, Municipal Buildings, Town Halls

A. Total Heat	**200–250 Sq.Ft./Ton**	**(Range 160–340)**
B. Total Heat	**48–60 Btuh/Sq.Ft.**	**(Range 35–75)**
C. Room Sens. Heat	**28–38 Btuh/Sq.Ft.**	**(Range 21–48)**
D. SHR	**0.75–0.90**	
E. Air Change Rate	**4–10 AC/Hr.**	

6.03 Police Stations, Fire Stations, Post Offices

A. Total Heat	**250–350 Sq.Ft./Ton**	**(Range 200–400)**
B. Total Heat	**34–48 Btuh/Sq.Ft.**	**(Range 30–60)**
C. Room Sens. Heat	**25–35 Btuh/Sq.Ft.**	**(Range 20–40)**
D. SHR	**0.75–0.90**	
E. Air Change Rate	**4–10 AC/Hr.**	

6.04 Precision Manufacturing

A. Total Heat 50–300 Sq.Ft./Ton

B. Total Heat 40–240 Btuh/Sq.Ft.

C. Room Sens. Heat 32–228 Btuh/Sq.Ft.

D. SHR 0.80–0.95

E. Air Change Rate 10–50 AC/Hr.

6.05 Computer Rooms

A. Total Heat 50–150 Sq.Ft./Ton

B. Total Heat 80–240 Btuh/Sq.Ft.

C. Room Sens. Heat 64–228 Btuh/Sq.Ft.

D. SHR 0.80–0.95

E. Air Flow 2.0–4.0 CFM/Sq.Ft.

F. Air Change Rate 15–20 AC/Hr.

6.06 Restaurants

A. Total Heat 100–250 Sq.Ft./Ton (Range 75–300)

B. Total Heat 48–120 Btuh/Sq.Ft. (Range 40–155)

C. Room Sens. Heat 21–62 Btuh/Sq.Ft. (Range 20–80)

D. SHR 0.65–0.80

E. Air Flow 1.5–4.0 CFM/Sq.Ft.

F. Air Change Rate 8–12 AC/Hr.

6.07 Kitchens (Depends Primarily on Kitchen Equipment)

A. Total Heat 150–350 Sq.Ft./Ton (At 85°F. Space)

B. Total Heat 34–80 Btuh/Sq.Ft. (At 85°F. Space)

C. Room Sens. Heat 20–56 Btuh/Sq.Ft. (At 85°F. Space)

D. SHR 0.60–0.70

E. Air Flow 1.5–2.5 CFM/Sq.Ft.

F. Air Change Rate 12–15 AC/Hr.

6.08 Cocktail Lounges, Bars, Taverns, Clubhouses, Nightclubs

A. Total Heat	150–200 Sq.Ft./Ton	(Range 75–300)
B. Total Heat	60–80 Btuh/Sq.Ft.	(Range 40–155)
C. Room Sens. Heat	27–40 Btuh/Sq.Ft.	(Range 20–80)
D. SHR	0.65–0.80	
E. Spaces	1.5–4.0 CFM/Sq.Ft.	
F. Air Change Rate	15–20 AC/Hr.	Cocktail Lounges, Bars, Taverns, Clubhouses
G. Air Change Rate	20–30 AC/Hr.	Night Clubs

6.09 Hospital Patient Rooms, Nursing Home Patient Rooms

A. Total Heat	250–300 Sq.Ft./Ton	(Range 200–400)
B. Total Heat	40–48 Btuh/Sq.Ft.	(Range 30–60)
C. Room Sens. Heat	32–46 Btuh/Sq.Ft.	(Range 25–50)
D. SHR	0.75–0.85	

6.10 Buildings w/100% OA Systems (i.e., Laboratories, Hospitals)

A. Total Heat	100–300 Sq.Ft./Ton
B. Total Heat	40–120 Btuh/Sq.Ft.

6.11 Medical/Dental Centers, Clinics, and Offices

A. Total Heat	250–300 Sq.Ft./Ton	(Range 200–400)
B. Total Heat	40–48 Btuh/Sq.Ft.	(Range 30–60)
C. Room Sens. Heat	32–46 Btuh/Sq.Ft.	(Range 25–50)
D. SHR	0.75–0.85	
E. Air Change Rate	8–12 AC/Hr.	

6.12 Residential

A. Total Heat	500–700 Sq.Ft./Ton	
B. Total Heat	17–24 Btuh/Sq.Ft.	
C. Room Sens. Heat	12–20 Btuh/Sq.Ft.	
D. SHR	0.80–0.95	

6.13 Apartments (Eff., 1 Room, 2 Room)

A. Total Heat	350–450 Sq.Ft./Ton	(Range 300–500)
B. Total Heat	27–34 Btuh/Sq.Ft.	(Range 24–40)
C. Room Sens. Heat	22–30 Btuh/Sq.Ft.	(Range 20–35)
D. SHR	0.80–0.95	

6.14 Motel and Hotel Public Spaces

A. Total Heat	250–300 Sq.Ft./Ton	(Range 160–375)
B. Total Heat	40–48 Btuh/Sq.Ft.	(Range 32–74)
C. Room Sens. Heat	32–46 Btuh/Sq.Ft.	(Range 25–60)
D. SHR	0.75–0.90	

6.15 Motel and Hotel Guest Rooms, Dormitories

A. Total Heat	400–500 Sq.Ft./Ton	(Range 300–600)
B. Total Heat	24–30 Btuh/Sq.Ft.	(Range 20–40)
C. Room Sens. Heat	20–25 Btuh/Sq.Ft.	(Range 15–35)
D. SHR	0.80–0.95	

6.16 School Classrooms

A. Total Heat	225–275 Sq.Ft./Ton	(Range 150–350)
B. Total Heat	43–53 Btuh/Sq.Ft.	(Range 35–80)
C. Room Sens. Heat	25–42 Btuh/Sq.Ft.	(Range 20–65)
D. SHR	0.65–0.80	
E. Air Change Rate	4–12 AC/Hr.	

6.17 Dining Halls, Lunch Rooms, Cafeterias, Luncheonettes

A. Total Heat	100–250 Sq.Ft./Ton	(Range 75–300)
B. Total Heat	48–120 Btuh/Sq.Ft.	(Range 40–155)
C. Room Sens. Heat	21–62 Btuh/Sq.Ft.	(Range 20–80)
D. SHR	0.65–0.80	
E. Spaces	1.5–4.0 CFM/Sq.Ft.	
F. Air Change Rate	12–15 AC/Hr.	

6.18 Libraries, Museums

A. Total Heat	250–350 Sq.Ft./Ton	(Range 160–400)
B. Total Heat	34–48 Btuh/Sq.Ft.	(Range 30–75)
C. Room Sens. Heat	22–32 Btuh/Sq.Ft.	(Range 20–50)
D. SHR	0.80–0.90	
E. Air Change Rate	8–12 AC/Hr.	

6.19 Retail, Department Stores

A. Total Heat	200–300 Sq.Ft./Ton	(Range 200–500)
B. Total Heat	40–60 Btuh/Sq.Ft.	(Range 24–60)
C. Room Sens. Heat	32–43 Btuh/Sq.Ft.	(Range 16–43)
D. SHR	0.65–0.90	
E. Air Change Rate	6–10 AC/Hr.	

6.20 Drug, Shoe, Dress, Jewelry, Beauty, Barber, and Other Shops

A. Total Heat	175–225 Sq.Ft./Ton	(Range 100–350)
B. Total Heat	53–69 Btuh/Sq.Ft.	(Range 35–115)
C. Room Sens. Heat	23–54 Btuh/Sq.Ft.	(Range 15–90)
D. SHR	0.65–0.90	
E. Air Change Rate	6–10 AC/Hr.	

6.21 Supermarkets

A. Total Heat	250–350 Sq.Ft./Ton	(Range 150–400)
B. Total Heat	34–48 Btuh/Sq.Ft.	(Range 30–80)
C. Room Sens. Heat	25–40 Btuh/Sq.Ft.	(Range 22–67)
D. SHR	0.65–0.85	
E. Air Change Rate	4–10 AC/Hr.	

6.22 Malls, Shopping Centers

A. Total Heat	150–350 Sq.Ft./Ton	(Range 150–400)
B. Total Heat	34–80 Btuh/Sq.Ft.	(Range 30–80)
C. Room Sens. Heat	25–67 Btuh/Sq.Ft.	(Range 22–67)
D. SHR	0.65–0.85	
E. Air Change Rate	6–10 AC/Hr.	

6.23 Jails

A. Total Heat	350–450 Sq.Ft./Ton	(Range 300–500)
B. Total Heat	27–34 Btuh/Sq.Ft.	(Range 24–40)
C. Room Sens. Heat	22–30 Btuh/Sq.Ft.	(Range 20–35)
D. SHR	0.80–0.95	

6.24 Auditoriums, Theaters

A. Total Heat	0.05–0.07 Tons/Seat
B. Total Heat	600–840 Btuh/Seat
C. Room Sens. Heat	325–385 Btuh/Seat
D. SHR	0.65–0.75
E. Air Flow	15–30 CFM/Seat
F. Air Change Rate	8–15 AC/Hr.

6.25 Churches

A. Total Heat	0.04–0.06 Tons/Seat
B. Total Heat	480–720 Btuh/Seat
C. Room Sens. Heat	260–330 Btuh/Seat
D. SHR	0.65–0.75
E. Air Flow	15–30 CFM/Seat
F. Air Change Rate	8–15 AC/Hr.

6.26 Bowling Alleys

A. Total Heat	1.5–2.5 Tons/Alley
B. Total Heat	18,000–30,000 Btuh/Alley
C. Air Change Rate	10–15 AC/Hr.

6.27 All Spaces

A. Total Heat	300–500 CFM/Ton @ 20°F. ΔT
B. Total Heat	400 CFM/Ton ±20% @ 20°F. ΔT
C. Perimeter Spaces	1.0–3.0 CFM/Sq.Ft.
D. Interior Spaces	0.5–1.5 CFM/Sq.Ft.
E. Building Block CFM	1.0–1.5 CFM/Sq.Ft.
F. Air Change Rate	4 AC/Hr. Minimum

Total heat includes ventilation. Room sensible heat does not include ventilation.

6.28 Cooling Load Calculation Procedure

A. Obtain building characteristics:

1. Materials
2. Size
3. Color
4. Shape
5. Location
6. Orientation, N, S, E, W, NE, SE, SW, NW, etc.
7. External/Internal shading
8. Occupancy type and time of day

B. Select outdoor design weather conditions:

1. Temperature
2. Wind direction and speed
3. Conditions in selecting outdoor design weather conditions:
   a. Type of structure, heavy, medium or light
   b. Is structure insulated?
   c. Is structure exposed to high wind?
   d. Infiltration or ventilation load
   e. Amount of glass
   f. Time of building occupancy
   g. Type of building occupancy
   h. Length of reduced indoor temperature
   i. What is daily temperature range, minimum/maximum?
   j. Are there significant variations from ASHRAE weather data?
   k. What type of heating devices will be used?
   l. Expected cost of fuel
4. See Part 16, Energy Conservation and Design Conditions, for code restrictions on selection of outdoor design conditions.

C. Select indoor design temperature to be maintained in each space. See Part 16, Energy Conservation and Design Conditions, for code restrictions on selection of indoor design conditions.

D. Estimate temperatures in un-conditioned spaces.

E. Select and/or compute U-values for walls, roof, windows, doors, partitions, etc.

F. Determine area of walls, windows, floors, doors, partitions, etc.

G. Compute conduction heat gains for all walls, windows, floors, doors, partitions, skylights, etc.

H. Compute solar heat gains for all walls, windows, floors, doors, partitions, skylights, etc.

I. Infiltration heat gains are generally ignored unless space temperature and humidity tolerance are critical.

J. Compute ventilation heat gain required.

K. Compute internal heat gains from lights, people, and equipment.

L. Compute sum of all heat gains indicated in items G, H, I, J, and K above

M. Include morning cool-down for buildings with intermittent use and night set up. See Part 16, Energy Conservation and Design Conditions, for code restrictions on excess HVAC system capacity permitted for morning cool-down.

N. Consider equipment and materials which will be brought into building above inside design temperature.

O. Cooling load calculations should be conducted using industry accepted methods to determine actual cooling load requirements.

6.29 Cooling Load Peak Time Estimate

MONTH OF PEAK ROOM COOLING LOAD FOR VARIOUS EXPOSURES										
WINDOW CHARACTERISTICS			PROBABLE MONTH OF PEAK ROOM COOLING LOAD							
% GLASS	SHADE COEF.	OVER-HANG	N	S	E	W	NE	SE	SW	NW
25	0.4	0	JULY	SEPT.	JULY	JULY	JULY	SEPT.	SEPT.	JULY
25	0.4	1:2	JULY	OCT.	JULY	AUG.	JULY	SEPT.	SEPT.	JULY
25	0.4	1:1	JULY	OCT.	JULY	JULY	JULY	SEPT.	OCT.	JULY
25	0.6	0	JULY	SEPT.	JULY	JULY	JULY	SEPT.	SEPT.	JULY
25	0.6	1:2	JULY	OCT.	JULY	AUG.	JULY	SEPT.	SEPT.	JULY
25	0.6	1:1	JULY	DEC.	JULY	SEPT.	JULY	SEPT.	OCT.	JULY
50	0.4	0	JULY	SEPT.	JULY	JULY	JULY	SEPT.	SEPT.	JULY
50	0.4	1:2	JULY	OCT.	JULY	AUG.	JULY	SEPT.	SEPT.	JULY
50	0.4	1:1	JULY	DEC.	JULY	SEPT.	JULY	SEPT.	OCT,	JULY
50	0.6	0	JULY	OCT.	JULY	JULY	JULY	SEPT.	SEPT.	JULY
50	0.6	1:2	JULY	DEC.	JULY	AUG.	JULY	SEPT.	OCT.	JULY
50	0.6	1:1	JULY	DEC.	JULY	SEPT.	JULY	SEPT.	DEC.	JULY

Notes:

1. Percent glass is percentage of gross wall area for the particular exposure.
2. Shading coefficient refers to the overall shading coefficient. Shading coefficient of 0.4 is approximately equal to double pane glass with heat absorbing plate out and regular plate in, combined with medium color venetian blinds.
3. Although the room peak for south, southeast, and southwest exposures is September or later, the system peak will more than likely be in July.
4. Value for overhang is the ratio of the depth of the overhang to height of the window with the overhang at the same elevation as the top of the window.
5. The roof will peak in June or July.

PART 7

Heating Load Rules of Thumb

7.01 All Buildings and Spaces

A. 20–60 Btuh/Sq.Ft.

B. 25–40 Btuh/Sq.Ft. Average

7.02 Buildings w/100% OA Systems (i.e., Laboratories, Hospitals)

A. 40–120 Btuh/Sq.Ft.

7.03 Buildings w/Ample Insulation, Few Windows

A. AC Tons × 12,000 Btuh/Ton × 1.2

7.04 Buildings w/Limited Insulation, Many Windows

A. AC Tons × 12,000 Btuh/Ton × 1.5

7.05 Walls Below Grade (Heat Loss at Outside Air Design Condition)

A. −30°F.–6.0 Btuh/Sq.Ft.

B. −25°F.–5.5 Btuh/Sq.Ft.

C. −20°F.–5.0 Btuh/Sq.Ft.

D. −15°F.–4.5 Btuh/Sq.Ft.

E. −10°F.–4.0 Btuh/Sq.Ft.

F. −5°F.–3.5 Btuh/Sq.Ft.

G. 0°F.–3.0 Btuh/Sq.Ft.

H. 5°F.–2.5 Btuh/Sq.Ft.

I. 10°F.–2.0 Btuh/Sq.Ft.

J. 15°F.–1.9 Btuh/Sq.Ft.

K. 20°F.–1.8 Btuh/Sq.Ft.

L. 25°F.–1.7 Btuh/Sq.Ft.

M. 30°F.–1.5 Btuh/Sq.Ft.

7.06 Floors Below Grade (Heat Loss at Outside Air Design Condition)

A. –30°F.–3.0 Btuh/Sq.Ft.

B. –25°F.–2.8 Btuh/Sq.Ft.

C. –20°F.–2.5 Btuh/Sq.Ft.

D. –15°F.–2.3 Btuh/Sq.Ft.

E. –10°F.–2.0 Btuh/Sq.Ft.

F. –5°F.–1.8 Btuh/Sq.Ft.

G. 0°F.–1.5 Btuh/Sq.Ft.

H. 5°F.–1.3 Btuh/Sq.Ft.

I. 10°F.–1.0 Btuh/Sq.Ft.

J. 15°F.–0.9 Btuh/Sq.Ft.

K. 20°F.–0.8 Btuh/Sq.Ft.

L. 25°F.–1.7 Btuh/Sq.Ft.

M. 30°F.–0.5 Btuh/Sq.Ft.

7.07 Heating System Selection Guidelines

A. If heat loss exceeds 450 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.

B. If heat loss is between 250 and 450 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, blanketing the exposed wall and window areas.

C. If heat loss is less than 250 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at, or both directed at and directed away, from the exposed wall and window areas.

7.08 Heating Load Calculation Procedure

A. Obtain building characteristics:

1. Materials
2. Size
3. Color
4. Shape

5. Location
6. Orientation, N, S, E, W, NE, SE, SW, NW, etc.
7. External shading
8. Occupancy type and time of day

B. Select outdoor design weather conditions:

1. Temperature.
2. Wind direction and speed.
3. Conditions in selecting outdoor design weather conditions:
   a. Type of structure, heavy, medium or light.
   b. Is structure insulated?
   c. Is structure exposed to high wind?
   d. Infiltration or ventilation load.
   e. Amount of glass.
   f. Time of building occupancy.
   g. Type of building occupancy.
   h. Length of reduced indoor temperature.
   i. What is daily temperature range, minimum/maximum?
   j. Are there significant variations from ASHRAE weather data?
   k. What type of heating devices will be used?
   l. Expected cost of fuel.
4. See Part 16, Energy Conservation and Design Conditions, for code restrictions on selection of outdoor design conditions.

C. Select indoor design temperature to be maintained in each space. See Part 16, Energy Conservation and Design Conditions, for code restrictions on selection of indoor design conditions.

D. Estimate temperatures in un-heated spaces.

E. Select and/or compute U-values for walls, roof, windows, doors, partitions, etc.

F. Determine area of walls, windows, floors, doors, partitions, etc.

G. Compute heat transmission losses for all walls, windows, floors, doors, partitions, etc.

H. Compute heat losses from basement and/or grade level slab floors.

I. Compute infiltration heat losses.

J. Compute ventilation heat loss required.

K. Compute sum of all heat losses indicated in items G, H, I, and J above.

L. For a building with sizable and steady internal heat release, a credit may be taken, but only a portion of the total. Use extreme caution!!! For most buildings, credit for heat gain should not be taken.

M. Include morning warm-up for buildings with intermittent use and night set-back. See Part 16, Energy Conservation and Design Conditions, for code restrictions on excess HVAC system capacity permitted for morning warm-up.

N. Consider equipment and materials which will be brought into the building below inside design temperature.

O. Heating load calculations should be conducted using industry accepted methods to determine actual heating load requirements.

PART 8

Infiltration Rules of Thumb

8.01 Heating Infiltration (15 mph wind)

A. Air Change Rate Method:

1. Range 0–10 AC/Hr.
2. Commercial Buildings
   a. 1.0 AC/Hr. 1 Exterior Wall
   b. 1.5 AC/Hr. 2 Exterior Walls
   c. 2.0 AC/Hr. 3 or 4 Exterior Walls
3. Vestibules 3.0 AC/Hr.

B. CFM/Sq.Ft. of Wall Method:

1. Range 0–1.0 CFM/Sq.Ft.
2. Tight Buildings 0.1 CFM/Sq.Ft.
3. Average Buildings 0.3 CFM/Sq.Ft.
4. Leaky Building 0.6 CFM/Sq.Ft.

C. Crack Method:

1. Range 0.12–2.8 CFM/Ft. of Crack
2. Average 1.0 CFM/Ft. of Crack

8.02 Cooling Infiltration (7.5 mph wind)

A. Cooling load infiltration is generally ignored unless close tolerances in temperature and humidity control are required. Cooling infiltration values are generally taken as ½ of the values listed above for heating infiltration.

8.03 No Infiltration Losses or Gains for Rooms Below Grade or Interior Spaces

8.04 Buildings Which Are Not Humidified Have No Latent Infiltration Heating Load

8.05 Winter Sensible Infiltration Loads Will Generally Be 1/2 to 3 Times the Conduction Heat Losses (Average 1.0–2.0 Times)

PART 9

Ventilation Rules of Thumb

9.01 Outdoor Air

A. *1990 BOCA Code* **5 CFM/Person Minimum**

B. *1993 BOCA Code* **Based on ASHRAE Standard 62-1989**

C. *1988 SBCCI Code* **5 CFM/Person Minimum**

D. *1988 UBC Code* **5 CFM/Person Minimum**

E. *ASHRAE Standard 62-1989* (Minimum Outdoor Air):

1. Range	15–60 CFM/Person
2. Most Common Range	15–35 CFM/Person, Based on type of Occupancy
3. Average Range	15–20 CFM/Person
4. Smoking Lounges	60 CFM/Person
5. Outdoor Background Level	350 ppm CO_2 Avg.
6. *ASHRAE Standard 62* Recommends	1000 ppm CO_2 max.
7. OSHA & U.S. Air Force Proposing	650 ppm CO_2 Max.
8. Human Discomfort Begins	800–1000 ppm CO_2
9. Long-Term Health Effects	>12,000 ppm CO_2

F. Outside Air Intake and Exhaust Locations:

1. *1990 and 1993 BOCA:*
   a. Intakes or exhausts—10 feet from lot lines, buildings on same lot or center line of street or public way
   b. Intakes—10 feet from any hazardous or noxious contaminant (plumbing vents, chimneys, vents, stacks, alleys, streets, parking lots, loading docks). When within 10 feet, intake must be a minimum of 2 feet below any source of contaminant.
   c. Exhausts—shall not create a nuisance or be directed onto walkways.
2. *1988 SBCCI:*
   a. Intakes—10 feet from any hazardous or noxious contaminant (plumbing vents, chimneys, vents, stacks, alleys, streets, parking lots, loading docks). When within 10 feet, intake must be a minimum of 2 feet below any source of contaminant.
3. *1988 UBC:*
   a. Intakes—10 feet from any hazardous or noxious contaminant (plumbing vents, chimneys, vents, stacks, alleys, streets, parking lots, loading docks). When within 10 feet, intake must be a minimum of 3 feet below any source of contaminant.
4. *Guidelines for Construction and Equipment of Hospital and Medical Facilities*—AIA Committee on Architecture for Health and U.S. Department of Health and Human Services:
   a. Fresh air intakes shall be located at least 25 feet from exhaust outlets of ventilating systems, combustion equipment stacks, medical-surgical vacuum systems, plumbing vents, or areas that may collect vehicular exhaust or other noxious fumes. Prevailing winds and/or proximity to other structures may require greater clearances.
   b. Plumbing and vacuum vents that terminate at a level above the top of the air intake may be as close as 10 feet.
   c. The bottom of outdoor air intakes serving central systems shall be as high as practical, but at least 6 feet above ground level, or if installed above the roof, 3 feet above roof level.
   d. Exhaust outlets from areas that may be contaminated shall be above roof level and arranged to minimize recirculation of exhaust air into the building.

G. Outside Air Requirements–*ASHRAE Standard 62-1989*–are shown in the following table:

TYPE OF SPACE	OUTDOOR AIR CFM/PERSON
Offices	20
Banks, Court Houses, Municipal Buildings, Town Halls	20
Police Stations, Fire Stations, Post Offices	20
Precision Manufacturing	20
Computer Rooms	20
Restaurants	20
Kitchens	15
Cocktail Lounges, Bars, Taverns, Clubhouses, Night Clubs	30
Hospital Patient Rooms, Nursing Home Patient Rooms	25
Hospital General Areas	15
Medical Centers, Medical and Dental Clinics, Dental Offices	20
Residential (CFM/Room)	30
Apartments (CFM/Room)	30
Motel and Hotel Public Spaces	20
School Classrooms	15
Dinign Halls, Lunch Rooms, Cafeterias, Luncheonettes	20
Libraties, Museums	20
Retail, Department Stores (CFM/Sq.Ft.)	0.2 - 0.3
Beauty Shops, Barber Shops	25
Drug, Shoe, Jewelry and Other Specialty Shops	15
Supermarkets	15
Malls, Shopping Centers	15
Jails	20
Auditoriums, Theaters	15
Churches	15
Bowling Alleys	25

9.02 Indoor Air Quality (IAQ)—*ASHRAE Standard 62-1989*

A. Causes of Poor IAQ:

1. Inadequate Ventilation—50% of all IAQ problems due to lack of ventilation
2. Poor Intake/Exhaust Locations
3. Inadequate Filtration or Dirty Filters
4. Intermittent Airflow
5. Poor Air Distribution
6. Inadequate Operation
7. Inadequate Maintenance

B. IAQ Control Methods:

1. Control Temperature and Humidity
2. Ventilation—Dilution
3. Remove Pollution Source
4. Filtration

C. IAQ Factors:

1. Thermal Environment
2. Smoke
3. Odors
4. Irritants—Dust
5. Stress Problems (Perceptible, Non-Perceptible)
6. Toxic Gases—Carbon Monoxide, Carbon Dioxide
7. Allergens—Pollen
8. Biological Contaminants—Bacteria, Mold, Pathogens, Legionella, Micro-organisms, Fungi

9.03 Effects of Carbon Monoxide

A. Effects of Various Concentrations of Carbon Monoxide with Respect to Time are shown in the following table:

HOURS OF EXPOSURE	CONCENTRATION OF CARBON MONOXIDE IN PPM ±		
	BARELY PERCEPTABLE	SICKNESS	DEADLY
0.5	600	1000	2000
1.0	200	600	1600
2	100	300	1000
3	75	200	700
4	50	150	400
5	35	125	300
6	25	120	200
7	25	100	200
8	25	100	150

B. Carbon Monoxide Concentration vs. Time vs. Symptoms are shown in the table on page 79.

C. Carbon monoxide is lighter than air (specific gravity is 0.968).

9.04 Toilet Rooms

A. Recommended Design Requirements:

1. 2.0 CFM/Sq.Ft.
2. 10 AC/Hr.
3. 100 CFM/Water Closet and Urinal

B. *ASHRAE Standard 62-1989* 50 CFM/Water Closet and Urinal

C. *1990 & 1993 BOCA Codes* 75 CFM/Water Closet and Urinal

CONCENTRATION OF CO IN THE AIR	INHALATION TIME	TOXIC SYMPTOMS DEVELOPED
9 PPM	Short Term Exposure	ASHRAE recommended maximum allowable concentration for short term exposure in living area.
35 PPM	8 Hour	The maximum allowable concentration for a continuous exposure, in any 8 hour period, according to federal law.
200 PPM	2 - 3 Hours	Slight headache, tiredness, dizziness, nausea; Maximum CO concentration exposure at any time as prescribed by OSHA
400 PPM	1 - 2 Hours	Frontal headaches
	After 3 Hours	Life Threatening
	---	Maximum PPM in flue gas (on a free air basis) according to EPA and AGA
800 PPM	45 Minutes	Dizziness, nausea, and convulsions
	2 Hours	Unconscious
	2 - 3 Hours	Death
1,600 PPM	20 Minutes	Headache, dizziness, nausea
	1 Hour	Death
3,200 PPM	5 - 10 Minutes	Headache, dizziness, nausea
	30 Minutes	Death
6,400 PPM	1 - 2 Minutes	Headache, dizziness, nausea
	10 - 15 Minutes	Death
12,800 PPM	1 - 3 Minutes	Death

D. *1988 SBCCI Code* **2.0 CFM/Sq.Ft.**

E. *1988 UBC Code* **5.0 AC/Hr.**

F. Toilet Room Ventilation:

1. For toilet rooms with high fixture densities (stadiums, auditoriums), the 75 CFM/Water Closet and Urinal dictates.
2. For toilet rooms with ceiling heights over 12 feet, the 10 AC/Hr dictates.
3. For toilet rooms ceiling heights 12 feet and under, the 2.0 CFM/Sq.Ft. dictates.
4. If toilet rooms are designed for 100 CFM/Water Closet and Urinal, all three major U.S. codes and the 10 AC/Hr. can be met.
5. Note that sometimes women's toilet rooms will contain less fixtures. If both men's and women's toilet rooms are essentially the same size, use the larger (men's) CFM for both toilet rooms when using the CFM/Water Closet and Urinal method.

9.05 Electrical Rooms

A. 2.0 CFM/Sq.Ft.

B. 10 AC/Hr.

C. 5 CFM/KVA of Transformer.

D. Electrical Room Design Guidelines:

1. Generally, electrical equipment rooms only require ventilation to keep equipment from overheating. Most electrical rooms are designed for 95°F. to 104°F; however, consult electrical engineer for equipment temperature tolerances. If space temperatures below 90°F. are required by equipment, air conditioning of the space will be required.
2. If outside air is used to ventilate the electrical room, the electrical room design temperature will be 10°F. to 15°F. above outside summer design temperatures.
3. If conditioned air from an adjacent space is used to ventilate the electrical room, the electrical room temperature can be 10°F. to 20°F. above the adjacent spaces.

9.06 Mechanical Rooms

A. 2 CFM/Sq.Ft.

B. Cleaver Brooks 10 CFM/BHP:

1. 8 CFM/BHP Combustion Air
2. 2 CFM/BHP Ventilation
3. 1 BHP = 34,500 Btuh

C. Mechanical Equipment Room Design Guidelines:

1. Generally, mechanical equipment rooms only require ventilation. Most mechanical rooms are designed for 95°F. to 104°F; however, verify mechanical equipment temperature tolerances. If space temperatures below 90°F. are required by mechanical equipment, air conditioning of the space will be required.
2. If outside air is used to ventilate the mechanical room, the mechanical room design temperature will be 10°F. to 15°F. above outside summer design temperatures.
3. If conditioned air from an adjacent space is used to ventilate the mechanical room, the mechanical room temperature can be 10°F. to 20°F. above the adjacent spaces.

D. *ASHRAE Standard 15-1992:*

1. See *ASHRAE Standard 15-1992* for complete refrigeration system requirements.
2. Scope:
   a. To establish safeguards of life, limb, health, and property.
   b. Defines practices that are consistent with safety.
   c. Prescribes safety standards.
3. Application. The standard applies to all refrigerating systems and heat pumps used in institutional, public assembly, residential, commercial, industrial, and mixed use occupancies and to parts and components added after adoption of this code.
4. Refrigerant Classification is shown in the table on page 81.
5. Requirements for Refrigerant Use:
   a. Requirements for refrigerant use are based on probability that refrigerant will enter occupied space and on type of occupancy (institutional, public assembly, residential, commercial, industrial, and mixed use).
   b. The total amount of refrigerant permitted to be installed in a system is determined by the type of occupancy, the refrigerant group, and the probability that refrigerant will enter occupied space.
   c. Refrigerant systems, piping, and associated appurtenances shall not be installed in or on stairways, stair landings, entrances, or exits.

	SAFETY GROUP	
HIGHER FLAMMABILITY	A3	B3
LOWER FLAMMABILITY	A2	B2 Ammonia
NO FLAME PROPAGATION	A1 R-11, R-12, R-22, R-134a	B1 R-123
	LOWER TOXICITY	HIGHER TOXICITY

   d. Refrigeration system components shall not interfere with free passage through public hallways and limitations on size are based on refrigerant type.
6. Service Provisions:
   a. All serviceable components of refrigerating systems shall be safely accessible.
   b. Properly located stop valves, liquid transfer valves, refrigerant storage tanks, and adequate venting are required when needed for safe servicing of equipment.
   c. Refrigerant Systems with more than 6.6 Lbs. of Refrigerant (except Group A1) require stop valves at:
      1) Suction inlet of each compressor, compressor unit, or condensing unit.
      2) Discharge outlet of each compressor, compressor unit, or condensing unit.
      3) The outlet of each liquid receiver.
   d. Refrigerant Systems with more than 110 Lbs. of Refrigerant require stop valves at:
      1) Suction inlet of each compressor, compressor unit, or condensing unit.
      2) Discharge outlet of each compressor, compressor unit, or condensing unit.
      3) The inlet of each liquid receiver, except for self-contained systems or where the receiver is an integral part of the condenser or condensing unit.
      4) The outlet of each liquid receiver.
      5) The inlet and outlet of condensers when more than one condenser is used in parallel.
7. Installation Requirements:
   a. Air ducts passing through machinery rooms shall be of tight construction and shall have no openings in such rooms.
   b. Refrigerant piping crossing an open space that affords passageway in any building shall not be less than 7′-3″ above the floor.
   c. Passages shall not be obstructed by refrigerant piping.
   d. Refrigerant piping shall not be placed in or pass through any elevator, dumbwaiter, or other shaft containing moving objects or in any shaft that has openings to living quarters or to main exits.
   e. Refrigerant piping shall not be placed in exits, lobbies, or stairways, except that such refrigerant piping may pass across an exit if there are no joints in the section in the exit.
   f. Refrigerant piping shall not be installed vertically through floors from one story to another except as follow:

1) Basement to first floor, top floor to mechanical equipment penthouse or roof.
2) For the purpose of interconnecting separate pieces of equipment. The piping may be carried in an approved, rigid and tight, continuous fire-resistive pipe, duct, or shaft having no openings into floors not served by the refrigerating system or carried exposed on the outer wall of the building.

8. Refrigeration Equipment Room Requirements:
   a. Provide proper space for service, maintenance, and operation.
   b. Minimum clear head room shall be 7′-3″.
   c. Doors shall be outward opening, self closing, fire rated, and tight fitting. No other openings shall be permitted in equipment rooms (except doors) that will permit passage of refrigerant to other part of the building.
   d. Group A1 refrigerants require an oxygen sensor located in the equipment room set to alarm when oxygen levels fall below 19.5 volume percent.
   e. Group A2, A3, B1, B2, and B3 refrigerants require a refrigerant vapor detector located in the equipment room set to alarm and start the ventilation system when the level reaches the refrigerant's toxicity level.
   f. Periodic test of alarm and sensors are required.
   g. Mechanical rooms shall be vented to the outdoors.
   h. Mechanical ventilation shall be capable of exhausting the air quantity determined by the formula in Part 5, Equations. The exhaust quantity is dependant on the amount of refrigerant contained in the system.
   i. No open flames that use combustion air from the machinery room shall be installed where any refrigerant other than carbon dioxide is used.
   j. There shall be no flame producing device or continuously operating hot surface over 800°F permanently installed in the room.
   k. Refrigeration compressors, piping, equipment, valves, switches, ventilation equipment, and associated appurtenances shall be labeled in accordance with *ANSI/ASME A13.1.*

9.07 Combustion Air

A. *1990 BOCA Code:*

1. Inside Air: 1 Sq.In./1000 Btuh.
2. Outside Air:
   a. 1 Sq.In./4000 Btuh without Horizontal Ducts.
   b. 1 Sq.In./2000 Btuh with Horizontal Ducts.
3. 1 opening high and 1 opening low for both paragraphs 1 and 2 above. Area listed is for each opening.
4. Mechanical Ventilation: 1 CFM/3000 Btuh.

B. *1993 BOCA Code:*

1. Inside Air:
   a. 40 Cu.Ft. of Room Volume/1000 Btuh.
   b. 1 Sq.In./1000 Btuh; 100 Sq.In. Minimum.
2. Outside Air:
   a. 1 Sq.In./4000 Btuh with out Horizontal Ducts.
   b. 1 Sq.In./2000 Btuh with Horizontal Ducts.
   c. 1 Sq.In./4000 Btuh for Floor, Ceiling, or Vertical Duct openings.
3. 1 opening high and 1 opening low for both paragraphs 1 and 2 above. Area listed is for each opening.
4. Mechanical Ventilation: 1 CFM/3000 Btuh

C. *1988 SBCCI Code:*

1. Solid Fuels 2 Sq.In./1000 Btuh; 200 Sq.In. Min.
2. Liquid & Gas Fuels:
   a. Confined Spaces:
      1) Inside Air: 1 Sq.In./1000 Btuh; 100 Sq.In. Min.
      2) Outside Air:
         a) 1 Sq.In./4000 Btuh with out Horizontal Ducts.
         b) 1 Sq.In./2000 Btuh with Horizontal Ducts.
   b. Unconfined Spaces:
      1) Outside Air: 1 Sq.In./5000 Btuh.
3. 1 opening 12″ above finished floor and 1 opening 12″ below top of space applies to all fuels and spaces. Area listed for each opening.

D. *1988 UBC Code:*

1. Confined Spaces:
   a. Inside Air: 1 Sq.In./1000 Btuh Each Opening.
   b. Outside Air:
      1) 1 Sq.In./4000 Btuh with out Horizontal Ducts.
      2) 1 Sq.In./2000 Btuh with Horizontal Ducts.
2. Unconfined Spaces:
   a. Outside Air: 1 Sq.In./5000 Btuh.
3. 1 opening 12″ above finished floor and 1 opening 12″ below top of space applies to all spaces. ½ area high, ½ area low.

E. *1992 NFPA 54–National Fuel Gas Code:*

1. Confined Spaces:
   a. Inside Air: 1 Sq.In./1000 Btuh; 100 Sq.In. Min.
   b. Outside Air:
      1) 1 Sq.In./4000 Btuh; Direct communication with outside.
      2) 1 Sq.In./4000 Btuh with Vertical Ducts.
      3) 1 Sq.In./2000 Btuh with Horizontal Ducts.
2. Unconfined spaces:
   a. Tight Buildings: As specified for confined spaces.
   b. Leaky Buildings: Infiltration may be adequate.
3. 1 opening 12″ above finished floor and 1 opening 12″ below top of space. Area listed for each opening.
4. Louvers and grilles—¼″ mesh screens minimum; Wood louvers 20–25% free area; Metal louvers 60–75% free area.

9.08 Hazardous Locations

A. Hazardous location requirements for electrical and electronic equipment are defined in the *1996 National Electrical Code* (*NEC*), Articles 500 through 505.

B. Hazardous Classifications:

1. Class I: Class I locations are spaces or areas which contain flammable gases or vapors.
   a. Class I locations are subdivided into four groups based on type of flammable gases or vapors:
      1) Group A: Acetylene.

2) Group B: Hydrogen, Ethylene Oxide, Propylene Oxide.
3) Group C: Ethyl Ether, Ethylene.
4) Group D: Acetone, Ammonia, Butane, Gasoline, Propane.

b. Class I locations are also subdivided into 2 divisions:
1) Class I, Division 1:
   a) Locations where ignitable concentrations of flammable gases or vapors can exist under normal operating conditions; or
   b) Locations where ignitable concentrations of flammable gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or
   c) Locations where breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and might cause simultaneous failure of electric equipment.
2) Class I, Division 2:
   a) Locations where volatile flammable liquids or flammable gases are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed containers or closed systems where they can escape only in case of an accidental rupture or breakdown of such containers or systems; or
   b) Locations where ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and have the potential to become hazardous through failure or abnormal operation of the ventilating equipment; or
   c) Locations that are adjacent to Class I, Division 1 locations, and to which ignitable concentrations of gases or vapors might occasionally be communicated unless such communication is prevented by adequate positive pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

2. Class II: Class II locations are spaces or areas which contain combustible dusts.
3. Class III: Class II locations are spaces or areas which contain easily ignitable fibers or flyings.

C. Hazardous Location Protection Techniques:

1. Purged and Pressurized Systems: Spaces and equipment are pressurized at pressures above the external atmosphere with non-contaminated air or other non-flammable gas to prevent explosive gases or vapors from entering the enclosure.
2. Intrinsically Safe Systems: Electrical circuits are designed so that they do not release sufficient energy to ignite an explosive atmosphere.
3. Explosionproof Equipment: Explosionproof equipment is designed and built to withstand an internal explosion without igniting the surrounding atmosphere.
4. Nonicendive Circuits and Components: Circuits designed to prevent any arc or thermal effect produced, under intended operating conditions of the equipment or produced by opening, shorting, or grounding of the field wiring, is not capable, under specified test conditions, of igniting the flammable gas, vapor, or dust-air mixture.
5. Oil Immersed Equipment: The arcing portions of the equipment are immersed in an oil at a depth that the arc will not set off any hazardous gases or vapors above the surface of the oil.
6. Hermetically Sealed Equipment: The equipment is sealed against the external atmosphere to prevent the entry of hazardous gases or vapors.
7. Dust-Ignitionproof Equipment: Dust-ignitionproof equipment is designed and built to exclude dusts and, where installed and protected, will not permit arcs, sparks, or heat generated or liberated inside the enclosure to cause ignition of the exterior accumulations or atmospheric suspensions of a specified dust on or in the enclosure.
8. Classification versus Protection Techniques is shown in the following table:

PROTECTION TECHNIQUE	CLASS I, DIVISION 1	CLASS I, DIVISION 2	CLASS II	CLASS III
PURGED AND PRESSURIZED	X	X	X	X
INTRINSICALLY SAFE SYSTEMS	X	X	X	X
EXPLOSIONPROOF EQUIPMENT	X	X	X	X
NONINCENDIVE CIRCUITS AND COMPONENTS	N/A	X	X	X
HERMETICALLY SEALED EQUIPMENT	N/A	X	X	X
OIL IMMERSED EQUIPMENT	N/A	X	X	X
DUST-IGNITIONPROOF EQUIPMENT	N/A	N/A	X	X

Notes:
1. X = Appropriate to the classification.
2. N/A = Not acceptable to the classification.

D. Ventilation Requirements:

1. Ventilation, natural or mechanical, must be sufficient to limit the concentrations of flammable gases or vapors to a maximum level of 25% of their Lower Flammable Limit/Lower Explosive Limit (LFL/LEL).
2. Minimum Ventilation Required: 1.0 CFM/Sq. Ft. of floor area or 6.0 air changes per hour, whichever is greater. If a reduction in the classification is desired, the airflow must be 4 times the airflow specified above.
3. Recommendation: Ventilate all hazardous locations with 2.0 CFM/Sq. Ft. of floor area or 12 air changes per hour minimum with half the airflow supplied and exhausted high (within 6 inches of the ceiling or structure) and half the airflow supplied and exhausted low (within 6 inches of the floor).
4. Ventilation rate a minimum of 4 times the ventilation rate required to prevent the space from exceeding the maximum level of 25% LFL/LEL using fugitive emissions calculations.
5. Ventilate the space so that accumulation pockets for lighter than air or heavier than air gases or vapors are eliminated.
6. Monitoring of the space is recommended to assure that the 25% LFL/LEL is not exceeded.

E. Hazardous Location Definitions:

1. Boiling Point. The temperature at which the vapor pressure of a liquid equals the atmospheric pressure of 14.7 pounds per square inch absolute.
2. Combustible Liquids. Liquids having flash points at or above 100 F. Combustible liquids shall be subdivided as Class II or Class III liquids as follows:
   a. Class II. Liquids having flash points at or above 100°F. and below 140°F.
   b. Class IIIA. Liquids having flash points at or above 140°F. and below 200°F.
   c. Class IIIB. Liquids having flash points at or above 200°F.
3. Explosion. An effect produced by the sudden violent expansion of gases, which can be accompanied by a shockwave or disruption, or both, of enclosing materials or structures. An explosion might result from chemical changes such as rapid oxidation, deflagration, or detonation; decomposition of molecules, and runaway polymerization; or physical changes such as pressure tank ruptures.
4. Explosive. Any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion.

5. Flammable. Any material capable of being ignited from common sources of heat or at a temperature of 600 F. or less.
6. Flammable Compressed Gas. An air/gas mixture that is flammable when the gas is 13% or less by volume or when the flammable range of the gas is wider than 12% regardless of the lower limitation determined at atmospheric temperature and pressures.
7. Flammable Liquids. Liquids having flash points below 100°F. and having vapor pressures not exceeding 40 pounds per square inch absolute at 100°F. Flammable liquids shall be subdivided as Class IA, IB, and IC as follows:
   a. Class IA. Liquids having flash points below 73°F. and having boiling points below 100°F.
   b. Class IB. Liquids having flash points below 73°F. and having boiling points above 100°F.
   c. Class IC. Liquids having flash points at or above 73°F. and below 100°F.
8. Flammable Solids. A solid, other than a blasting agent or explosive, that is capable of causing a fire through friction, absorption of moisture, spontaneous chemical change, or retaining heat from manufacturing or processing, or which has an ignition temperature below 212°F. or which burns so vigorously and persistently when ignited as to create a serious hazard.
9. Flash Point. The minimum temperature in °F. at which a flammable liquid will give off sufficient vapors to form an ignitable mixture with air near the surface or in the container, but will not sustain combustion.
10. Noncombustible. A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subject to fire or heat.
11. Pyrophoric. A material that will spontaneously ignite in air at or below 130°F.

PART 10

Humidification Rules of Thumb

10.01 Window Types and Space Humidity Values

A. Single Pane Windows ±10% RH Maximum

B. Double Pane Windows ±30% RH Maximum

C. Triple Pane Windows ±40% RH Maximum

D. The above numbers are based on the following:

1. 0°F. outside design temperature.
2. 72°F. inside design temperature.
3. $R_{INSIDE\ AIR\ FILM} = 0.680$ $U_{INSIDE\ AIR\ FILM} = 1.471$
4. $R_{SINGLE\ GLASS} = 0.909$ $U_{SINGLE\ GLASS} = 1.100$
5. $R_{DOUBLE\ GLASS} = 1.667$ $U_{DOUBLE\ GLASS} = 0.600$
6. $R_{TRIPLE\ GLASS} = 2.000$ $U_{TRIPLE\ GLASS} = 0.500$
7. Standard air at sea level
8. The relative humidity numbers listed above are rounded for ease of remembrance.
9. The glass R-values and U-values are for average glass construction. Modern glass construction can achieve higher R-values/lower U-values.
10. For additional information on moisture condensation on glass see the tables at the end of this chapter.

10.02 Proper Vapor Barriers

Proper vapor barriers and moisture control must be provided to prevent moisture condensation in walls and to prevent mold, fungi, bacteria, and other plant and micro-organism growth.

10.03 Human Comfort

30–60% RH

10.04 Electrical Equipment, Computers

35–55% RH

10.05 Winter Design Relative Humidities

A. Outdoor Air Below 32°F.:

1. 70–80% RH
2. Design Wet Bulb Temperatures 2 to 4°F. below Design Dry Bulb Temperatures

B. Outdoor Air 32–60°F: 50% RH

10.06 Energy Code Winter Design Relative Humidities

A. CABO Model Energy Code:

1. Winter: 30% RH Maximum
2. Summer: 60% RH Minimum

B. *ASHRAE Standard 90A-1980:*

1. Winter: 30% RH Maximum
2. Summer: 60% RH Minimum, if Humidistat is used

C. *ASHRAE Standard 90A-1987:*

1. Winter: 30% RH Maximum
2. Summer: 60% RH Minimum, if Humidistat is used

D. *ASHRAE Standard 90.1-1989:*

1. Winter: 30% RH Maximum
2. Summer: 60% RH Minimum, if Humidistat is used

10.07 Optimum Relative Humidity Ranges for Health

HEALTH ASPECT	OPTIMUM RELATIVE HUMIDITY RANGE FOR CONTROLLING HEALTH ASPECT
BACTERIA	20 - 70%
VIRUSES	40 - 78%
FUNGI	0 - 70%
MITES	0 - 60%
RESPIRATORY INFECTIONS (1)	40 - 50%
ALLERGIC RHINITIS AND ASTHMA	40 - 60%
CHEMICAL INTERACTIONS	0 - 40%
OZONE PRODUCTION	75 - 100%
COMBINED HEALTH ASPECTS	40 - 60%

Notes:

1. **Insufficient data above 50% RH.**

10.08 Moisture Condensation on Glass

A. The moisture condensation tables below are based on the following:

1. $R_{\text{INSIDE AIR FILM}} = 0.680$ $U_{\text{INSIDE AIR FILM}} = 1.471$
2. $R_{\text{SINGLE GLASS}} = 0.909$ $U_{\text{SINGLE GLASS}} = 1.100$
3. $R_{\text{DOUBLE GLASS}} = 1.818$ $U_{\text{DOUBLE GLASS}} = 0.550$
4. $R_{\text{TRIPLE GLASS}} = 2.500$ $U_{\text{TRIPLE GLASS}} = 0.400$
5. Standard air at sea level.

B. The glass surface temperatures, which are also the space dewpoint temperatures, listed in the moisture condensation tables that follow, were developed using the equations in Part 5.

TEMP. ROOM °F.	TEMP. OUTSIDE °F.	SINGLE PANE GLASS		DOUBLE PANE GLASS		TRIPLE PANE GLASS	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
65	-30	-6.1	4.5	29.5	25.9	39.2	38.5
	-25	-2.3	5.6	31.3	27.9	40.5	40.5
	-20	1.4	6.9	33.2	30.2	41.9	42.8
	-15	5.2	8.4	35.1	32.6	43.2	45.0
	-5	12.6	12.1	38.8	37.9	46.0	50.1
	0	16.4	14.5	40.7	40.8	47.3	52.7
	5	20.1	17.2	42.6	44.0	48.7	55.5
	10	23.9	20.3	44.4	47.1	50.0	58.3
	20	31.3	27.9	48.2	54.5	52.8	64.7
	25	35.1	32.6	50.0	58.3	54.1	67.9
	30	38.8	37.9	51.9	62.6	55.5	71.4
	35	42.6	44.0	53.8	67.1	56.8	74.9
66	-30	-5.8	4.4	30.1	25.6	39.9	38.2
	-25	-2.1	5.5	32.0	27.7	41.2	40.2
	-20	1.7	6.7	33.8	29.9	42.6	42.5
	-15	5.4	8.2	35.7	32.3	44.0	44.8
	-5	12.9	11.8	39.4	37.4	46.7	49.7
	0	16.6	14.1	41.3	40.4	48.0	52.2
	5	20.4	16.8	43.2	43.5	49.4	55.1
	10	24.1	19.8	45.1	46.8	50.8	58.0
	20	31.6	27.3	48.8	53.8	53.5	64.1
	25	35.3	31.8	50.7	57.8	54.8	67.2
	30	39.1	37.0	52.5	61.8	56.2	70.8
	35	42.8	42.8	54.4	66.3	57.6	74.4
67	-30	-5.6	4.3	30.7	25.4	40.6	37.9
	-25	-1.8	5.4	32.6	27.5	42.0	40.1
	-20	1.9	6.6	34.5	29.7	43.3	42.2
	-15	5.7	8.0	36.3	32.0	44.7	44.5
	-5	13.1	11.6	40.1	37.2	47.4	49.3
	0	16.9	13.8	41.9	39.9	48.8	52.0
	5	20.6	16.4	43.8	43.0	50.1	54.6
	10	24.4	19.4	45.7	46.2	51.5	57.5
	20	31.8	26.6	49.4	53.2	54.2	63.5
	25	35.6	31.1	51.3	57.1	55.6	66.9
	30	39.3	36.0	53.2	61.3	56.9	70.1
	35	43.1	41.8	55.0	65.4	58.3	73.7

TEMP. ROOM °F.	TEMP. OUTSIDE °F.	SINGLE PANE GLASS		DOUBLE PANE GLASS		TRIPLE PANE GLASS	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
68	-30	-5.3	4.3	31.3	25.1	41.3	37.7
	-25	-1.6	5.3	33.2	27.2	42.7	39.8
	-20	2.2	6.5	35.1	29.4	44.1	42.0
	-15	5.9	7.8	37.0	31.8	45.4	44.2
	-5	13.4	11.3	40.7	36.8	48.1	48.9
	0	17.1	13.5	42.6	39.6	49.5	51.6
	5	20.9	16.0	44.4	42.5	50.9	54.4
	10	24.6	18.9	46.3	45.7	52.2	57.0
	20	32.1	26.0	50.0	52.6	54.9	63.0
	25	35.8	30.3	51.9	56.4	56.3	66.3
	30	39.6	35.2	53.8	60.5	57.7	69.7
	35	43.3	40.7	55.7	64.8	59.0	73.0
69	-30	-5.1	4.2	32.0	25.0	42.1	37.6
	-25	-1.3	5.2	33.8	26.9	43.4	39.5
	-20	2.4	6.3	35.7	29.1	44.8	41.7
	-15	6.2	7.7	37.6	31.4	46.2	44.0
	-5	13.6	11.1	41.3	36.4	48.9	48.7
	0	17.4	13.2	43.2	39.2	50.2	51.2
	5	21.1	15.6	45.1	42.2	51.6	53.9
	10	24.9	18.5	46.9	45.2	53.0	56.8
	20	32.3	25.3	50.7	52.1	55.7	62.7
	25	36.1	29.6	52.5	55.7	57.0	65.7
	30	39.8	34.3	54.4	59.8	58.4	69.1
	35	43.6	39.8	56.3	64.0	59.8	72.6
70	-30	-4.8	4.1	32.6	24.8	42.8	37.3
	-25	-1.1	5.0	34.5	26.8	44.2	39.4
	-20	2.7	6.2	36.3	28.8	45.5	41.4
	-15	6.4	7.5	38.2	31.1	46.9	43.7
	-5	13.9	10.8	41.9	36.0	49.6	48.3
	0	17.6	12.9	43.8	38.8	51.0	51.0
	5	21.4	15.3	45.7	41.7	52.3	53.5
	10	25.1	18.0	47.6	44.8	53.7	56.3
	20	32.6	24.8	51.3	51.5	56.4	62.1
	25	36.3	28.8	53.2	55.3	57.8	65.3
	30	40.1	33.6	55.0	59.0	59.1	68.4
	35	43.8	38.8	56.9	63.2	60.5	71.9

TEMP. ROOM °F.	TEMP. OUTSIDE °F.	SINGLE PANE GLASS		DOUBLE PANE GLASS		TRIPLE PANE GLASS	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
71	-30	-4.6	4.0	33.2	23.6	43.5	37.0
	-25	-0.8	5.0	35.1	26.5	44.9	39.1
	-20	2.9	6.0	37.0	28.7	46.2	41.1
	-15	6.7	7.4	38.8	30.8	47.6	43.3
	-5	14.1	10.6	42.6	35.8	50.3	48.0
	0	17.9	12.6	44.4	38.4	51.7	50.5
	5	21.6	14.9	46.3	41.3	53.0	53.0
	10	25.4	17.6	48.2	44.3	54.4	55.8
	20	32.8	24.1	51.9	50.9	57.1	61.6
	25	36.6	28.2	53.8	54.6	58.5	64.7
	30	40.3	32.7	55.7	58.5	59.8	67.8
	35	44.1	37.9	57.5	62.5	61.2	71.3
72	-30	-4.3	4.0	33.8	24.3	44.3	36.9
	-25	-0.6	4.8	35.7	26.3	45.6	38.8
	-20	3.2	5.9	37.6	28.4	47.0	41.0
	-15	6.9	7.2	39.5	30.6	48.3	43.0
	-5	14.4	10.4	43.2	35.4	51.1	47.8
	0	18.1	12.3	45.1	38.1	52.4	50.1
	5	21.9	14.6	46.9	40.8	53.8	52.8
	10	25.6	17.2	48.8	43.8	55.1	55.3
	20	33.1	23.6	52.6	50.5	57.9	61.2
	25	36.8	27.5	54.4	54.0	59.2	64.2
	30	40.6	32.0	56.3	57.8	60.6	67.4
	35	44.3	36.9	58.2	61.9	61.9	70.6
73	-30	-4.1	3.8	34.5	24.2	45.0	36.7
	-25	-0.3	4.8	36.3	26.0	46.3	38.6
	-20	3.4	5.8	38.2	28.1	47.7	40.7
	-15	7.2	7.1	40.1	30.3	49.1	42.9
	-5	14.7	10.2	43.8	35.0	51.8	47.4
	0	18.4	12.1	45.7	37.7	53.1	49.7
	5	22.1	14.3	47.6	40.5	54.5	52.4
	10	25.9	16.9	49.4	43.3	55.9	55.1
	20	33.4	23.1	53.2	49.9	58.6	60.7
	25	37.1	26.9	55.0	53.3	59.9	63.6
	30	40.8	31.2	56.9	57.1	61.3	66.8
	35	44.6	36.1	58.8	61.2	62.7	70.2

TEMP. ROOM °F.	TEMP. OUTSIDE °F.	SINGLE PANE GLASS		DOUBLE PANE GLASS		TRIPLE PANE GLASS	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
74	-30	-3.8	3.8	35.1	24.0	45.7	36.4
	-25	-0.1	4.7	37.0	25.9	47.1	38.4
	-20	3.7	5.7	38.8	27.8	48.4	40.4
	-15	7.4	6.9	40.7	30.0	49.8	42.5
	-5	14.9	9.9	44.5	34.8	52.5	47.0
	0	18.6	11.8	46.3	37.3	53.9	49.5
	5	22.4	14.0	48.2	40.1	55.2	51.9
	10	26.1	16.4	50.1	43.0	56.6	54.6
	20	33.6	22.6	53.8	49.3	59.3	60.2
	25	37.3	26.2	55.7	52.9	60.7	63.3
	30	41.1	30.5	57.5	56.4	62.0	66.2
	35	44.8	35.2	59.4	60.4	63.4	69.6
75	-30	-3.5	3.7	35.7	23.8	46.4	36.2
	-25	0.2	4.6	37.6	25.6	47.8	38.2
	-20	3.9	5.6	39.5	27.7	49.2	40.3
	-15	7.7	6.8	41.3	29.7	50.5	42.2
	-5	15.2	9.7	45.1	34.4	53.2	46.7
	0	18.9	11.6	46.9	36.9	54.6	49.1
	5	22.6	13.6	48.8	39.6	56.0	51.7
	10	26.4	16.1	50.7	42.6	57.3	54.2
	20	33.9	22.1	54.4	48.8	60.0	59.7
	25	37.6	25.7	56.3	52.3	61.4	62.7
	30	41.3	29.7	58.2	56.0	62.8	65.9
	35	45.1	34.4	60.0	59.7	64.1	69.0
76	-30	-3.3	3.6	36.4	23.6	47.2	36.1
	-25	0.4	4.5	38.2	25.4	48.5	37.9
	-20	4.2	5.5	40.1	27.4	49.9	39.9
	-15	7.9	6.6	42.0	29.5	51.2	41.9
	-5	15.4	9.5	45.7	34.1	54.0	46.5
	0	19.1	11.3	47.6	36.6	55.3	48.8
	5	22.9	13.4	49.4	39.2	56.7	51.3
	10	26.6	15.7	51.3	42.1	58.0	53.8
	20	34.1	21.5	55.1	48.4	60.8	59.4
	25	37.8	25.0	56.9	51.7	62.1	62.2
	30	41.6	29.1	58.8	55.3	63.5	65.3
	35	45.3	33.6	60.7	59.2	64.8	68.3

TEMP. ROOM °F.	TEMP. OUTSIDE °F.	SINGLE PANE GLASS		DOUBLE PANE GLASS		TRIPLE PANE GLASS	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
77	-30	-3.0	3.6	37.0	24.4	47.9	35.8
	-25	0.7	4.4	38.8	25.2	49.3	37.8
	-20	4.4	5.3	40.7	27.2	50.6	39.7
	-15	8.2	6.5	42.6	29.3	52.0	41.8
	-5	15.7	9.3	46.3	33.7	54.7	46.1
	0	19.4	11.1	48.2	36.3	56.1	48.6
	5	23.1	13.0	50.1	38.9	57.4	50.9
	10	26.9	15.4	51.9	41.6	58.8	53.5
	20	34.4	21.1	55.7	47.9	61.5	58.9
	25	38.1	24.5	57.6	51.3	62.9	61.9
	30	41.8	28.4	59.4	54.7	64.2	64.7
	35	45.6	32.8	61.3	58.5	65.6	68.0
78	-30	-2.8	3.5	37.6	23.2	48.6	35.6
	-25	0.9	4.3	39.5	25.1	50.0	37.5
	-20	4.7	5.3	41.3	26.9	51.3	39.4
	-15	8.4	6.3	43.2	29.0	52.7	41.5
	-5	15.9	9.1	47.0	33.5	55.4	45.8
	0	19.7	10.8	48.8	35.9	56.8	48.2
	5	23.4	12.8	50.7	38.5	58.1	50.5
	10	27.1	15.0	52.6	41.3	59.5	53.1
	20	34.6	20.6	56.3	47.3	62.2	58.4
	25	38.4	24.0	58.2	50.7	63.6	61.3
	30	42.1	27.8	60.0	54.0	64.9	64.2
	35	45.8	32.0	61.9	57.8	66.3	67.4
79	-30	-2.5	3.5	38.2	23.0	49.4	35.5
	-25	1.2	4.2	40.1	24.8	50.7	37.3
	-20	4.9	5.1	42.0	26.8	52.1	39.3
	-15	8.7	6.2	43.8	28.7	53.4	41.2
	-5	16.2	8.9	47.6	33.2	56.2	45.6
	0	19.9	10.6	49.5	35.6	57.5	47.8
	5	23.6	12.5	51.3	38.1	58.9	50.3
	10	27.4	14.7	53.2	40.9	60.2	52.7
	20	34.9	20.2	56.9	46.8	63.0	58.1
	25	38.6	23.4	58.8	50.1	64.3	60.8
	30	42.3	27.1	60.7	53.6	65.7	63.9
	35	46.1	31.3	62.5	57.1	67.0	66.8

TEMP. ROOM °F.	TEMP. OUTSIDE °F.	SINGLE PANE GLASS		DOUBLE PANE GLASS		TRIPLE PANE GLASS	
		T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.	T_{GLASS} / $T_{DEWPOINT}$	% R.H.
80	-30	-2.3	3.4	38.9	22.9	50.1	35.3
	-25	1.5	4.2	40.7	24.6	51.4	37.0
	-20	5.2	5.0	42.6	26.5	52.8	39.0
	-15	8.9	6.1	44.5	28.5	54.2	41.0
	-5	16.4	8.7	48.2	32.8	56.9	45.3
	0	20.2	10.4	50.1	35.3	58.2	47.4
	5	23.9	12.2	51.9	37.7	59.6	49.9
	10	27.6	14.4	53.8	40.5	61.0	52.4
	20	35.1	19.7	57.6	46.4	63.7	57.6
	25	38.9	22.9	59.4	49.5	65.0	60.3
	30	42.6	26.5	61.3	53.0	66.4	63.3
	35	46.3	30.6	63.2	56.6	67.8	66.4

PART 11

People/Occupancy Rules of Thumb

11.01 Offices, Commercial

A. General	80–150 Sq.Ft./Person
B. Private	1, 2, or 3 People
C. Private	100–150 Sq.Ft./Person
D. Conference, Meeting Rooms	20–50 Sq.Ft./Person

11.02 Banks, Court Houses, Municipal Buildings, Town Halls

50–150 Sq.Ft./Person

11.03 Police Stations, Fire Stations, Post Offices

100–500 Sq.Ft./Person

11.04 Precision Manufacturing

100–300 Sq.Ft./Person

11.05 Computer Rooms

80–150 Sq.Ft./Person

11.06 Restaurants

15–50 Sq.Ft./Person

11.07 Kitchens

50–150 Sq.Ft./Person

11.08 Cocktail Lounges, Bars, Taverns, Clubhouses, Nightclubs

15–50 Sq.Ft./Person

11.09 Hospital Patient Rooms, Nursing Home Patient Rooms

80–150 Sq.Ft./Person

11.10 Hospital General Areas

50–150 Sq.Ft./Person

11.11 Medical/Dental Centers, Clinics, and Offices

50–150 Sq.Ft./Person

11.12 Residential

200–600 Sq.Ft./Person

11.13 Apartments (Eff., 1 Room, 2 Room)

100–400 Sq.Ft./Person

11.14 Motel and Hotel Public Spaces

100–200 Sq.Ft./Person

11.15 Motel and Hotel Guest Rooms, Dormitories

100–200 Sq.Ft./Person

11.16 School Classrooms

20–30 Sq.Ft./Person

11.17 Dining Halls, Lunch Rooms, Cafeterias, Luncheonettes

10–50 Sq.Ft./Person

11.18 Libraries, Museums

30–100 Sq.Ft./Person

11.19 Retail, Department Stores

15–75 Sq.Ft./Person

11.20 Drug, Shoe, Dress, Jewelry, Beauty, Barber, and Other Shops

15–50 Sq.Ft./Person

11.21 Supermarkets

50–100 Sq.Ft./Person

11.22 Malls, Shopping Centers

50–100 Sq.Ft./Person

11.23 Jails

50–300 Sq.Ft./Person

11.24 Auditoriums, Theaters

5–20 Sq.Ft./Person

11.25 Churches

5–20 Sq.Ft./Person

11.26 Bowling Alleys

2–6 People/Lane

Note: People/Occupancy requirements should be determined from architect or client whenever possible.

PART 12

Lighting Rules of Thumb

12.01 Offices, Commercial

A. General	1.5–3.0 Watts/Sq.Ft.
B. Private	2.0–5.0 Watts/Sq.Ft.
C. Conference, Meeting Rooms	2.0–6.0 Watts/Sq.Ft.

12.02 Banks, Court Houses, Municipal Buildings, Town Halls

2.0–5.0 Watts/Sq.Ft.

12.03 Police Stations, Fire Stations, Post Offices

2.0–3.0 Watts/Sq.Ft.

12.04 Precision Manufacturing

3.0–10.0 Watts/Sq.Ft.

12.05 Computer Rooms

1.5–5.0 Watts/Sq.Ft.

12.06 Restaurants

1.5–3.0 Watts/Sq.Ft.

12.07 Kitchens

1.5–2.5 Watts/Sq.Ft.

12.08 Cocktail Lounges, Bars, Taverns, Clubhouses, Nightclubs

1.5–2.0 Watts/Sq.Ft.

12.09 Hospital Patient Rooms, Nursing Home Patient Rooms

1.0–2.0 Watts/Sq.Ft.

12.10 Hospital General Areas

1.5–2.5 Watts/Sq.Ft.

12.11 Medical/Dental Centers, Clinics, and Offices

1.5–2.5 Watts/Sq.Ft.

12.12 Residential

1.0–4.0 Watts/Sq.Ft.

12.13 Apartments (Eff., 1 Room, 2 Room)

1.0–4.0 Watts/Sq.Ft.

12.14 Motel and Hotel Public Spaces

1.0–3.0 Watts/Sq.Ft.

12.15 Motel and Hotel Guest Rooms, Dormitories

1.0–3.0 Watts/Sq.Ft.

12.16 School Classrooms

2.0–6.0 Watts/Sq.Ft.

12.17 Dining Halls, Lunch Rooms, Cafeterias, Luncheonettes

1.5–2.5 Watts/Sq.Ft.

12.18 Libraries, Museums

1.0–3.0 Watts/Sq.Ft.

12.19 Retail, Department Stores

2.0–6.0 Watts/Sq.Ft.

12.20 Drug, Shoe, Dress, Jewelry, Beauty, Barber, and Other Shops

1.0–3.0 Watts/Sq.Ft.

12.21 Supermarkets

1.0–3.0 Watts/Sq.Ft.

12.22 Malls, Shopping Centers

1.0–2.5 Watts/Sq.Ft.

12.23 Jails

1.0–2.5 Watts/Sq.Ft.

12.24 Auditoriums, Theaters

1.0–3.0 Watts/Sq.Ft. (3)

12.25 Churches

1.0–3.0 Watts/Sq.Ft.

12.26 Bowling Alleys

1.0–2.5 Watts/Sq.Ft.

Notes:

1. The lighting values for most energy conscious construction will be the lower values.
2. Actual lighting layouts should be used for calculating lighting loads whenever available.
3. Does not include theatrical lighting.

PART 13

Appliance/Equipment Rules of Thumb

13.01 Offices and Commercial Spaces

A. Total Appliance/Equipment Heat Gain: 0.5–5.0 Watts/Sq.Ft.

B. Computer equipment loads for office spaces range between 0.5 Watt/Sq.Ft. and 2.5 Watts/Sq.Ft. (recommend 1.5 Watts/Sq.Ft.). If actual computer equipment loads are available, they should be used in lieu of values listed here.

13.02 Computer Rooms, Data Centers, and Internet Host Facilities

2.0–300.0 Watts/Sq.Ft.

13.03 Telecommunication Rooms

50.0–120.0 Watts/Sq.Ft.

13.04 Electrical Equipment Heat Gain

A. Transformers:

1. 150 KVA and Smaller	50 Watts/KVA
2. 151–500 KVA	30 Watts/KVA
3. 501–1000 KVA	25 Watts/KVA
4. 1001–2500 KVA	20 Watts/KVA
5. Larger than 2500 KVA	15 Watts/KVA

B. Switchgear:

1. Low Voltage Breaker 0–40 Amps	10 Watts
2. Low Voltage Breaker 50–100 Amps	20 Watts
3. Low Voltage Breaker 225 Amps	60 Watts
4. Low Voltage Breaker 400 Amps	100 Watts
5. Low Voltage Breaker 600 Amps	130 Watts
6. Low Voltage Breaker 800 Amps	170 Watts
7. Low Voltage Breaker 1,600 Amps	460 Watts
8. Low Voltage Breaker 2,000 Amps	600 Watts
9. Low Voltage Breaker 3,000 Amps	1,100 Watts
10. Low Voltage Breaker 4,000 Amps	1,500 Watts
11. Medium Voltage Breaker/Switch 600 Amps	1,000 Watts
12. Medium Voltage Breaker/Switch 1,200 Amps	1,500 Watts
13. Medium Voltage Breaker/Switch 2,000 Amps	2,000 Watts
14. Medium Voltage Breaker/Switch 2,500 Amps	2,500 Watts

C. Panelboards:

1. 2 Watts per circuit

D. Motor Control Centers

1. 500 Watts per section—each section is approximately 20″ wide × 20″ deep × 84″ high.

E. Starters:

1. Low Voltage Starters Size 00	50 Watts
2. Low Voltage Starters Size 0	50 Watts

3. Low Voltage Starters Size 1 — 50 Watts
4. Low Voltage Starters Size 2 — 100 Watts
5. Low Voltage Starters Size 3 — 130 Watts
6. Low Voltage Starters Size 4 — 200 Watts
7. Low Voltage Starters Size 5 — 300 Watts
8. Low Voltage Starters Size 6 — 650 Watts
9. Medium Voltage Starters Size 200 Amp — 400 Watts
10. Medium Voltage Starters Size 400 Amp — 1,300 Watts
11. Medium Voltage Starters Size 700 Amp — 1,700 Watts

F. Variable Frequency Drives:

1. 2 to 6 percent of the KVA rating

G. Miscellaneous Equipment:

1. Bus Duct 0.015 Watts/Ft/Amp
2. Capacitors 2 Watts/KVAR

Notes:

1. Actual electrical equipment heat gain values will vary from one manufacturer to another—use actual values when available.
2. Generally, electrical equipment rooms only require ventilation to keep equipment from overheating. Most electrical rooms are designed for 95°F. to 104°F.; however, consult electrical engineer for equipment temperature tolerances. If space temperatures below 90°F. are required by equipment, air conditioning of space will be required.
3. If outside air is used to ventilate the electrical room, the electrical room design temperature will be 10°F. to 15°F. above outside summer design temperatures.
4. If conditioned air from an adjacent space is used to ventilate the electrical room, the electrical room temperature can be 10°F. to 20°F. above the adjacent spaces.

13.05 Motor Heat Gain

A. Motors Only:

1. Motors 0 to 2 Hp — 190 Watts/Hp
2. Motors 3–20 Hp — 110 Watts/Hp
3. Motors 25–200 Hp — 75 Watts/Hp
4. Motors 250 Hp and Larger — 60 Watts/Hp

B. Motors and Driven Equipment are shown in the following table:

MOTOR HORSEPOWER	LOCATION OF MOTOR AND DRIVEN EQUIPMENT WITH RESPECT TO CONDITIONED SPACE OR AIRSTREAM		
	MOTOR IN, DRIVEN EQUIPMENT IN BTU/HR	MOTOR OUT, DRIVEN EQUIPMENT IN BTU/HR	MOTOR IN, DRIVEN EQUIPMENT OUT BTU/HR
1/20	360	130	240
1/12	580	200	380
1/8	900	320	590
1/6	1,160	400	760
1/4	1,180	640	540
1/3	1,500	840	660
1/2	2,120	1,270	850
3/4	2,650	1,900	740
1	3,390	2,550	850
1-1/2	4,960	3,820	1,140
2	6,440	5,090	1,350
3	9,430	7,640	1,790
5	15,500	12,700	2,790
7-1/2	22,700	19,100	3,640
10	29,900	24,500	4,490
15	44,400	38,200	6,210
20	58,500	50,900	7,610
25	72,300	63,600	8,680
30	85,700	76,300	9,440
40	114,000	102,000	12,600
50	143,000	127,000	15,700
60	172,000	153,000	18,900
75	212,000	191,000	21,200
100	283,000	255,000	28,300
125	353,000	318,000	35,300
150	420,000	382,000	37,800
200	569,000	509,000	50,300
250	699,000	636,000	62,900

13.06 Miscellaneous Guidelines

A. Actual equipment layouts and information should be used for calculating equipment loads.
B. Movie projectors, slide projectors, overhead projectors, and similar types of equipment can generally be ignored because lights are off when being used and lighting load will normally be larger than this equipment heat gain.
C. Items such as coffee pots, microwave ovens, refrigerators, food warmers, etc., should be considered when calculating equipment loads.
D. Kitchen, laboratory, hospital, computer room, and process equipment should be obtained from owner, architect, engineer, or consultant due to extreme variability of equipment loads.

PART 14

Cooling Load Factors

14.01 Diversity Factors

Diversity factors are an engineer's judgement applied to various people, lighting, equipment, and total loads to consider actual usage. Actual diversities may vary depending on building type and occupancy. Diversities listed here are for office buildings and similar facilities.

A. Room/Space Peak Loads:

1. People 1.0 × Calc. Load
2. Lights 1.0 × Calc. Load
3. Equipment 1.0 × Calc. Load*

*Calc. Load may have diversity factor calculated with individual pieces of equipment or as a group or not at all.

B. Floor/Zone Block Loads:

1. People 0.90 × Sum of Peak Room/Space People Loads
2. Lights 0.95 × Sum of Peak Room/Space Lighting Loads
3. Equipment 0.90 × Sum of Peak Room/Space Equipment Loads
4. Floor/Zone Total Loads 0.90 × Sum of Peak Room/Space Total Loads

C. Building Block Loads:

1. People 0.75 × Sum of Peak Room/Space People Loads
2. Lighting 0.95 × Sum of Peak Room/Space Lighting Loads
3. Equipment 0.75 × Sum of Peak Room/Space Equipment Loads
4. Building Total Load 0.85 × Sum of Peak Room/Space Total Loads

14.02 Safety Factors

A. Room/Space Peak Loads 1.1 × Calc. Load

B. Floor/Zone Loads (Sum of Peak) 1.0 × Calc. Load

C. Floor/Zone Loads (Block) 1.1 × Calc. Load

D. Building Loads (Sum of Peak) 1.0 × Calc. Load

E. Building Loads (Block) 1.1 × Calc. load

F. ASHRAE Standard 90.1-1989 10% Maximum Safety Factor

14.03 Cooling Load Factors

A. Lighting Load Factors:

1. Fluorescent Lights 1.25 × Bulb Watts
2. Incandescent Lights 1.00 × Bulb Watts
3. HID Lighting 1.25 × Bulb Watts

B. Return Air Plenum (RAP) Factors:

1. Heat of Lights to Space with RAP 0.76 × Lighting Load
2. Heat of Lights to RAP 0.24 × Lighting Load
3. Heat of Roof to space with RAP 0.30 × Roof Load
4. Heat of Roof to RAP 0.70 × Roof Load

C. Ducted Exhaust or Return Air (DERA) Factors:

1. Heat of Lights to Space with DERA 1.00 × Lighting Load
2. Heat of Roof to Space with DERA 1.00 × Roof Load

D. Other Cooling Load Factors (CLF) are in accordance with ASHRAE Recommendations:

1. CLF × Other Loads

14.04 *ASHRAE Standard 90.1-1989*

A. Pick-Up Loads 10% Maximum System Capacity Allowance for Morning Cool Down Cycles

B. Safety Factor 10% Maximum

PART 15

Heating Load Factors

15.01 Safety Factors

A. Room/Space Peak Loads	1.1 × Calc. Load
B. Floor/Zone Loads (Sum of Peak)	1.0 × Calc. Load
C. Floor/Zone Loads (Block)	1.1 × Calc. Load
D. Building Loads (Sum of Peak)	1.0 × Calc. Load
E. Building Loads (Block)	1.1 × Calc. Load

F. Generally: Sum of Peak Loads = 1.1 × Block Loads

15.02 Heating Load Credits

A. Solar. Credit for solar gains should not be taken unless building is specifically designed for solar heating. Solar gain is not a factor at night when design temperatures generally reach their lowest point.

B. People. Credit for people should not be taken. People gain is not a factor at night when design temperatures generally reach their lowest point because buildings are generally unoccupied at night.

C. Lighting. Credit for lighting should not be taken. Lighting is an inefficient means to heat a building and lights are generally off at night when design temperatures generally reach their lowest point.

D. Equipment. Credit for equipment should not be taken unless a reliable source of heat is generated 24 hours a day (i.e., Computer Facility, Industrial Process). Only a portion of this load should be considered (50%) and the building heating system should be able to keep the building from freezing if these equipment loads are shut down for extended periods of time. Consider what would happen if the system or process shut down for extended periods of time.

15.03 Heating System Selection Guidelines

A. If heat loss exceeds 450 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.

B. If heat loss is between 250 and 450 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, blanketing the exposed wall and window areas.

C. If heat loss is less than 250 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at or both directed at and directed away from the exposed wall and window areas.

15.04 *ASHRAE Standard 90.1-1989*

A. Pick-Up Loads	**30% Maximum System Capacity Allowance for Morning Warm-Up Cycles**
B. Safety Factor	**10% Maximum**

PART 16

Energy Conservation and Design Conditions

16.01 *The 1989 CABO Model Energy Code*

A. *The 1989 CABO Model Energy Code* is common to all three major U.S. codes (*1990 BOCA, 1988 SBCCI, 1988 UBC*) and is based on *ASHRAE Standard 90A 1980, Energy Conservation in New Building Design.*

B. *1990 BOCA, 1988 SBCCI,* and the *1988 UBC* codes also reference *ASHRAE Standard 90A-1980.*

C. Model Energy Code Design Conditions:

1. Outdoor Latest Version of *ASHRAE Handbook of Fundamentals:*
   a. Heating 97½% Values, Minimum
   b. Cooling 2½% Values, Maximum
2. Indoor:
   a. Heating 70°F.; 30% RH Max.
   b. Cooling 78°F.; 30 to 60% RH

D. The Model Energy Code Economizer Requirements:

1. Systems 5,000 CFM and larger or 134,000 Btuh total cooling capacity and larger shall be designed to use up to and including 100 percent of the fan system capacity for cooling with outdoor air automatically whenever the use of outdoor air will result in lower usage of energy.
2. Exceptions (partial list):
   a. Systems where the quality of outdoor is poor and will require extensive treatment.
   b. Systems where humidification or dehumidification requires more energy than is saved by outdoor air cooling.
   c. Systems where outdoor air cooling will increase the overall energy consumed by other systems.
   d. Systems where cooling is accomplished by equipment other than refrigeration equipment (i.e., cooling towers—waterside economizer).

E. Ventilation:

1. Systems shall be provided with a readily accessible means for ventilation shutoff (close OA dampers) when ventilation is not required (i.e., unoccupied periods).

F. Simultaneous Heating and Cooling:

1. Systems that employ simultaneous heating and cooling in order to achieve comfort conditions shall be limited to those situations where more efficient methods of providing HVAC cannot be effectively utilized. Simultaneous heating and cooling by reheating or recooling supply air or by concurrent operations of independent HVAC systems shall be restricted as follows:
   a. Reheat systems shall be provided with controls to automatically reset the system's cold deck supply air temperature to the highest temperature that will satisfy the zone requiring the coolest air.
   b. Dual duct and multizone systems shall be provided with controls to automatically reset the cold deck and the hot deck supply air temperatures to the highest and lowest temperatures, respectively, that will satisfy the zones requiring the coolest and warmest air.

G. Controls:

1. Temperature Controls:
   a. Heating Only 55°F.–75°F.

b. Cooling Only 70°F.–85°F.
c. Heating and Cooling 55°F.–85°F.

2. Humidity Controls:
   a. Winter/Heating 30% Maximum.
   b. Summer/Cooling 60% Minimum.
   c. Note above items are values when using energy to humidify/dehumidify, respectively.
3. Setback and Shutoff. Each HVAC system shall be equipped with a readily accessible means of reducing energy used for HVAC during periods of non-use or alternate uses of the building spaces or zones served by the system.
   a. Winter. Night Setback.
   b. Summer. Night Setup.
   c. Occupied Periods. Time Clocks, Automatic Control Systems.
   d. Unoccupied Periods. Manually Adjustable Automatic Timing Devices.

16.02 *ASHRAE Standard 90A-1980, Energy Conservation in New Building Design*

A. Purpose:

1. To provide design requirements which will improve utilization of energy in new buildings and to provide a means of determining the anticipated impact of that energy utilization on the depletion of energy resources.
2. To provide energy efficient design of building envelopes, energy efficient design and selection of mechanical, electrical, service water heating, and illumination systems and equipment, and to provide prudent selection of fuel and energy sources.
3. To encourage the use of innovative approaches and techniques to achieve effective utilization of energy.
4. To provide energy efficient design standards for new buildings which can be utilized during the preconstruction stage.

B. Scope:

1. Design of new buildings for human occupancy.
2. Building Envelope.
3. Selection of Systems and Equipment:
   a. HVAC.
   b. Service Water Heating.
   c. Energy Distribution.
   d. Illuminating Systems.
4. Exceptions:
   a. Buildings whose peak energy usage is less than 3.5 Btu/Hr. Sq.Ft. of gross floor area
   b. Buildings which are neither heated nor cooled
5. This standard does not include operation and maintenance criteria.

C. HVAC Systems Design:

1. Heating and Cooling Load Calculation Procedures—*ASHRAE Handbook & Product Directory 1977 Fundamentals* or equivalent computational procedure.
2. Indoor Design Conditions: *ANSI\ASHRAE Standard 55-1974 Thermal Environmental Conditions for Human Occupancy:*
   a. Heating (Winter)
      1) *ASHRAE Standard 90A-1980:* 72°F. Dry Bulb Recommended; 30% RH Maximum.
      2) Most Commonly Used Design Condition: 72°F. DB.

   b. Cooling (Summer):
      1) *ASHRAE Standard 90A-1980:* 78°F. Dry Bulb Recommended.
      2) Most Commonly Used Design Condition: 75°F./50% R.H.
3. Outdoor Design Conditions: *ASHRAE Handbook & Product Directory 1977 Fundamentals* or from local climate data:
   a. Heating (Winter): 97.5% Values, Minimum.
   b. Cooling (Summer): 2.5% Values, Maximum.
4. Ventilation:
   a. Meet *ASHRAE/ANSI Standard 62-1973, Natural and Mechanical Ventilation*.
   b. Air required for exhaust makeup, for source control of contaminants, or codes.

D. Controls:

1. System Control. At least 1 temperature control device:
   a. Heating Only: 55°F. to 75°F.
   b. Cooling Only: 70°F. to 85°F.
   c. Heating and Cooling: 55°F. to 85°F. with adjustable deadband of 10°F. or more.
2. Humidity Control:
   a. Humidistat is required for winter humidification, 30% maximum winter humidity level for comfort purposes.
   b. If a humidistat is used for summer dehumidification, 60% minimum summer humidity level is required for comfort purposes.
3. Zone Control:
   a. Residential Occupancies: Individual thermostatic controls for each system or dwelling unit.
   b. All Other Occupancies:
      1) Each System.
      2) Each Floor.
      3) Each Separate Zone. A zone is a space or group of spaces with similar heating and/or cooling requirements.
4. Off-Hours Controls:
   a. Provide each system with a readily accessible, manual, or automatic means of shutting off or reducing the energy used during unoccupied periods.

E. Simultaneous Heating and Cooling Systems:

1. The use of simultaneous heating and cooling systems will be limited to circumstances where more energy efficient systems cannot meet building design requirements.
2. Reheat, Dual Duct, Multi-Zone, and Recooling Systems will employ automatic temperature reset controls for both hot and cold airstreams.

F. Economizer controls are required:

1. Air Side Economizers: Dry-Bulb Temperature or Enthalpy.
2. Exceptions:
   a. Fans with a capacity of less than 5000 CFM or total cooling capacity of less than 134,000 Btuh.
   b. Annual heating degree days are less than 1,200.
   c. When the system will be operated less than 30 hours per week.
   d. Systems serving single-family or multi-family residential buildings.

G. Mechanical Ventilation:

1. Supply and exhaust systems shall be provided with a readily accessible means to shut off or reduce the ventilation air when the building is unoccupied.

H. Transport Energy:

1. All air systems, air and water systems, and water systems shall have a transport factor 5.5 or greater. Transport factors are the space sensible heat expressed in Btu/Hr. divided by the sum of the supply fan(s), return fan(s), terminal fan(s), and pump(s) input energy expressed in Btu/Hr.

I. Piping Insulation. Insulation is required on:

1. Heating Systems (Hot Water, Steam, Steam Condensate): 120°F. and Higher.
2. Cooling Systems (Chilled Water, Brine, and Refrigerant): 55°F. and Lower.
3. Domestic and Service Hot Water Systems: 100°F. and Higher.
4. Insulation not required on systems where Fluid Temperature is between 55°F. and 120°F.
5. Required Insulation Thickness depends on Fluid Temperature, Insulation Type, and Pipe Size.
6. Insulation Thickness is given in the following table:

PIPING SYSTEM	FLUID TEMP. °F.	INSULATION THICKNESS FOR PIPE SIZES - INCHES (1,3)					
		RUNOUTS UP TO 2" (2)	1" & SMALLER	1-1/4" - 2"	2-1/2" - 4"	5" & 6"	8" & LARGER
HEATING SYSTEMS - STEAM AND HOT WATER							
HIGH PRESSURE/ TEMPERATURE	306-450	1.5	2.5	2.5	3.0	3.5	3.5
MEDIUM PRESSURE/ TEMPERATURE	251-305	1.5	2.0	2.5	2.5	3.0	3.0
LOW PRESSURE/ TEMPERATURE	201-250	1.0	1.5	1.5	2.0	2.0	2.0
LOW TEMPERATURE	120-200	0.5	1.0	1.0	1.5	1.5	1.5
STEAM CONDENSATE	ANY	1.0	1.0	1.5	2.0	2.0	2.0
COOLING SYSTEMS							
CHILLED WATER	40-55	0.5	0.5	0.75	1.0	1.0	1.0
REFRIGERANT OR BRINE	BELOW 40	1.0	1.0	1.5	1.5	1.5	1.5

Notes:

1. **Insulation thicknesses based on insulation having a thermal resistivity in the range of 4.0 to 4.6 Ft^2 Hr. °F./Btu. In.**
2. **Runouts to individual terminal units not exceeding 12 feet.**
3. **For piping exposed to ambient temperatures, increase insulation thickness by 0.5″.**

J. Air Handling System Insulation. Insulation is required on all ducts, plenums, and enclosures:

1. Insulation is required when the Temperature Difference between Air Temperature and Space Temperature is Greater than 25°F.
2. Exceptions:

   a. Where the temperature difference is 14°F or less.
   b. Within HVAC equipment.
   c. Exhaust air ducts.
3. Insulation Thickness is given in the following table:

TEMPERATURE DIFFERENCE °F	R-VALUE SQ.FT. HR. °F./BTU
25	1.7
27	1.8
54	3.6
81	5.4
108	7.2
136	9.1
162	11.0

K. Duct Construction:

1. *SMACNA Heating and Air Conditioning Systems Installation Standards*, 3rd Ed., February 1977.
2. *SMACNA Low Pressure Duct Construction Standards,* 5th Ed., 1976.
3. *SMACNA High Pressure Duct Construction Standards,* 3rd Ed., 1975.
4. *SMACNA Fibrous Glass Duct Construction Standards,* 4th Ed., 1975.
5. High pressure and medium pressure ducts shall be leak tested in accordance with SMACNA Standard.

L. Balancing:

1. System design shall provide a means for balancing both air and water systems.

M. HVAC Equipment:

1. Minimum Equipment Efficiencies.
2. Equipment Rating shall be Certified by Nationally Recognized Standards.

16.03 *ASHRAE Standard 90A-a-1987, Energy Conservation in New Building Design*

A. HVAC Systems Design:

1. Heating and Cooling Load Calculation Procedures. *ASHRAE Handbook 1981 Fundamentals* or similar computational procedure.
2. Indoor Design Conditions: *ANSI\ASHRAE Standard 55-1981 Thermal Environmental Conditions for Human Occupancy*.
   a. Satisfy 80% or More of the Occupants.
   b. Heating (Winter):
      1) *ASHRAE Standard 90A-a-1987:* 72°F. Dry Bulb Recommended; 30% RH Maximum.

2) *ASHRAE Standard 55:* 68°F.–74°F. Dry Bulb (DB) at 60% RH; 69°F.–76°F. DB at 36°F Dew Point (DP).
3) Most Commonly Used Design Condition: 72°F DB.

c. Cooling (Summer):
1) *ASHRAE Standard 90A-a-1987:* 78°F. Dry Bulb Recommended.
2) *ASHRAE Standard 55:* 73°F.–79°F. DB at 60% RH; 74°F.–81°F. DB at 36°F DP.
3) Most Commonly Used Design Condition: 75°F/50% R.H.

3. Outdoor Design Conditions: *ASHRAE Handbook 1981 Fundamentals* or from local climate data:
   a. Heating (Winter): 97.5% Values, Minimum.
   b. Cooling (Summer): 2.5% Values, Maximum.

B. Duct Construction:

1. *SMACNA Heating and Air Conditioning Systems Installation Standards,* 3rd Ed., February 1977.
2. *SMACNA Low Pressure Duct Construction Standards,* 5th Ed., 1976.
3. *SMACNA High Pressure Duct Construction Standards,* 3rd Ed., 1975.
4. *SMACNA Fibrous Glass Duct Construction Standards,* 5th Ed., 1979.

16.04 *ASHRAE Standard 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*

A. Purpose:

1. To set minimum requirements for the energy efficient design of new buildings so that they may be constructed, operated, and maintained in a manner that minimizes the use of energy without constraining the building function or the comfort or productivity of the occupants.
2. To provide criteria for energy efficient design and methods for determining compliance with these criteria.
3. To provide sound guidance for energy efficient design.
4. It is estimated that as much as 40% of the energy used to heat, cool, and illuminate buildings and to provide hot water could be saved through the effective application of existing technology without reducing building performance or human comfort.

B. Scope:

1. Building Envelope
2. Distribution of Energy
3. Systems and Equipment:
   a. Auxiliaries
   b. Heating
   c. Ventilating
   d. Air-Conditioning
   e. Service Water Heating
   f. Lighting
4. Energy Management

C. Application:

1. To all new Buildings or Portions of Buildings that provide Facilities or Shelter for Human Occupancy and use Energy Primarily to provide Human Comfort.

2. Does not apply to: Areas of Buildings used for Manufacturing, Commercial or Industrial Processing.

D. NEMA Design B; Single Speed; 1200, 1800, or 3600 RPM; Open Drip Proof (ODP) or Totally Enclosed Fan Cooled (TEFC) Motors 1 Hp and Larger that operate more than 500 hours per year must meet the following minimum nominal efficiencies:

Horsepower	Minimum Nominal Efficiency
1 - 4	78.5
5 - 9	84.0
10 - 19	85.5
20 - 49	88.5
50 - 99	90.2
100 - 124	91.7
125 or Greater	92.4

Note: Above table is based on *ASHRAE Standard 90.1* prior to adoption of Addendum 90.1c by ASHRAE Board of Directors.

E. NEMA Design A and B; Open Drip Proof (ODP) or Totally Enclosed Fan Cooled (TEFC) Motors 1 Hp and Larger that operate more than 1000 hours per year must meet the following minimum nominal efficiencies; Minimum Acceptable Nominal Full-Load Motor Efficiency for Single Speed Polyphase Squirrel-Cage Induction Motors having Synchronous Speed of 3600, 1800, 1200, and 900 RPM:

Full Load Efficiencies—Open Motors

HP	2-POLE		4-POLE		6-POLE		8-POLE	
	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.
1.0	---	---	82.5	81.5	80.0	78.5	74.0	72.0
1.5	82.5	81.5	84.0	82.5	84.0	82.5	75.5	74.0
2.0	84.0	82.5	84.0	82.5	85.5	84.0	85.5	84.0
3.0	84.0	82.5	86.5	85.5	86.5	85.5	86.5	85.5
5.0	85.5	84.0	87.5	86.5	87.5	86.5	87.5	86.0
7.5	87.5	86.5	88.5	87.5	88.5	87.5	88.5	87.5
10.0	88.5	87.5	89.5	88.5	90.2	89.5	89.5	88.5
15.0	89.5	88.5	91.0	90.2	90.2	89.5	89.5	88.5
20.0	90.2	89.5	91.0	90.2	91.0	90.2	90.2	89.5
25.0	91.0	90.2	91.7	91.0	91.7	91.0	90.2	89.5
30.0	91.0	90.2	92.4	91.7	92.4	91.7	91.0	90.2
40.0	91.7	91.0	93.0	92.4	93.0	92.4	91.0	90.2
50.0	92.4	91.7	93.0	92.4	93.0	92.4	91.7	91.0
60.0	93.0	92.4	93.6	93.0	93.6	93.0	92.4	91.7
75.0	93.0	92.4	94.1	93.6	93.6	93.0	93.6	93.0
100.0	93.0	92.4	94.1	93.6	94.1	93.6	93.6	93.0
125.0	93.6	93.0	94.5	94.1	94.1	93.6	93.6	93.0
150.0	93.6	93.0	95.0	94.5	94.5	94.1	93.6	93.0
200.0	94.5	94.1	95.0	94.5	94.5	94.1	93.6	93.0

Full Load Efficiencies—Enclosed Motors

HP	2-POLE		4-POLE		6-POLE		8-POLE	
	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.
1.0	75.5	74.0	82.5	81.5	80.0	78.5	74.0	72.0
1.5	82.5	81.5	84.0	82.5	85.5	84.0	77.0	75.5
2.0	84.0	82.5	84.0	82.5	86.5	85.5	82.5	81.5
3.0	85.5	84.0	87.5	86.5	87.5	86.5	84.0	82.5
5.0	87.5	86.5	87.5	86.5	87.5	86.5	85.5	84.0
7.5	88.5	87.5	89.5	88.5	89.5	88.5	85.5	84.0
10.0	89.5	88.5	89.5	88.5	89.5	88.5	88.5	87.5
15.0	90.2	89.5	91.0	90.2	90.2	89.5	88.5	87.5
20.0	90.2	89.5	91.0	90.2	90.2	89.5	89.5	88.5
25.0	91.0	90.2	92.4	91.7	91.7	91.0	89.5	88.5
30.0	91.0	90.2	92.4	91.7	91.7	91.0	91.0	90.2
40.0	91.7	91.0	93.0	92.4	93.0	92.4	91.0	90.2
50.0	92.4	91.7	93.0	92.4	93.0	92.4	91.7	91.0
60.0	93.0	92.4	93.6	93.0	93.6	93.0	91.7	91.0
75.0	93.0	92.4	94.1	93.6	93.6	93.0	93.0	92.4
100.0	93.6	93.0	94.5	94.1	94.1	93.6	93.0	92.4
125.0	94.5	94.1	94.5	94.1	94.1	93.6	93.6	93.0
150.0	94.5	94.1	95.0	94.5	95.0	94.5	93.6	93.0
200.0	95.0	94.5	95.0	94.5	95.0	94.5	94.1	93.6

Note: **Above tables are based on *ASHRAE Standard 90.1, Addendum 90.1c.***

F. HVAC Systems Design:

1. Heating and Cooling Load Calculation Procedures. *ASHRAE Handbook 1985 Fundamentals* or similar computational procedure:
   a. Building envelope loads based on building envelope criteria of *ASHRAE Standard 90.1.*
   b. Lighting loads based on actual lighting level or power budgets consistent with lighting requirements of *ASHRAE Standard 90.1.*
   c. Other Loads, People and Equipment:
      1) Actual information based on intended use.
      2) Manufacturer's data.
      3) Technical Publications such as ASHRAE.
      4) Other sources.
      5) Designer's experience.
   d. Safety Factor: 10% Maximum
   e. Pick-Up Loads:
      1) Heating: 30% Maximum system capacity allowance for morning warm-up cycles.
      2) Cooling: 10% Maximum system capacity allowance for morning cool-down cycles.

   f. Areas requiring special process temperature requirements, humidity requirements, or both shall be served by separate HVAC systems.
2. Indoor Design Conditions: *ANSI\ASHRAE Standard 55-1981 Thermal Environmental Conditions for Human Occupancy* or Chapter 8, *ASHRAE Handbook 1985 Fundamentals:*
   a. Satisfy 80% or More of the Occupants.
   b. Heating (Winter):
      1) *ASHRAE Standard 55:* 68°F.–74°F. Dry Bulb (DB) at 60% RH; 69°F.–76°F. DB at 36°F Dew Point (DP).
      2) Most Commonly Used Design Condition: 72°F DB.
   c. Cooling (Summer):
      1) *ASHRAE Standard 55:* 73°F.–79°F. DB at 60% RH; 74°F.–81°F. DB at 36°F DP.
      2) Most Commonly Used Design Condition: 75°F/50% R.H.
3. Outdoor Design Conditions: *ASHRAE Handbook 1985 Fundamentals* or from National Climatic Center or similar recognized data source:
   a. Heating (Winter): 99% Values, Minimum.
   b. Cooling (Summer): 2.5% Values, Maximum.
4. Ventilation:
   a. Lowest volume necessary to maintain adequate indoor air quality.
   b. Meet *ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality.*
   c. Air required for exhaust makeup for source control of contaminants.

G. Controls

1. System Control. At least 1 temperature control device.
2. Zone Control. Individual thermostatic controls within each zone.
3. Off-Hours Controls:
   a. Automatic controls capable of setback temperatures or equipment shutdown.
   b. Automatic or reduced outdoor air volume during unoccupied periods.
4. Humidity Control:
   a. Humidistat is required for winter humidification, 30% maximum winter humidity level for comfort purposes.
   b. If a humidistat is used for summer dehumidification, 60% minimum summer humidity level is required for comfort purposes.
5. Economizer controls are required:
   a. Air Side Economizers: Dry-Bulb Temperature or Enthalpy.
   b. Water Side Economizers: Direct Evaporation, Indirect Evaporation, or Both.
   c. Exceptions:
      1) Fans with a capacity of less than 3,000 CFM or total cooling capacity of less than 90,000 Btuh.
      2) Systems serving residential spaces or hotel or motel rooms.
6. Controls shall prevent:
   a. Reheating.
   b. Recooling.
   c. Simultaneous mixing of hot and cold air.
   d. Other simultaneous heating and cooling systems.
   e. Exceptions:
      1) VAV systems that reduce air flow to minimum before reheating, recooling or mixing take place.
      2) Zones where pressure relationships or cross-contamination requirements are impractical—Hospitals, Laboratories.
      3) Heat recovery is used for reheating.
      4) Zones with peak supply air of 300 CFM or less.

7. Temperature Reset Controls:
   a. Air Systems: Systems supplying heated or cooled air to multiple zones shall include controls that automatically reset supply air temperatures by respective building loads or outside air temperature.
      1) Exceptions:
         a) VAV Systems.
         b) Where resetting supply air temperatures can be shown to increase energy usage.
   b. Hydronic Systems: Systems supplying heated and/or chilled water shall include controls that automatically reset supply water temperatures by respective building loads or outside air temperature.
      1) Exceptions:
         a) Variable Flow Pumping Systems.
         b) Where resetting supply water temperatures can be shown to increase energy usage.
         c) Systems with less than 600,000 Btuh design capacity.

H. Piping Insulation. Insulation is required on:

1. Heating Systems (Hot Water, Steam, Steam Condensate): 105°F. and Higher.
2. Cooling Systems (Chilled Water, Brine, and Refrigerant): 55°F. and Lower.
3. Domestic and Service Hot Water Systems: 105°F. and Higher.
4. Insulation not required on systems where Fluid Temperature is between 55°F. and 105°F.
5. Required Insulation Thickness depends on Fluid Temperature, Insulation Type, and Pipe Size.
6. Insulation Thickness is given in the following table:

FLUID DESIGN OPERATING TEMP. RANGE °F.	INSULATION CONDUCTIVITY		NOMINAL PIPE DIAMETER - INCHES (3)					
	RANGE (1)	MRT (2)	RUNOUTS UP TO 2" (3)	1" AND LESS	1-1/4" - 2"	2-1/2" - 4"	5" & 6"	8" & LARGER
HEATING SYSTEMS - STEAM, STEAM CONDENSATE, AND HOT WATER								
ABOVE 350	0.32-0.34	250	1.5	2.5	2.5	3.0	3.5	3.5
251-350	0.29-0.31	200	1.5	2.0	2.5	2.5	3.5	3.5
201-250	0.27-0.30	150	1.0	1.5	1.5	2.0	2.0	3.5
141-200	0.25-0.29	125	0.5	1.5	1.5	1.5	1.5	1.5
105-140	0.24-0.28	100	0.5	1.0	1.0	1.0	1.5	1.5
DOMESTIC AND SERVICE HOT WATER SYSTEMS								
105 & GREATER	0.24-0.28	100	0.5	1.0	1.0	1.5	1.5	1.5
COOLING SYSTEMS - CHILLED WATER, BRINE, AND REFRIGERANT								
40-55	0.23-0.27	75	0.5	0.5	0.75	1.0	1.0	1.0
BELOW 40	0.23-0.27	75	1.0	1.0	1.5	1.5	1.5	1.5

Notes:
1. Conductivity Range (Btu. In./Hr. Ft^2 °F.)
2. MRT = Mean Rating Temperature (°F.)
3. Runouts to individual terminal units not exceeding 12 feet.
4. For piping exposed to ambient temperatures, increase insulation thickness by 0.5″.

I. Air Handling System Insulation. Insulation is required on:

1. Exterior Building Systems: Insulation Thickness is Based on CDD65 or HDD65, whichever results in greater insulation thickness and insulation type.
2. Inside Building Systems: Insulation is required when the temperature difference between air temperature and space temperature is greater than 15°F. Insulation thickness is based on temperature difference and insulation type.
3. Insulation Thickness is given in the following table:

DUCT LOCATION	COOLING (3)		
	ANNUAL COOLING DEGREE DAYS BASE 65 °F.	INSULATION R-VALUE	INSULATION THICKNESS (2)
EXTERIOR OF BUILDING:	BELOW 500 500 TO 1150 1151 TO 2000 ABOVE 2000	3.3 5.0 6.5 8.0	0.75 1.5 1.5 2.0
INSIDE BUILDING OR IN UNCONDITIONED SPACES (1):			
Δ T ≤ 15	---	NONE REQ'D	---
15 < Δ T ≤ 40	---	3.3	0.75
Δ T > 40	---	5.0	1.5

DUCT LOCATION	COOLING (3)		
	ANNUAL COOLING DEGREE DAYS BASE 65 °F.	INSULATION R-VALUE	INSULATION THICKNESS (2)
EXTERIOR OF BUILDING:	BELOW 500 500 TO 1150 1151 TO 2000 ABOVE 2000	3.3 5.0 6.5 8.0	0.75 1.5 1.5 2.0
INSIDE BUILDING OR IN UNCONDITIONED SPACES (1):			
Δ T ≤ 15	---	NONE REQ'D	---
15 < Δ T ≤ 40	---	3.3	0.75
Δ T > 40	---	5.0	1.5

Notes:

1. **Δ T (Temperature difference) is the difference between space design temperature and the design air temperature in the duct.**
2. **Minimum insulation thickness required. Internally insulated (lined) ducts usually use 1″ thickness. Externally insulated ducts usually use 1½″ or 2″ thickness.**
3. **Table based on *ASHRAE Standard 90.1-1989.***

J. Duct Construction:

1. *SMACNA HVAC Duct Construction Standards—Metal and Flexible, 1985.*
2. *SMACNA Fibrous Glass Duct Construction Standard, 1979.*
3. *SMACNA HVAC Duct Leakage Test Manual, 1985.*
4. If duct system is to operate in excess of 3 in. wc., ductwork shall be leak tested and be in conformance with *SMACNA HVAC Duct Leakage Test Manual, 1985.*

K. Operation and Maintenance Information:

1. O&M Manual shall be provided to Building Owner.
2. Manual to include:
   a. Required Routine Maintenance
   b. HVAC Control Information: Including schematics, diagrams, control descriptions, and maintenance and calibration information.

L. Testing, Adjusting, and Balancing shall be conducted in accordance with AABC or NEBB Standards or equivalent procedures (ASHRAE, SMACNA):

1. Air System Balancing: Accomplished first to minimize Throttling Losses and then Fan Speed.
   a. Damper throttling may be used for air systems under the following conditions:
      1) Fan motors of 1 Hp or less.
      2) If throttling results in no Greater than ⅓ Hp Fan Horsepower draw above that required if fan speed were adjusted.
2. Hydronic System Balancing: Accomplished first to minimize Throttling Losses and then Pump Impeller shall be trimmed or Pump Speed shall be adjusted.
   a. Valve throttling may be used for hydronic systems under the following conditions:
      1) Pumps with motors of 10 Hp or less.
      2) If throttling results in no greater than 3 Hp Pump horsepower draw above that required if the impeller were trimmed.
3. HVAC Control Systems shall be tested to assure that control elements are calibrated, adjusted, and in proper working order.

M. System Sizing: Systems and equipment shall be sized to provide no more than the space and system loads calculated in accordance with *ASHRAE Standard 90.1:*

1. Exceptions:
   a. Standard equipment sizing limitations.
   b. If oversizing does not increase energy usage.
   c. Stand-by equipment with automatic change-over control only when primary equipment is not operating.
   d. Multiple units of the same equipment (Chillers, Boilers, etc.) may be specified to operate concurrently only if optimization controls are provided.

N. Fan System Design Criteria: Supply Air, Return Air and Exhaust Fans:

1. Constant Volume Systems: 0.8 W/CFM of Supply Air.
2. Variable Air Volume (VAV) Systems: 1.25 W/CFM of Supply Air.
3. VAV Systems with Fan Motors 75 Hp and Larger requires controls or devices to demand no more than 50% of design wattage at 50% flow.
4. *ASHRAE Standard 90.1* requires air handling systems to utilize either:
   a. VAV Systems.
   b. Supply Air Temperature Reset Systems.

O. Pumping System Design Criteria:

1. Maximum Piping System Design Friction Rate: 4.0 Ft./100 Ft. of Pipe.
2. Variable Flow: Systems with control valves which modulate or step open and closed to meet load shall be designed for variable flow. System shall be capable of reducing flow to 50% or less using variable-speed-driven pumps, staged pumping, or pumps riding pump performance curves.

3. Exceptions:
   a. Systems where a Minimum Flow greater than 50% of Design Flow is required (Chiller Systems).
   b. Systems which include Supply Water Temperature Reset.
4. *ASHRAE Standard 90.1* requires pumping systems to utilize either:
   a. Variable Flow Pumping Systems.
   b. Supply Water Temperature Reset Systems.

P. HVAC Equipment:

1. Minimum Equipment Efficiencies:
   a. Full Load Efficiencies.
   b. Part Load Efficiencies.
   c. Includes Service Water Heating Equipment.
   d. Includes Field Assembled Equipment: Individual Components to Meet Requirements (Coils, Fans); Sum all Component Energy Usage.
2. Equipment Rating shall be certified by nationally recognized standards.
3. Operation and Maintenance: O&M Information shall be provided with Equipment including Mechanical Prints, Equipment Manuals, Preventive Maintenance Procedures and Schedules, and Names and Addresses of Qualified Service Agencies.

Q. Energy Management:

1. Each Distinct Building Energy Service shall have a Measurement System to accumulate a Record or Indicator Reading of the overall amounts of energy being delivered.
2. All Equipment used for Heating or Cooling and HVAC delivery of greater than 20 KVA or 60,000 Btuh energy input shall be arranged so that inputs and outputs such as Flow, Temperature, and Pressure can be individually measured to determine the equipment energy consumption, the installed performance capabilities and efficiencies, or both. Installation of measurement equipment is not required but proper access is required to permit measurements in the future.
3. Central Monitoring and Control Systems:
   a. Energy Management Systems should be considered in any building exceeding 40,000 Sq. Ft. in Gross Floor Area.
   b. Minimum Energy Management System Capabilities:
      1) Readings and Daily Totals for Electrical Power and Demand.
      2) Readings and Daily Totals for External Energy and Fossil Fuel Use.
      3) Record, Summarize, and Retain Weekly Totals.
      4) Time Schedule HVAC Equipment and Service Water Heating Equipment.
      5) Reset Local Loop Control System for HVAC Equipment.
      6) Monitor and Verify Heating, Cooling, and Energy Delivery Systems.
      7) Time Schedule Lighting Systems.
      8) Provide Readily Accessible Override Controls.
      9) Provide Optimum Start/Stop Control for HVAC Systems.

16.05 Fuel Conversion Factors

A. Electric Baseboard to Hydronic Baseboard:

1. KWH × 1.19 = KWH for Electric Boiler
2. KWH × 0.033 = Gals. for Oil-Fired Boiler
3. KWH × 0.046 = Therms for Gas-Fired Boiler

B. Electric Furnace to Hydronic Baseboard:

1. KWH × 1.0 = KWH for Electric Boiler
2. KWH × 0.028 = Gals. for Oil-Fired Boiler
3. KWH × 0.038 = Therms for Gas-Fired Boiler

C. Ceiling Cable to Hydronic Baseboard:

1. KWH × 1.06 = KWH for Electric Boiler
2. KWH × 0.03 = Gals. for Oil-Fired Boiler
3. KWH × 0.041 = Therms for Gas-Fired Boiler

D. Heat Pump to Hydronic Baseboard:

1. KWH × 1.88 = KWH for Electric Boiler
2. KWH × 0.052 = Gals. for Oil-Fired Boiler
3. KWH × 0.073 = Therms for Gas-Fired Boiler

E. Electric Baseboard to Warm Air Furnace:

1. KWH × 1.19 = KWH for Electric Furnace
2. KWH × 0.039 = Gals. for Oil-Fired Furnace
3. KWH × 0.054 = Therms for Gas-Fired Furnace

F. Electric Furnace to Fuel-Fired Furnace:

1. KWH × 0.032 = Gals. for Oil-Fired Furnace
2. KWH × 0.045 = Therms for Gas-Fired Furnace

G. Ceiling Cable to Warm Air Furnace:

1. KWH × 1.06 = KWH for Electric Furnace
2. KWH × 0.034 = Gals. for Oil-Fired Furnace
3. KWH × 0.048 = Therms for Gas-Fired Furnace

H. Heat Pump to Warm Air Furnace:

1. KWH × 1.88 = KWH for Electric Furnace
2. KWH × 0.061 = Gals. for Oil-Fired Furnace
3. KWH × 0.085 = Therms for Gas-Fired Furnace

I. Warm Air Systems to Hydronic Baseboard System:

1. Gals. Oil for W.A. × 0.857 = Gals. for Hydronics
2. Therms Gas for W.A. × 0.857 = Therms for Hydronics
3. Gals. Oil for W.A. × 1.2 = Therms for Hydronics
4. Therms Gas for W.A. × 0.612 = Gals. for Hydronics

PART 17

HVAC System Selection Criteria

17.01 HVAC System Selection Criteria

A. Building Type:

1. Institutional. Hospital, Prisons, Nursing Homes, Education
2. Commercial. Offices, Stores
3. Residential. Hotel, Motel, Apartments
4. Industrial, Manufacturing
5. Research and Development. Laboratories

B. Owner Type:

1. Government
2. Developer
3. Business
4. Private

C. Performance Requirements:

1. Supporting a Process. Computer Facility, Telephone Facility
2. Promoting an Germ Free Environment
3. Increasing Sales and Rental Income
4. System Efficiency
5. Increasing Property Salability
6. Standby and Reserve Capacity
7. Reliability, Life Expectancy. Frequency of Maintenance and Failure
8. How will Equipment Failures affect the Building? Owner Operations?

D. Capacity Requirements:

1. Cooling Loads. Magnitude and Characteristics
2. Heating Loads. Magnitude and Characteristics
3. Ventilation
4. Zoning Requirements:
   a. Occupancy
   b. Solar Exposure
   c. Special Requirements
   d. Space Temperature and Humidity Tolerances

E. Spatial Requirements:

1. Architectural Constraints:
   a. Aesthetics
   b. Structural Support
   c. Architectural Style and Function
2. Space Available to House Equipment and Location
3. Space Available for Distribution of Ducts and Pipes
4. Acceptability of Components Obtruding into Occupied Space, Physically and Visually
5. Furniture Placement
6. Flexibility
7. Maintenance Accessibility
8. Roof
9. Available Space Constraints
10. Are Mechanical Rooms/Shafts Required?

F. Comfort Considerations:

1. Control Options
2. Noise and Vibration Control
3. Heating, Ventilating, and Air Conditioning
4. Filtration
5. Air Quality Control

G. First Cost:

1. System Cost. Return on Investment
2. Cost to Add Zones
3. Ability to Increase Capacity
4. Contribution to Life Safety Needs
5. Air Quality Control
6. Future Cost to Replace and/or Repair

H. Operating Costs:

1. Energy Costs
2. Energy Type:
   a. Electricity. Voltage Available, Rate Schedule
   b. Gas
   c. Oil
   d. District Steam
   e. Other Sources
3. Energy Types Available at Project Site
4. Equipment Selection

I. Maintenance Cost:

1. Cost to Repair
2. Capabilities of Owners Maintenance Personnel
3. Cost of System Failure on Productivity
4. Economizer Cycle
5. Heat Recovery
6. Future Cost to Replace
7. Ease and Quickness of Servicing
8. Ease and Quickness of Adding Zones
9. Extent and Frequency of Maintenance

J. Codes

1. Codes govern HVAC and other building systems design.
2. Most building codes are adopted and enforced at the local level.
3. It is estimated that there are 13,000 building codes in the U.S.
4. Codes are not enforceable unless adopted by municipality, borough, county, state, etc.
5. Codes Regulate:
   a. Design and Construction
   b. Allowable Construction Types
   c. Building Height
   d. Egress Requirements
   e. Structural Components
   f. Light and Ventilation Requirements
   g. Material Specifications

6. Code Approaches:
   a. Prescriptive. Dictate specific materials and methods (ASTM A53, Steel Pipe, Welded)
   b. Performance. Dictate desired results (HVAC system to provide and maintain design temperature of 72°F winter and 75°F/50% RH summer.)
7. Codes Developed Because of:
   a. Loss of Life
   b. Loss of Property
   c. Pioneered by Insurance Industry
8. Model Codes:
   a. Basic/National Building Code (BOCA), Northeastern U.S.
   b. Southern Building Code (SBCCI), Southern U.S.
   c. Uniform Building Code (ICBO), Western U.S.
   d. Model codes are similar in their requirements, but quite different in format and technical language.

17.02 Heating System Selection Guidelines

A. If heat loss exceeds 450 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall to prevent downdrafts.

B. If heat loss is between 250 and 450 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to the perimeter wall, discharging air directly downward, blanketing the exposed wall and window areas.

C. If heat loss is less than 250 Btu/Hr. per lineal feet of wall, heat should be provided from under the window or from the base of the wall, or it may be provided from overhead diffusers, located adjacent to or slightly away from the perimeter wall, discharging air directed at or both directed at and directed away from the exposed wall and window areas.

Air Distribution Systems

18.01 Ductwork Systems

A. Ductwork System Sizing:

1. Low Pressure: 0.10 (0.15) In.W.G./100 Ft.; 1,500–1,800 Fpm Maximum
2. Medium Pressure: 0.20 (0.25) In.W.G./100 Ft.; 2,000–2,500 Fpm Maximum
3. High Pressure: 0.40 (0.45) In.W.G./100 Ft.; 2,500–3,500 Fpm Maximum
4. Transfer Ducts: 0.03–0.05 In.WG./100 Ft. 1,000 Fpm Maximum
5. Transfer Grilles: 0.03–0.05 In.WG. pressure drop
6. Outside Air Shafts: 0.05–0.10 In. W.G./100 Ft. 1,000 Fpm Maximum
7. Gravity Relief Air Shafts: 0.03–0.05 In. W.G./100 Ft. 1,000 Fpm Maximum
8. Decrease or increase duct size whenever duct changes by 4″ or more in one or two dimensions. Do *NOT* use fractions of an inch for duct sizes.
9. Try to change only one duct dimension at a time because it is easier to fabricate fittings and therefore generally less expensive, i.e., 36 × 12 to 30 × 12 in lieu of 36 × 12 to 32 × 10.
10. Duct taps should be 2″ smaller than main duct to properly construct and seal duct. Duct size should be 2″ wider than diffusers, registers, and grilles.
11. All 90 degree square elbows should be provided with double radius turning vanes. Elbows in dishwasher, kitchen, and laundry exhaust should be unvaned smooth radius construction with radius equal to 1½ times width of duct.
12. Provide flexible connections at point of connection to equipment in all ductwork systems (supply, return, and exhaust) connected to air handling units, fans, and other equipment.
13. Provide access doors to access all fire dampers, smoke dampers, smoke detectors, volume dampers, motor operated dampers, humidifiers, coils (steam, hot water, chilled water, electric), and other items located in ductwork which require service and/or inspection.
14. All rectangular duct taps should be made with shoe (45 degree) fittings. Do *NOT* use splitter dampers or extractors.
15. Maximum ductwork hanger spacing:
    a. SMACNA Minimum Requirements:
        1) Horizontal: 8 feet maximum
        2) Vertical: 16 feet and at each floor
    b. Recommended:
        1) Horizontal Ducts less than 4 square feet: 8 feet maximum
        2) Horizontal Ducts 4 to 10 square feet: 6 feet maximum
        3) Horizontal Ducts greater than 10 square feet: 4 feet maximum
        4) Vertical Round Ducts: 12 feet maximum
        5) Vertical Rectangular Ducts: 10 feet maximum

B. Friction Loss Estimate:

1. 1.5 × System Length (Ft./100) × Friction Rate (In.W.G./100 Ft.).

C. Ductwork Sizes:

1. 4″ × 4″ smallest rectangular size.
2. 8″ × 4″ smallest recommended size.

3. Rectangular ducts: Use even duct sizes, i.e., 24 × 12, 10 × 6, 72 × 36, 48 × 12.
4. 4 : 1 Maximum recommended aspect ratio.
5. 3″ smallest round size, odd and even sizes available.
6. Round ducts available in 0.5 inch increments for duct sizes through 5.5 inch diameter, 1 inch increments for duct sizes 6 inches through 20 inches, and 2 inch increments for duct sizes 22 inches and greater.

18.02 Duct Construction

A. Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) Duct Construction Manuals:

1. *SMACNA—HVAC Duct Construction Standards Metal and Flexible,* First Edition, referred to herein as *SMACNA-HVAC.*
2. *SMACNA—Fibrous Glass Duct Construction Standards,* Fifth Edition, referred to herein as *SMACNA-FG.*
3. *SMACNA—Rectangular Industrial Duct Construction Standard,* First Edition, referred to herein as *SMACNA-IDC.*
4. *SMACNA—Round Industrial Duct Construction Standard,* First Edition, referred to herein as *SMACNA-RIDC.*
5. *SMACNA—Thermoplastic Duct (PVC) Construction Manual,* First Edition, referred to herein as *SMACNA-PVC.*

B. *SMACNA-HVAC* Pressure Ratings:

1. ±½″; ±1″; ±2″; ±3″; +4″; +6″; +10″

C. *SMACNA-IDC* and *SMACNA-RIDC* Pressure Ratings:

1. +12″ to +100″ by multiples of 2″
2. −4″ to −100″ by multiples of −2″

D. Ductwork Testing:

1. −3″ W.G. and Lower: 1.5 × Pressure Rating
2. −2″ to +2″ W.G.: Generally not tested
3. +3″ W.G. and Higher: 1.5 × Pressure Rating

E. *SMACNA-HVAC* Ductwork Leakage Classes:

1. Seal Class A: 2–5% Total System Leakage (All Transverse joints, longitudinal seams, and duct penetrations).
2. Seal Class B: 3–10% Total System Leakage (All Transverse joints and longitudinal seams).
3. Seal Class C: 5–20% Total System Leakage (All Transverse joints).
4. Unsealed: 10–40% Total System Leakage.
5. All ducts should be sealed for SMACNA Seal Class B minimum—Engineer must specify.

F. Ductwork Materials:

1. Galvanized Steel: HVAC Applications; Most Common; Galvanized steel sheets meeting *ASTM A90, A525,* and *A527, Lock Forming Quality.*
2. Carbon Steel: Breechings, Flues and Stacks; Carbon steel meeting *ASTM A569* for stacks and breechings 24″ and larger; Galvanized sheet steel meeting *ASTM A527* with *ANSI/ASTM A525 G90* zinc coating for stacks and breechings less than 24″.

3. Aluminum: Moisture Laden Air Streams; Aluminum base alloy sheets meeting *ASTM B209, Lock Forming Quality.*
4. Stainless Steel: Kitchen Hood and Fume Hood Exhaust; Stacks and Breechings (Prefabricated); Type 304, 304L, 316, or 316L stainless steel sheets meeting *ASTM A167:*
   a. 304 and 316: Non-welded applications.
   b. 304L and 316L: Welded applications.
   c. Kitchen Exhaust Finish:
      1) Concealed: None.
      2) Exposed: No. 2B, No 4, or Match Equipment (No. 4 preferred).
   d. Lab Fume Exhaust Finish:
      1) Concealed: No 2B.
      2) Exposed: No 2B.
5. Fiberglass: HVAC Applications; 1″ thick glass duct board meeting *U.L. 181.*
6. Fiberglass Reinforced: Chemical Exhaust; Plastic (FRP)
7. Polyvinyl Chloride (PVC): Chemical Exhaust, Underground Ducts; PVC conforming to *NFPA 91, ASTM D1784, D1785, D1927,* and *D2241.*
8. Concrete: Underground Ducts, Air Shafts; Reinforced concrete pipe meeting *ASTM C76, Class IV.*
9. Sheet Rock: Air Shafts (Generally Provided by Architects).
10. Copper: Ornamental.
11. Polyvinyl Steel and Stainless Steel (PVS and PVSS): Chemical Exhaust, Common Type: Halar Coated Stainless Steel.
12. Sheet Metal Gauges (Applies to item numbers 1, 3, 4, and 10 above):
    a. 16, 18, 20, 22, 24, 26 SMACNA or Welded Construction.
    b. 10, 11, 12, 13, 14 Welded Construction Only.
13. For ductwork system weights, see Appendix A.

G. Flexible Duct:

1. 5–8 Ft. Maximum recommended length.
2. Insulated, Uninsulated.

18.03 Kitchen Exhaust Ducts and Hoods

A. *1990 BOCA Code:*

1. Exhaust/Makeup Air:
   a. 1500–2200 Ft./Min Duct Velocity.
   b. Supply shall be approximately equal to exhaust.
   c. Δ T shall not be greater than 10°F. unless part of AC system or will not cause a decrease in comfort conditions.
   d. Terminate 40″ above the roof.
2. Duct Sheet Metal Gauge:
   a. 16 ga. Galvanized Steel.
   b. 18 ga. 304 Stainless Steel.
3. Cleanouts:
   a. Base of Riser.
   b. Every 20 feet.
4. Hoods:
   a. Hood Construction 18 ga. Minimum.

b. Hood Exhaust:
   1) Canopy Hoods (attached to wall): 100 CFM/Sq.Ft.
   2) Canopy Hoods (Exposed all sides): 150 CFM/Sq.Ft.
   3) Non-Canopy: 300 CFM/Lineal Ft. of cooking surface.
   4) As listed above or per *U.L. 710.*

B. *1993 BOCA Code:*

1. Exhaust/Makeup Air:
   a. 1500–2200 Ft./Min Duct Velocity.
   b. Supply shall be approximately equal to exhaust.
   c. Δ T shall not be greater than 10°F. unless part of AC system or will not cause a decrease in comfort conditions.
   d. Terminate 40″ above the roof.
2. Duct Sheet Metal Gauge:
   a. 16 ga. Galvanized Steel.
   b. 18 ga. 304 Stainless Steel.
3. Cleanouts:
   a. Base of Riser.
   b. Every 20 feet.
4. Hoods:
   a. Hood Construction:
      1) Galvanized Steel: 18 ga. Minimum.
      2) Stainless Steel: 20 ga. Minimum.
   b. Hood Exhaust:
      1) Canopy Hoods (attached to wall): 100 CFM/Sq.Ft.
      2) Canopy Hoods (exposed all sides): 150 CFM/Sq.Ft.
      3) Non-Canopy: 300 CFM/Lineal Ft. of cooking surface.
      4) As listed above or per *U.L. 710.*

C. *1988 SBCCI Code*

1. Exhaust Air:
   a. 1500 Ft./Min. Minimum Duct Velocity.
   b. Terminate 40″ above the roof.
2. Duct Sheet Metal Gauge:
   a. 16 ga. Galvanized Steel.
   b. 18 ga. 304 Stainless Steel.
3. Duct Slope: 1″ per foot toward hood.
4. Hoods:
   a. Hood Construction:
      1) 18 ga. Galvanized Steel.
      2) 20 ga. 304 Stainless Steel.
   b. Hood Exhaust:
      1) Canopy Hoods (attached to wall): 100 CFM/Sq.Ft.
      2) Canopy Hoods (exposed all sides): 150 CFM/Sq.Ft.
      3) Non-Canopy: 300 CFM/Lineal Ft. of cooking surface.

D. *1988 UBC Code:*

1. Exhaust/Makeup Air:
   a. 1500–2500 Ft./Min Duct Velocity.
   b. Supply shall be equal to exhaust.

2. Duct Sheet Metal Gauge:
   a. 16 ga. Galvanized Steel.
   b. 18 ga. 304 Stainless Steel.
3. Duct Slope:
   a. Lengths 75 and less: ¼″ per foot toward hood.
   b. Lengths greater than 75 feet: 1″ per foot toward hood.
4. Hoods:
   a. Hood Construction:
      1) 22 ga. Galvanized Steel.
      2) 22 ga. 304 Stainless Steel.
   b. Hood Exhaust:
      1) Canopy Hoods (attached to wall).
         200 CFM/Sq.Ft. over charbroilers.
         100 CFM/Sq.Ft. over high temperature appliances.
         75 CFM/Sq.Ft. over medium temperature appliances.
         50 CFM/Sq.Ft. over low temperature appliances.
      2) Canopy Hoods (exposed all sides).
         300 CFM/Sq.Ft. over charbroilers.
         150 CFM/Sq.Ft. over high temperature appliances.
         100 CFM/Sq.Ft. over medium temperature appliances.
         75 CFM/Sq.Ft. over low temperature appliances.
      3) Non-Canopy: 300 CFM/Lineal Ft. of cooking surface.

E. *1991 NFPA 96:*

1. Exhaust/Makeup Air:
   a. 1500 Ft./Min. Minimum Duct Velocity.
2. Duct Sheet Metal Gauge:
   a. 16 ga. Galvanized Steel.
   b. 18 ga. 304 Stainless Steel.
   c. Ducts shall not pass through fire walls or partitions.
   d. Ducts shall lead directly as possible to the outside.
   e. Ducts shall not be connected with other ventilating or exhaust systems.
   f. Ducts shall terminate a minimum of 40″ above roof surface, 10 feet from outside air intakes and property lines, and 3 feet above any air intake within 10 feet.
3. Duct Slope: toward hood.
4. Hood Construction:
   a. 18 ga. Galvanized Steel.
   b. 20 ga. 304 Stainless Steel.

18.04 Louvers

A. Louvers: Use stationary louvers only. Do not use operable louvers because they become rusty or become covered with snow and ice and may not operate:

1. Intake (Outdoor Air): 500 Ft./Min. Maximum Velocity through Free Area.
2. Exhaust or Relief: 700 Ft./Min. Maximum Velocity through Free Area.
3. Free Area Range:
   a. Metal: 40–70% of Gross Area.
   b. Wood: 20–25% of Gross Area.
4. Pressure Loss: 0.01–0.10″ W.G.

18.05 Volume Dampers

A. Volume Dampers: Frames of duct mounted dampers shall be totally recessed out of the air stream:

1. Opposed Blade: Balancing, Mixing, and Modulating Control Applications.
2. Parallel Blade: 2 Position Applications (Open/Closed).
3. Pressure Loss (MOD): 0.15″ W.G. @ 2000 Fpm (Full Open).
4. Standard Dampers: 10–15 CFM/Sq.Ft. @ 1″ W.G. Differential.
5. Low Leakage Dampers: 10 CFM/Sq.Ft. @ 4″ W.G. Differential Max.
6. Ultra Low Leakage Dampers: 6 CFM/Sq.Ft. @ 4″ W.G. Differential Max.
7. Size dampers at a flow rate of approximately 1200 to 1500 CFM/Sq.Ft. rather than on duct size.

18.06 Fire Dampers

A. Fire Dampers: Interlocking blade or expanding curtain type. Frame and damper storage should be totally recessed out of air stream.

1. Fire Damper Types:
   a. Type A: Frame and damper storage are located in the airstream.
   b. Type B: Damper storage is totally recessed out of the airstream.
   c. Type C: Frame and damper storage are totally recessed out of the airstream.

B. Fire Damper Requirements:

1. *1990 BOCA Code:*
   a. 1 Hr. Construction: Fire dampers are not required if building is fully equipped with automatic sprinklers. 1 Hr. dampers required otherwise.
   b. 2, 3, and 4 Hr. Construction: 2 and 3 Hr. dampers are required.
2. *1993 BOCA Code:*
   a. 1 Hr. Construction: 1 Hr. dampers are required.
   b. 2, 3, and 4 Hr. Construction: 2 and 3 Hr. dampers are required.
   c. Exception. Fire dampers are not required:
      1) In steel exhaust air subducts extending at least 22″ vertically in an exhaust shaft and where there is continuous airflow upward to the outside.
      2) In penetrations of walls with a required 1 hour fire-resistance rating or less by a ducted HVAC system in areas of other than Use Group H where the building is equipped throughout with an automatic sprinkler system.
      3) In garage exhaust or supply shafts which are separated from all other building shafts by not less than a 2 hour fire-resistance rated fire separation assembly.
3. *1988 SBCCI Code:*
   a. 1 Hr. Construction: 1 Hr. dampers are required.
   b. 2, 3, and 4 Hr. Construction: 2 and 3 Hr. dampers are required.
4. *1988 UBC Code:*
   a. 1 Hr. Construction: 1 Hr. dampers are required.
   b. 2, 3, and 4 Hr. Construction: 2 and 3 Hr. dampers are required.
5. *1991 NFPA 90A:*
   a. 1 Hr. Construction: Dampers are not required.
   b. 2, 3, and 4 Hr. Construction: 2 and 3 Hr. dampers are required.
6. *U.L. 555:*

a. *U.L. 555* requires fire dampers to bear an affixed label stating whether the damper is static or dynamic rated.
b. Dynamic rated fire dampers must be U.L. tested and show airflow and maximum static pressure against which the damper will operate (fully close). Fire dampers are tested to 4″ static pressure for "no duct" applications and 8″ static pressure or "in duct" applications.
c. Static rated fire dampers have not been U.L. tested against airflow and may not close under medium to high airflow conditions that may be encountered in HVAC systems which do not shut down in event of fire (i.e., smoke control systems).
d. Recommend using dynamically rated fire dampers in all applications.

18.07 Smoke Dampers

A. Smoke Damper Requirements:

1. *1991 NFPA 90A:*
   a. Smoke dampers shall be installed in systems over 15,000 CFM in the supply and return. Exceptions:
      1) When AHU is located on the floor it serves and only serves that floor.
      2) When the AHU is located on the roof and only serves the floor immediately below it.
   b. Smoke dampers shall be installed at or adjacent (2 feet maximum distance from barrier) to the point where air ducts pass through required smoke barriers. See *NFPA 90A* for exceptions.

18.08 Combination Fire/Smoke Dampers

A. Operable Fire Dampers, Smoke Dampers and Combination Fire/Smoke Dampers:

1. Blowout panels should be considered for ductwork systems whenever human operation of fire, smoke, and/or combination fire/smoke dampers is required by code, by local authorities, or for smoke evacuation systems, in the event that the fire department personnel or Owner's operating personnel inadvertently close all the dampers, and system pressures exceed construction pressures of the ductwork.

18.09 Smoke Detectors

A. Smoke Detector Requirements:

1. *1990 BOCA:*
   a. Air distribution systems with capacity greater than 2,000 CFM shall be equipped with smoke detector in return upstream of any filters, decontamination equipment, or outside air intake.
   b. Air distribution systems connecting two or more floors shall have smoke detectors for each return duct on each floor.
   c. Systems that exhaust greater 50% of the supply air shall have smoke detectors in both the return and exhaust.
   d. Activation shall shut down fan, except smoke control equipment shall switch to smoke control mode.

2. *1993 BOCA:*
   a. Supply air distribution systems with capacity greater than 2,000 CFM shall be equipped with smoke detectors downstream of any filters and ahead of any branch connections.
   b. Return air distribution systems with capacity greater than 15,000 CFM shall be equipped with smoke detectors in return air duct or plenum upstream of any filters, exhaust air connections, outdoor air connections, or decontamination equipment.
   c. Systems that exhaust greater than 50% of the supply air shall have smoke detectors in both the return and exhaust.
   d. Smoke detectors shall be installed at each story, upstream of the connection between a return riser serving two or more stories, and air ducts or plenums in return air systems with a design capacity greater than 15,000 CFM.
   e. Activation shall shut down fan, except smoke control equipment shall switch to smoke control mode.
3. *1988 SBCCI:*
   a. Recirculating systems with fan capacity of 2,000 CFM and greater shall be equipped with smoke detector in return upstream of any filters, decontamination equipment, or outside air intake.
   b. Recirculating systems with fan capacity less than 2,000 CFM, but serving an area used for egress, shall be equipped with smoke detector in return upstream of any filters, decontamination equipment or outside air intake.
   c. Activation shall shut down fan. System shall not restart until manually reset.
4. *1988 UBC:*
   a. Air distribution systems with capacity greater than 2,000 CFM shall be equipped with smoke detector in return upstream of any filters, decontamination equipment, or outside air intake.
   b. Activation shall shut down fan.
5. *1991 NFPA 90A:*
   a. Air distribution systems with capacity greater than 2,000 CFM shall be equipped with smoke detector downstream of any filters and ahead of any branch connections in supply air system.
   b. At each story prior to the connection to a common return and prior to any recirculation or fresh air inlet connection in return systems over 15,000 CFM capacity and serving more than 1 story.
   c. Activation shall shut down fan, except smoke control equipment shall switch to smoke control mode.

18.10 Sound Attenuators

A. Types:

1. Rectangular: 3, 5, 7, and 10 foot lengths
2. Round: 2 or 3 times the diameter

B. Locating:

1. Centrifugal and Axial Fans
   Discharge: 1 duct diameter from discharge for every 1,000 FPM
   Intake: 0.75 duct diameters from intake for ever 1,000 FPM
2. Elbows: 3 duct diameters up and down stream
3. Terminal Boxes: 1 duct diameter down stream

4. Mechanical Equipment Rooms: Install in or close to mechanical equipment room wall opening

18.11 Terminal Units

A. Variable Air Volume (VAV) Terminal Units:

1. VAV w/o Reheat:
   a. Controls space temperature by varying the quantity of supply air.
   b. Supply temperature is constant.
   c. Energy savings is due to reduced supply air quantities and therefore reduced horsepower.
2. VAV w/Reheat:
   a. Integrates heating at the VAV terminal unit to offset heating load, limit maximum humidity, provide reasonable air movement, and provide ventilation air.
3. Minimum CFM for VAV Boxes:
   a. 20% of design flow: Perimeter Spaces.
   b. 0% of design flow: Interior Spaces.
   c. When interior spaces are occupied or lights are on, the VAV terminal unit will maintain a minimum flow to offset the heat gain. Therefore, the only time a VAV terminal unit serving an interior space will be closed is when the space is unoccupied and lights are off.

B. Fan Powered Terminal Units:

1. Parallel Fan Powered Terminal Units:
   a. Primary air is modulated in response to cooling demand and fan is energized at a predetermined reduced primary airflow.
   b. Fan is located outside the primary airstream to allow intermittent fan operation.
2. Series Fan Powered Terminal Units:
   a. A constant volume fan mixes primary air with air from the ceiling plenum.
   b. Fan is located within the primary airstream and runs continuously.

C. Induction Terminal Units:

1. Reduces cooling capacity by reducing primary air and inducing room or ceiling plenum air.
2. Incorporates reduced supply air quantity energy savings of VAV system and air volume to space is constant to reduce effect of stagnant air.

D. Constant Volume Reheat (CVR) Terminal Units:

1. CVR terminal units provide zone/space control for areas of unequal loading, simultaneous cooling/heating, and close tolerance of temperature control.
2. Conditioned air is delivered to each terminal unit at a fixed temperature then reheated to control space temperature.
3. Energy inefficient system.

E. Constant Volume Bypass Terminal Units:

1. Variation of CVR system. Constant volume primary air system with VAV secondary system.
2. Supply air to space varied by dumping air to return air plenum.

F. Dual Duct Terminal Units:

1. Constant volume of supply air is delivered to the space.
2. Space temperature is maintained by mixing varying amounts of hot and cold air.
3. Energy inefficient system.

G. VAV Dual Duct Terminal Units:

1. Variable volume of supply air is delivered to space.
2. Space temperature is maintained by supplying either hot or cold air in varying amounts and limiting the amount of hot and cold air mixing.
3. More energy efficient the standard dual duct systems.

H. Single Zone Systems:

1. Supply unit serves single temperature zone and varies supply air temperature to control space temperature.

I. Multizone Systems:

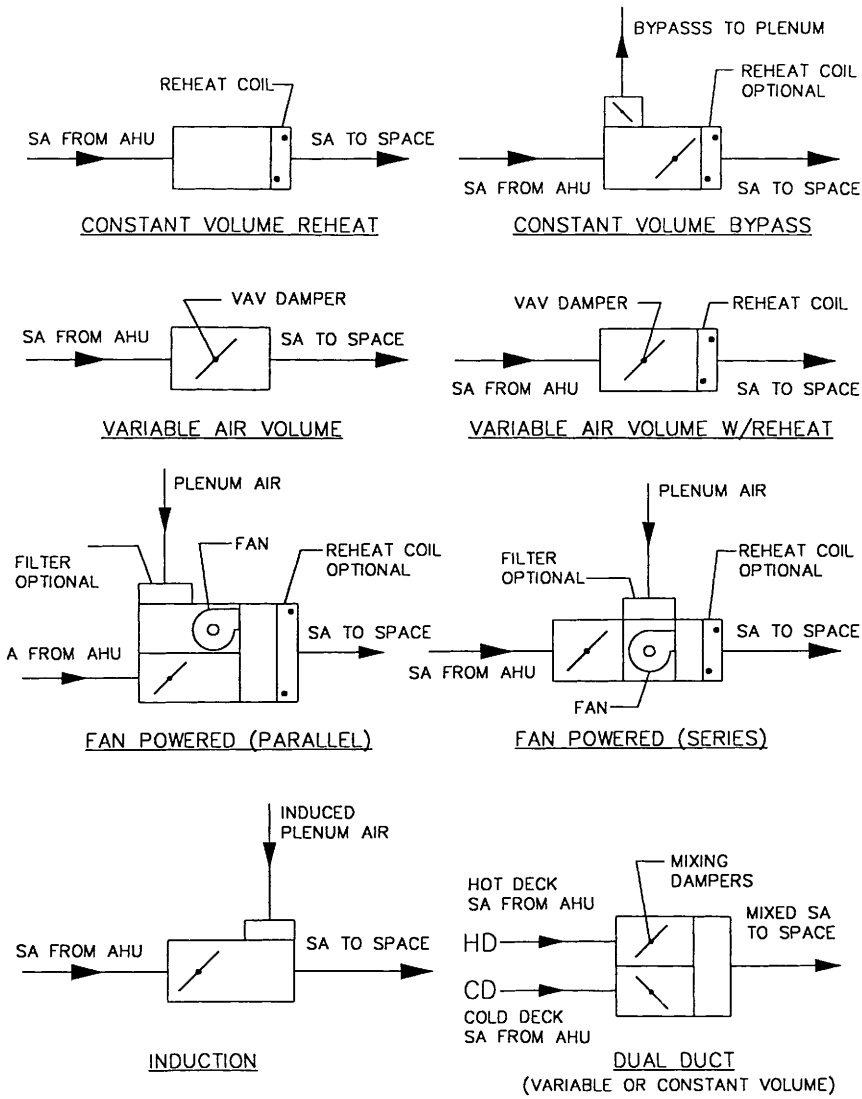
1. Supply unit serves two or more temperature zones and varies supply air temperature to each zone by mixing hot and cold air with zone dampers at the unit to control space temperature.
2. Each zone is served by separate ductwork system.
3. Similar to dual duct system but mixing occurs at unit.
4. Limited number of zones, inflexible system, energy inefficient, and not a recommended system.

J. Terminal Unit Types:

1. Pressure Independent Terminal Units: Terminal unit airflow is independent of pressure upstream of box. Recommend using pressure independant terminal units.
2. Pressure Dependant Terminal Units: Terminal unit airflow is dependant on pressure upstream of box.

K. Terminal Unit Installation:

1. Locate all terminal units for unobstructed access to unit access panels, controls, and valving.
2. Minimum straight duct length upstream of terminal units:
   a. Manufacturer's generally recommend 1.5 duct diameters based on terminal unit inlet size.
   b. 2.0 duct diameters recommended minimum.
   c. 3.0 to 5.0 duct diameters preferred.
   d. Best to use 3 feet of straight duct upstream of terminal units because you do not have to concern yourself with box size when producing ductwork layout (the maximum terminal unit inlet size is 16 inches with 2 duct diameters, which results in 32 inches, and most of the time you are not using 16 inches terminal units).
3. Duct runout to terminal unit should never be smaller than terminal units inlet size; it may be larger than inlet size. Terminal unit inlet and discharge ductwork should be sized based on ductwork sizing criteria and not the terminal unit inlet and discharge connection sizes. The transition from the inlet and discharge connection sizes to the air terminal unit should be made at the terminal unit. A minimum of 3 feet of straight duct should be provided upstream of all terminal units.



TERMINAL UNIT TYPES

L. Zoning:

1. Partitioned Offices:
   a. 1, 2, 3, or 4 offices/terminal unit.
   b. 2 or 3 offices/terminal unit most common.
   c. 1 office/terminal unit; most desirable, also most expensive.
2. Open Offices:
   a. 400–1,200 Sq.Ft./terminal Unit.
3. Perimeter and interior spaces should be zoned separately.

4. Group spaces/zones/rooms/areas of similar thermal occupancy:
   a. Offices with offices.
   b. Don't put offices with conference rooms or other dissimilar rooms.
   c. Don't put east offices with south offices, etc.
   d. Corner offices or spaces should be treated separately.

18.12 Process Exhaust Systems

A. Ductwork material must be selected to suit the material or chemical being exhausted–carbon steel, 304 or 316 stainless steel, Teflon or Halar coated stainless steel, fiberglass reinforced plastic (FRP), and polyvinyl chloride (PVC) are some examples. Sprinklers are generally required in FRP and PVC ductwork systems in all sizes larger than 8 inch in diameter.

B. Process exhaust ductwork cannot penetrate fire walls, fire separation assemblies, or smoke walls.

C. Process exhaust systems should be provided with a blast gate or butterfly damper at each tap for a hood or equipment, at each lateral, and at each submain. At all fans, large laterals, and submains, a tight shutoff style butterfly damper should be provided for balancing and positive shutoff in addition to the blast gate. Blast gates should be specified with a wiper gasket, of EPDM or other suitable material, to provide as tight a seal as possible for blast gates; otherwise blast gates tend to experience high leakage rates. Wind loading on blast gates installed on the roof or outside the building need to be considered, especially in large blast gates. Blast gate blades will act as a sail in the wind and cause considerable stress on the ductwork system.

D. Process exhaust ductwork should be sloped a minimum of 1⁄8 inch per foot with a drain provided at the low point. The drain should be piped to the appropriate waste system.

E. Process exhaust systems are required, in most cases, to undergo a treatment process–scrubbing, abatement, burning, or filtering.

F. Duct sizing must be based on capture velocities and entrainment velocities of the material or chemical being exhausted. For most chemical or fume exhaust systems, the mains, risers, submains, and large laterals should be sized for 2,000 to 3,000 feet per minute, and small laterals and branches should be sized for 1,500 to 2,500 feet per minute. Discharge stacks should be sized for 3,000 to 4,000 feet per minute discharge velocity and should terminate a minimum of 8 feet above the roof and a minimum of 10 feet from any openings or intakes. Properly locate discharge stacks and coordinate discharge height to prevent contamination of outside air intakes, CT intakes, and combustion air intakes. Clearly indicate termination heights.

G. The connection to a fume hood or other piece of equipment will generally require between 1.0 and 3.0 inches WC negative pressure.

H. Branches and laterals should be connected above duct centerline. If branches and laterals are connected below the duct centerline, drains will be required at the low

point. Hoods, tools, and equipment must be protected from the possibility of drainage contaminating or entering equipment when taps are connected below the centerline.

I. Specify proper pressure class upstream and downstream of scrubbers and other abatement equipment.

J. When ductwork is installed outside or in unconditioned spaces, verify if condensation will occur on the outside or inside this duct. Insulate duct and/or heat trace if required.

K. Process exhaust fans are required to be on emergency power by code.

L. Process exhaust ductwork cannot penetrate fire rated construction. Fire dampers are generally not desirable. If penetrating fire rated construction cannot be avoided, process exhaust ductwork must be enclosed in a fire rated enclosure until it exits the building or sprinkler protection in side the duct may be used if approved by authority having jurisdiction.

M. Provide pressure ports at the end of all laterals, submains, and mains.

N. Generally, drains are required in fan scroll, scrubber, and other abatement equipment.

O. Provide flexible connections at fans and specify flexible connection suitable for application.

P. If adjustable or variable frequency drives are required or used, locate and coordinated with electrical engineer. Use direct drive fans with adjustable or variable frequency drives.

PART 19

Piping Systems

19.01 Water (Hydronic) Piping Systems

A. Pipe Sizing (See Appendix B):

1. 4 Ft./100 Ft. Maximum Pressure Drop.
2. 8 FPS Maximum Velocity Occupied Areas.
3. 10 FPS Maximum Velocity Unoccupied Areas.
4. Minimum pipe velocity 1.5 Fps, even under low load/flow conditions.
5. *ASHRAE Standard 90.1:* 4 Ft./100 Ft. Maximum Pressure Drop.
6. Standard Steel Pipe Sizes. ½″, ¾″, 1″, 1¼″, 1½″, 2″, 2½″, 3″, 4″, 6″, 8″, 10″, 12″, 14″, 16″, 18″, 20″, 24″, 30″, 36″, 42″, 48″, 54″, 60″, 72″, 84″, 96″.
7. Standard Copper Pipe Sizes. ½″, ¾″, 1″, 1¼″, 1½″, 2″, 2½″, 3″, 4″, 6″, 8″, 10″, 12″.
8. Standard Stainless Steel Pipe Sizes. ½″, ¾″, 1″, 1¼″, 1½″, 2″, 2½″, 3″, 4″, 6″, 8″, 10″, 12″, 14″, 16″, 18″, 20″, 24″.

B. Friction Loss Estimate

1. 1.5 × System Length (Ft.) × Friction Rate (Ft./100 Ft.).
2. Pipe Friction Estimate: 3.0–3.5 Ft./100 Ft.

C. Hydronic System Design and Piping Installation Guidelines:

1. Hydronic Systems Design Principle and Goal. Provide the correct water flow at the correct water temperature to the terminal users.
2. Common Design Errors:
   a. Differential pressure control valves are installed in pump discharge bypasses.
   b. Control valves not selected to provide control with system design pressure differentials at maximum and minimum flows.
   c. Control valves are selected with improper pressure drop.
   d. Incorrect primary/secondary/tertiary system design.
   e. Constant flow secondary or tertiary systems connected to variable flow primary or secondary systems, respectively.
   f. Check valves are not provided in pump discharges when pumps are operating in parallel.
   g. Automatic relief valves are oversized which result in quick, sudden, and sometimes violent system pressure fluctuations.
3. Piping System Arrangements:
   a. When designing pumping systems for chillers, boilers, and cooling towers, provide either a unitized pumping arrangement (each pump piped directly to each piece of central plant equipment) or provide a headered system.
   b. Unitized System:
      1) A unitized system should only be used when all the equipment in the system is the same capacity (chillers, boilers, cooling towers, and associated pumps).
   c. Headered System:
      1) A true headered system is preferred especially when chillers, cooling towers, boilers, and associated pumps are of unequal capacity.
      2) **DO NOT USE A MODIFIED HEADERED SYSTEM.** A modified headered system causes major operational problems; it does not work.
      3) When designing a headered system, Griswold Valves (flow control device) must be installed in the supply piping to each piece of equipment to obtain the proper flow through each piece of equipment. In addition to Griswold Valves, control valves must be installed to isolate equipment not in service if system is to be fully

automatic. These control valves should be provided with manual means of opening and closing in case of control system malfunction or failure.

4) Provide adequate provisions for expansion and contraction of piping in boiler, chiller, cooling tower, and pump headered systems. Provide U-shaped header connections for all equipment to accommodate expansion and contraction (first route piping away from header, then route parallel to the header, and finally route back toward header; size of U-shape will depend on the temperature of the system).

4. Minimum recommended hydronic system pipe size should be ¾ inch.
5. In general, noise generation, in hydronic systems, indicates erosion is occurring.
6. Large system diversities:
   a. Campus Heating. 80%.
   b. Campus Cooling. 65%.
   c. Constant Flow. Load is diversified only; flow is not diversified resulting in temperature changes.
   d. Variable Flow. Load and flow are both diversified.
7. When designing a campus or district type heating or cooling system, the controls at the interface between the central system and the building system should be secured so that access is limited to the personnel responsible for operating the central plant and not accessible to the building operators. Building operators may not fully understand the central plant operation and may unknowingly disrupt the central plant operation with system interface tinkering.
8. Differential pressure control of the system pumps should never be accomplished at the pump. The pressure bypass should be provided at the end of the system or the end each of the subsystems regardless of whether the system is a bypass flow system or a variable speed pumping system. Bypass flow need not exceed 20 percent of the pump design flow.
9. Central plant equipment (chillers, boilers, cooling towers, and associated pumps) should be of equal size units; however, system design may include ½ size units or ⅓ size units with full size equipment. For example, a chiller system may be made up of 1,200 ton, 600 ton, and 400 ton chillers. However, ⅓ sized units have limited application. This permits providing multiple units to achieve the capacity of a single unit and having two or three pumps operate to replace the one larger pump.
10. Pump Discharge Check Valves:
    a. Pump discharge check valves should be center guided, spring loaded, disc type check valves.
    b. Pump discharge check valves should be sized so that the check valve is full open at design flow rate. Generally this will require the check valve to be one pipe size smaller than the connecting piping.
    c. Condenser water system and other open piping system check valves should have globe style bodies to prevent flow reversal and slamming.
    d. Install check valves with 4 to 5 pipe diameters upstream of flow disturbances is recommended by most manufacturers.
11. Install air vents at all high points in water systems. Install drains at all low points in water systems. All automatic air vents, manual air vents, and drains in hydronic systems should be piped to a safe location within 6 inches of the floor, preferably over a floor drain, especially heating water systems.
12. Thermometers should be installed in both the supply and return piping to all water coils, chillers, boilers, heat exchangers, and other similar equipment. Thermometers should also be installed at each location where major return streams mix at a location approximately 10 pipe diameters downstream of the mixing point. Placing thermometers upstream of this point is not required, but often desirable, because the other return

thermometers located upstream will provide the water temperatures coming into this junction point. Placing thermometers in these locations will provide assistance in troubleshooting system problems. Liquid filled type thermometers are more accurate than the dial type thermometers.

13. Select water coils with tube velocities high enough at design flow so that tube velocities do not end up in the laminar flow region when the flow is reduced in response to low load conditions. Tube velocities become critical with units designed for 100 percent outside air at low loads near 32°F. Higher tube velocity selection results in a higher water pressure drop for the water coil. Sometimes a trade-off between pressure drop and low load flows must be evaluated.
14. Install manual air vent and drain on coupon rack to relieve pressure from coupon rack to facilitate removing coupons. Pipe drain to floor drain.
15. Install manual air vent on chemical feed tank and also pipe drain to floor drain.
16. Provide water meters on all makeup water and all blowdown water connections to hydronic systems (heating water, chilled water, condenser water, and steam systems). System water usage is critical in operating the systems, maintaining chemical levels, and troubleshooting the systems. If project budget permits, these meter readings should be logged and recorded at the building facilities management and control system.
17. Locate all valves, strainers, unions, and flanges so that they are accessible. All valves (except control valves) and strainers should be full size of pipe before reducing size to make connections to equipment and controls. Union and/or flanges should be installed at each piece of equipment, in bypasses and in long piping runs (100 feet or more) to permit disassembly for alteration and repairs.
18. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7′-0″ above floor level, and chain should extend to 5′-0″ to 7′-0″ above floor level.
19. All balancing valves should be provided with position indicators and maximum adjustable stops (memory stops).
20. All valves should be installed so that valve remains in service when equipment or piping on equipment side of valve is removed.
21. Locate all flow measuring devices in accessible locations with straight section of pipe upstream (10 pipe diameters) and downstream (5 pipe diameters) of device or as recommended by manufacturer.
22. Provide a bypass around the water filters and water softeners. Show water filters and water softener feeding hydronic or steam systems on schematic drawings and plans.
23. Provide vibration isolators for all piping supports connected to and within 50 feet of isolated equipment and throughout mechanical equipment rooms, except at base elbow supports and anchor points.
24. Glycol systems do not use malleable iron fittings.
25. Water in a system should be maintained at a pH of approximately 8 to 9. A pH of 7 is neutral; below 7 is acid; above 7 is alkaline. Closed system water treatment should be 1600 to 2000 ppm Borax-Nitrite additive.
26. Terminal Systems:
    a. Design for the largest possible system delta T.
    b. Better to have terminal coils *slightly* oversized than undersized. Increasing flow rates in terminal coils to twice the design flow rate only increases coil capacity 5 to 16 percent, and tripling the flow rate only increases coil capacity 7 to 22 percent. Grossly oversized terminal unit coils can lead to serious control problems, so care must be taken in properly sizing coils.
27. Terminal Unit Control Methods:
    a. Constant Supply Temperature, Variable Flow.
    b. Variable Supply Temperature, Constant Flow.

c. Flow Modulation to a minimum value at constant supply temperature, at minimum flow a pump or fan, is started to maintain constant minimum flow at a variable supply temperature.
d. No primary system control, secondary system control accomplished by blending or face and bypass control.

28. Terminal Unit Design:
a. Terminal unit design should be designed for the largest possible system delta T.
b. Terminal unit design should be designed for the closest approach of primary return water temperature and secondary return temperature.
c. Terminals must be selected for full load and for partial load performance.
d. Select coils with high water velocities at full load, larger pressure drop. This will result in increased performance at partial loads.

29. Thermal Storage:
a. Peak shaving. Constant supply with variable demand.
b. Space heating/cooling. Variable supply with constant demand, waste heat recovery.
c. Variable supply with variable demand.

30. Provide stop check valves (located closest to the boiler) and isolation valves with a drain between these valves on both the supply and return connections to all heating water boilers.

31. Boiler warming pumps should be piped to both the system header and to the boiler supply piping, thus allowing the boiler to be kept warm (in standby mode) from the system water flow or to warm the boiler when is has been out of service for repairs without the risk of shocking the boiler with system water temperature. Boiler warming pumps should be selected for 0.1 gpm/BHP (range 0.05 to 0.1 gpm/BHP). At 0.1 gpm/BHP, it takes 45 to 75 minutes to completely exchange the water in the boiler. This flow rate is sufficient to offset the heat loss by radiation and stack losses on boilers when in standby mode of operation. In addition, this flow rate allows the system to keep the boiler warm without firing the boiler, thus allowing for more efficient system operation. For example, it takes 8 to 16 hours to bring a bring a boiler on-line from a cold start. Therefore, the standby boiler must be kept warm to enable immediate start-up of the boiler upon failure of an operating boiler.

32. To provide fully automatic heating water system controls, the controls must look at and evaluate the boiler metal temperature (water temperature) and the refractory temperature prior to starting the primary pumps or enabling the boiler to fire. First, the boiler system design must circulate system water through the boilers to keep the boiler water temperature at system temperature when the boiler is in standby mode as discussed for boiler warming pump arrangements. Second, the design must look at the water temperature prior to starting the primary pumps to verify that the boiler is ready for service. And third, the design must look at refractory temperature to prevent boiler from going to high fire if the refractory is not at the appropriate temperature. However, the refractory temperature is usually handled by the boiler control package.

33. Heating Water System Warm-Up Procedure:
a. Heating water system start-up should not exceed 120°F. temperature rise per hour, but boiler or heat exchanger manufacture limitations should be consulted.
b. It is recommended that no more than a 25°F. temperature rise per hour be used when warming heating water systems. Slow warming of the heating water system allows for system piping, supports, hangers, and anchors to keep up with system expansion.
c. Low temperature heating water systems (250°F and less) should be warmed slowly at 25°F. temperature rise per hour until system design temperature is reached.

d. Medium and high temperature heating water systems (above 250°F) should be warmed slowly at 25°F. temperature rise per hour until 250°F system temperature is reached. At this temperature the system should be permitted to settle for at least 8 hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 350°F or system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing the system to settle for an hour before increasing the temperature or pressure to the next increment. When the system reaches 350°F and the design temperature is above 350°F. the system should be allowed to settle for at least 8 hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 455°F or system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing the system to settle for an hour before increasing the temperature or pressure to the next increment.

34. Provide heating water systems with warm-up valves for in service startup as shown in the table on page 159. This will allow operators to warm these systems slowly and to prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when they are only opened a small amount in an attempt to control system warm-up speed.
35. Heating Water System Warming Valve Procedure:
    a. First, open warming return valve slowly to pressurize the equipment without flow.
    b. Once the system pressure has stabilized, then slowly open the warming supply valve to establish flow and to warm the system.
    c. Once the system pressure and temperature have stabilized, then proceed with the following items listed below, one at a time:
        1) Slowly open the main return valve.
        2) Close the warming return valve.
        3) Slowly open the main supply valve.
        4) Close the warming supply valve.

D. Chilled Water Systems:

1. Leaving Water Temperature (LWT): 40–48°F. (60°F. Maximum)
2. ΔT Range 10–20°F.
3. Chiller Start-up and Shutdown Bypass: When starting a chiller, it takes 5 to 15 minutes from the time the chiller start sequence is initiated until the time the chiller starts to provide chilled water at the design temperature. During this time the chilled water supply temperature rises above the desired set point. If chilled water temperature is critical and this deviation unacceptable, the method to correct this problem is to provide the chillers with a bypass which runs from the chiller discharge to the primary pump suction header return. The common pipe only needs to be sized for the flow of one chiller because it is unlikely that more than one chiller will be started at the same time. Chiller system operation with a bypass should be as follows:
    a. On chiller start sequence, the primary chilled water pump is started, the bypass valve is opened, and the supply header valve is closed. When the chilled water supply temperature is reached, as sensed in the bypass, the supply header valve is slowly opened. When the supply header valve is fully opened, the bypass valve is slowly closed.

Bypass and Warming Valves

MAIN VALVE NOMINAL PIPE SIZE	NOMINAL PIPE SIZE	
	SERIES A WARMING VALVES	SERIES B BYPASS VALVES
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

1. **Series A covers steam service for warming up before the main line is opened and for balancing pressures where lines are of limited volume.**
2. **Series B covers lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

   b. On chiller stop sequence, the bypass valve is slowly opened. When the bypass valve is fully opened, the supply header valve is slowly closed. When the primary chilled water pump stops, the bypass valve is closed.
4. Large and campus chilled water systems should be designed for large delta T's and for variable flow secondary and tertiary systems.
5. Chilled water pump energy must be accounted for in the chiller capacity because they add heat load to the system.
6. Methods of Maintaining Constant Chilled Water Flow:
   a. Primary/Secondary Systems.
   b. Bypassing-Control.
   c. Constant volume flow only applicable to two chillers in series flow or single chiller applications.
7. It is best to design chilled water and condenser water systems to pump through the chiller.
8. When combining independent chilled water systems into a central plant,
   a. Create a central system concept, control scheme, and flow schematics.

b. The system shall only have a single expansion tank connection point sized to handle entire system expansion and contraction.
c. All systems must be altered, if necessary, to be compatible with central system concept (temperatures, pressures, flow concepts, variable or constant, control concepts).
d. For constant flow and variable flow systems, the secondary chillers are tied into the main chiller plant return main. Chilled water is pumped from the return main through the chiller and back to the return main.
e. District chilled water systems, due to their size, extensiveness, or both, may require that independent plants feed into the supply main at different points. If this is required, design and layout must enable isolating the plant; provide start-up and shutdown bypasses; and provide adequate flow, temperature, pressure, and other control parameter readings and indicators for proper plant operation, and other design issues which affect plant operation and optimization.

9. In large systems, it may be beneficial to install a steam-to-water or water-to-water heat exchanger to place an artificial load on the chilled water system to test individual chillers or groups of chillers during plant start-up, after repairs, or for troubleshooting chiller or system problems.

E. Low Temperature Chilled Water Systems (Glycol or Ice Water Systems)

1. Leaving Water Temperature (LWT): 20–40°F. (0°F. minimum)
2. ΔT Range 20–40°F.

F. Heating Water Systems General:

1. From a design and practical standpoint, low temperature heating water systems are often defined as systems with water temperatures 210°F. and less, and high temperature heating water systems are defined as systems with water temperatures 211°F. and higher.
2. Provide manual vent on top of heating water boiler to vent air from top of boiler during filling and system operation. Pipe manual vent discharge to floor drain.
3. Blowdown separators are not required for hot water boilers, but desirable for maintenance purposes. Install the blowdown separator so that the inlet to the separator is at or below the boiler drain to enable the use of the blowdown separator during boiler draining for emergency repairs.
4. Safety: High temperature hydronic systems when operated at higher system temperatures and higher system pressures will result in lower chance of water hammer and the damaging effects of pipe leaks. These high temperature heating water systems are also safer than lower temperature heating water systems because system leaks subcool to temperatures below scalding due to the sudden decrease in pressure and the production of water vapor.
5. Outside air temperature reset of low temperature heating water systems is recommended for energy savings and controllability of terminal units at low load conditions. However, care must be taken with boiler design to prevent thermal shock by low return water temperatures or to prevent condensation in the boiler due to low supply water temperatures and, therefore, lower combustion stack discharge temperature.
6. Circulating hot water through a boiler which is not operating, to keep it hot for standby purposes, creates a natural draft of heated air through the boiler and up the stack, especially in natural draft boilers. Forced draft or induced draft boilers have combustion dampers which close when not firing and therefore reduce, but not eliminate, this heat loss. Although this heat loss is undesirable for standby boilers, circulating hot water through the boiler is more energy efficient than firing the boiler. Operating a standby boiler may be in violation of air permit regulations in many jurisdictions today.

G. Low Temperature Heating Water Systems:

1. Leaving Water Temperature (LWT): 180–200°F.
2. ΔT Range 20–40°F.
3. Low Temperature Water 250°F. and less; 160 psig maximum

H. Medium and High Temperature Heating Water Systems:

1. Leaving Water Temperature (LWT): 350–450°F.
2. ΔT Range 20–100°F.
3. Medium Temperature Water 251–350°F.; 160 psig maximum
4. High Temperature Water 351–450°F.; 300 psig maximum
5. Submergence or antiflash margin is the difference between the actual system operating pressure and the vapor pressure of water at the system operating temperature. However, submergence or antiflash margin is often expressed in degrees Fahrenheit—the difference between the temperature corresponding to the vapor pressure equal to the actual system pressure and the system operating temperature.
6. Provide operators on valves on the discharge of the feed water pumps for medium and high temperature systems to provide positive shutoff because the check valves sometimes leak with the large pressure differential. Interlock the valves to open when the pumps operate. Verify that valve is open with an end switch or with a valve positioner.
7. Provide space and racks for spare nitrogen bottles in mechanically pressurized medium and high temperature heating water systems.
8. Medium and High Temperature Heating Water System Design Principles:
   a. System pressure must exceed the vapor pressure at the design temperature in all locations in the system. Verify this pressure requirement at the highest location in the system, at the pump suction, and at the control valve when at minimum flow or part load conditions. The greater the elevation difference, above the pressure source (in most cases the expansion tank), the higher the selected operating temperature in the medium and high temperature heating water system should be.
   b. Medium and high temperature water systems are unforgiving to system design errors in capacity or flow rates.
   c. Conversion factors in standard HVAC equations must be adjusted for specific gravity and specific heat at the design temperatures.
   d. Thermal expansion and contraction of piping must be considered and are critical in system design.
   e. Medium and high temperature heating water systems can be transported over essentially unlimited distances.
   f. The greater the system delta T, the more economical the system becomes.
   g. Use medium and high temperature heating water systems when required for process applications, because it produces precise temperature control and more uniform surface temperatures in heat transfer devices.
   h. The net positive suction head requirements of the medium and high temperature system pumps are critical and must be checked for adequate pressure. It is best to locate and design the pumps so that cavitation does not occur as follows:
      1) Oversize the pump suction line to reduce resistance.
      2) Locate the pump at a lower level than the expansion tank to take advantage of the static pressure gain.
      3) Elevate the expansion tank above the pumps.
      4) Locate the pumps in the return piping circuit and pump through the boilers, thus reducing the system temperature at the pumps, which reduces the vapor pressure requirements.

   i. Either blending fittings or properly designed pipe fittings must be used when blending return water with supply water in large delta T systems or injecting medium and high temperature primary supply water into low temperature secondary circuits. When connecting piping to create a blending tee, the hotter water must always flow downward and the colder water must always flow upward. The blending pipe must remain vertical for a short length equal to a few pipe diameters on either side of the tee. Since turbulence is required for mixing action, it is not desirable to have straight piping for any great distance (a minimum of 10 pipe diameters is adequate).
9. Above approximately 300°F., the bearings and gland seals of a pump must be cooled. Consult factory representatives for all pumps for systems above 250°F. to determine specification requirements. Cooling water leaving the pump cooling jacket should not fall below 100°F. The best method for cooling seals is to provide a separate heat exchanger (one at each pump or one for a group of pumps) and circulate the water through the seal chamber. The heat exchanger should be constructed of stainless steel. Another method to cool the seals is to take a side stream flow off of the pump discharge, cool the flow, and inject it into the end face. This is not recommended because the amount of energy wasted is quite substantial.
10. Medium and high temperature heating water systems work well for radiant heating systems.
11. Control valves should be placed in the supply to heat exchangers with a check valve in the return. This practice provides a safety shutoff in case of a major leak in the heat exchanger. By placing the control valve in the supply when a leak occurs, the temperature or pressure increases on the secondary side causing the control valve to close while the check valve prevents back flow or pressure from the return. Flashing may occur with the control valve in the supply when a large pressure differential exists or when the system is operated without an antiflash margin. To correct this flashing, control must be split with one control valve in the supply and one control valve in the return.
12. If using medium or high temperature heating water systems to produce steam, the steam pressure dictates the delta T and thus the return water temperature.
13. Medium and High Temperature Heating Water Systems in Frequent Use:
    a. Cascade Systems with integral expansion space:
        1) Type 1. Feedwater pump piped to steam boiler.
        2) Type 2. Feedwater pump piped to medium or high temperature heating water system with steam boiler feedwater provided by medium and high temperature heating water system.
    b. Flooded generators with external expansion/pressurization provisions.
14. Medium and High Temperature Water System Boiler Types:
    a. Natural Circulators, Fire Tube and Water Tube Boilers.
    b. Controlled (Forced) Circulation.
    c. Combustion (Natural and Forced), Corner Tube Boilers.
15. Design Requirements:
    a. Settling camber to remove any foreign matter, dirt, and debris; oversized header with flanged openings for cleanout.
    b. Generator must never be blown down. Blowdown should only be done at the expansion tank or piping system.
    c. Boiler safety relief valves should only be tested when water content is cold; otherwise, flashing water-to-steam mixture will erode valve seat and after opening once or twice the safety relief valves will leak constantly.
    d. Boiler safety relief valves must only be considered protection for the boilers. Another safety relief valve must be provided on the expansion tank.
    e. Relief valves should be piped to a blowdown tank.

16. Medium and high temperature heating water systems may be pressurized by steam systems on the generator discharge or by pump or mechanical means on the suction side of the primary pumps pumping through the boilers.
17. Steam pressurized system characteristics are listed below:
    a. Steam pressurized systems are generally continuously operated with rare shutdowns.
    b. System expansion tank is pressurized with steam and contains a large volume of water at a high temperature, resulting in a considerable ability to absorb load fluctuations.
    c. Steam pressurized systems improve operation of combustion control.
    d. Steam pressurized system reduces the need to anticipate load changes.
    e. System is closed and the entry of air or gas is prevented, thus reducing or eliminating corrosion or flow restricting accumulations.
    f. Generally these systems can operate at a lower pressure than pump or mechanical pressurized systems.
    g. Steam pressurized systems have a higher first cost.
    h. These systems require greater space requirements.
    i. The large pressurization tank must be located above and over generators.
    j. Pipe discharges into a steam pressurized expansion tank should be vertically upward or should not exceed an angle greater than 45 degrees with respect to the vertical.
18. Mechanically pressurized system characteristics are listed below:
    a. Mechanically pressurized systems have flexibility in expansion tank location.
    b. Mechanically pressurized systems should be designed to pump through the generator; place the expansion and pressurization means at the pump suction inlet.
    c. Mechanically pressurized systems are best suited for intermittently operated systems.
    d. A submergence or antiflash margin must be provided.
    e. Nitrogen supply must be kept on hand. System cannot operate without nitrogen.
    f. Mechanically pressurized systems have a lower first cost.
    g. Mechanically pressurized systems require less expansion tank space.
    h. Start-up and shutdown of these systems simplified.
19. Pumps in medium and high temperature heating water systems should be provided with ½ to ¾ inch bypasses around the check valve and shutoff valves on the pump discharge:
    a. To refill the pump piping after repairs have been made.
    b. To allow for opening the system shutoff valve (often gate valve) which becomes difficult to open against the pressure differentials experienced.
    c. To allow for a slow warming of the pump and pump seals, and for letting sealing surfaces to seat properly.
20. Double valves should be installed on both the supply and return side of equipment for isolation on heating water systems, above 250°F. with a drain between these valves to visually confirm isolation. The double valving of systems ensures isolation because of the large pressure differentials which occur when the system is opened for repairs. Double valve all the following:
    a. Equipment.
    b. Drains.
    c. Vents.
    d. Gauges.
    e. Instrumentation.
    f. Double drain and vent valve operation: Fully open the valve closest to the system piping first. Then open the second valve modulating the second valve to control

flow to the desired discharge rate. Close second valve first when finished draining or venting. Operating in this fashion keeps the valve closest to the system from being eroded and thus allowing for the valve to provide tight shutoff when needed. In addition, this operation allows for replacement of the second valve with the system in operation since this valve receives most of the wear and tear during operation.

21. Do not use screw fittings because high and medium temperature water is very penetrating. Use welded or flanged fittings in lieu of screwed fittings. Do not use union joints.
22. Use of dissimilar metals must be avoided. Use only steel pipe, fittings, valves, flanges, and other devices.
23. Do not use cast iron or bronze body valves.
24. Use valves with metal to metal seats.
25. Do not use lubricated plug valves.

I. Dual Temperature Water System Types:

1. Leaving Cooling Water Temperature 40–48°F.
2. Cooling ΔT Range 10–20°F.
3. Leaving Heating Water Temperature: 180–200°F.
4. Heating ΔT Range 20–40°F.
5. 2-Pipe Switch-over Systems provide heating or cooling but not both.
6. 3-Pipe Systems provide heating and cooling at the same time with a blended return water temperature causing energy waste.
7. 4-Pipe Systems:
   a. Hydraulically joined at the terminal user (most common with fan coil systems with a single coil). Must design the heating and cooling systems with a common and single expansion tank connected at the generating end. At the terminal units the heating and cooling supplies should be connected and the heating and cooling returns should be connected.
   b. Hydraulically joined at the generator end (most common with condenser water heat recovery systems).
   c. Hydraulically joined at both ends.

J. Condenser Water Systems:

1. Entering Water Temperature (EWT): 85°F.
2. ΔT Range 10–20°F.
3. Normal ΔT 10°F.

K. Water Source Heat Pump Loop

1. Range: 60–90°F.
2. ΔT Range 10–15°F.

Water Equation Factors

SYSTEM TYPE	SYSTEM TEMPERATURE RANGE °F.	EQUATION FACTOR
LOW TEMPERATURE (GLYCOL) CHILLED WATER	0 - 40	SEE NOTE 2
CHILLED WATER	40 - 60	500
CONDENSER WATER HEAT PUMP LOOP	60 - 110	500
LOW TEMPERATURE HEATING WATER	110 - 150	490
	151 - 200	485
	201 - 250	480
MEDIUM TEMPERATURE HEATING WATER	251 - 300	475
	301 - 350	470
HIGH TEMPERATURE HEATING WATER	351 - 400	470
	401 - 450	470

Notes:
1. Water equation corrections for temperature, density and specific heat.
2. For glycol system equation factors, see paragraph 19.04, Glycol Solution Systems, below.

Hydronic System Design Temperaturers and Pressures

WATER TEMPERATURE °F.	VAPOR PRESSURE PSIG	SYSTEM OPERATING PRESSURE ANTIFLASH MARGIN						
		10 °F.	20 °F.	30 °F.	40 °F.	50 °F.	60 °F.	70 °F.
200	-3.2	-0.6	2.5	6	10	15	21	27
210	-0.6	2.5	6	10	15	21	27	35
212	0.0	3	7	11	16	22	29	36
215	0.9	4	8	13	18	24	31	39
220	2.5	6	10	15	21	27	35	43
225	4.2	8	13	18	24	30	39	48
230	6.1	10	15	21	27	35	43	52
240	10.3	15	21	27	34	43	52	63
250	15.1	21	27	34	43	52	63	75
260	20.7	27	34	43	52	63	75	88
270	27.2	34	43	52	63	75	88	103
275	30.7	39	47	58	69	81	96	111
280	34.5	43	52	63	75	88	103	120
290	42.8	52	63	75	88	103	120	138
300	52.3	63	75	88	103	120	138	159
310	62.9	75	88	103	120	138	159	181
320	74.9	88	103	120	138	159	181	206
325	81.4	96	111	129	148	170	193	219
330	88.3	103	120	138	159	181	206	232
340	103.2	120	138	159	181	206	232	262
350	119.8	138	159	181	206	232	262	294
360	138.2	159	181	206	232	262	294	329
370	158.5	181	206	232	262	294	329	367
375	169.5	193	219	247	277	311	347	387
380	180.9	206	232	262	294	329	367	407
390	205.5	232	262	294	329	367	407	452
400	232.4	262	294	329	367	407	452	500
410	261.8	294	329	367	407	452	500	551
420	293.8	329	367	407	452	500	551	606
425	310.9	347	387	429	475	524	578	635
430	328.6	367	407	452	500	551	606	665
440	366.5	407	452	500	551	606	665	729
450	407.4	452	500	551	606	665	729	797
455	429.1	475	525	578	635	697	762	832

Notes:

1. **Safety: High temperature hydronic systems when operated at higher system temperatures and higher system pressures will result in lower chance of water hammer and the damaging effects of pipe leaks. These high temperature heating water systems are also safer than lower temperature heating water systems because system leaks subcool to temperatures below scalding due to the sudden decrease in pressure and the production of water vapor.**
2. **The antiflash margin of 40°F. minimum is recommended for nitrogen or mechanically pressurized systems.**

L. Piping Materials:

1. 125 Psi (289 Ft.) and Less:
   a. 2″ and Smaller:
      1) Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B.
         Fittings: Black Malleable Iron Screw Fittings, 150 lb. *ANSI/ASME B16.3.*
         Joints: Pipe Threads, General Purpose (American) *ANSI/ASME B1.20.1.*
      2) Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B.
         Fittings: Cast Iron Threaded Fittings, 150 lb. *ANSI/ASME B16.4.*
         Joints: Pipe Threads, General Purpose (American) *ANSI/ASME B1.20.1.*

3) Pipe: Type "L" Copper Tubing, *ASTM B88,* Hard Drawn.
   Fittings: Wrought Copper Solder Joint Fittings, *ANSI/ASME B16.22.*
   Joints: Solder Joint with 95-5 tin antimony solder, 96-4 tin silver solder, or 94-6 tin silver solder, *ASTM B32.*

b. 2½″ thru 10″:
   1) Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B.
      Fittings: Steel Butt-Welding Fittings *ANSI/ASME B16.9.*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   2) Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B.
      Fittings: Factory Grooved End Fittings equal to Victaulic Full-Flow. Tees shall be equal to Victaulic Style 20, 25, 27, or 29.
      Joints: Mechanical Couplings equal to Victaulic couplings Style 75 or 77 with Grade H gaskets, lubricated per manufacturer's recommendation.

c. 12″ and Larger:
   1) Pipe: Black Steel Pipe, *ASTM A53,* ⅜″ wall, Type E or S, Grade B.
      Fittings: Steel Butt-Welding Fittings *ANSI/ASME B16.9.*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   2) Pipe: Black Steel Pipe, *ASTM A53,* ⅜″ wall, Type E or S, Grade B.
      Fittings: Factory Grooved End Fittings equal to Victaulic Full-Flow. Tees shall be equal to Victaulic Style 20, 25, 27, or 29.
      Joints: Mechanical Couplings equal to Victaulic couplings Style 75 or 77 with Grade H gaskets, lubricated per manufacturer's recommendation.

2. 126–250 psig (290–578 Ft.):
   a. 1½″ and Smaller:
      1) Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
         Fittings: Forged Steel Socket-Weld, 300 lb., *ANSI B16.11.*
         Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
      2) Pipe: Carbon Steel Pipe, *ASTM A106, Schedule 80,* Grade B.
         Fittings: Forged Steel Socket-Weld, 300 lb., *ANSI B16.11.*
         Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   b. 2″ and Larger:
      1) Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B.
         Fittings: Steel Butt-Welding Fittings, 300 lb., *ANSI/ASME B16.9.*
         Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
      2) Pipe: Carbon Steel Pipe, *ASTM A106, Schedule 80,* Grade B.
         Fittings: Steel Butt-Welding Fittings, 300 lb., *ANSI/ASME B16.9.*
         Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

M. Pipe Testing:

1. 1.5 × System Working Pressure.
2. 100 Psi Minimum.

N. Closed Piping Systems: Piping systems with no more than one point of interface with a compressible gas (generally air).

O. Open Piping Systems: Piping systems with more than one point of interface with a compressible gas (generally air).

P. Reverse Return Systems: Length of supply and return piping is nearly equal. Reverse return systems are nearly self-balancing.

Q. Direct Return Systems: Length of supply and return piping is unequal. Direct return systems are more difficult to balance.

R. One-Pipe Systems:

1. One-pipe systems are constant volume flow systems.
2. All Series Flow Arrangements. Total circulation flows through every terminal user with lower inlet supply temperatures with each successive terminal device.
3. Diverted Series Flow Arrangements. Part of the flow goes through the terminal unit and the remainder is diverted around the terminal unit using a resistance device (balancing valve, fixed orifice, diverting tees, or flow control devices).

S. Two-Pipe Systems:

1. Same piping used to circulate chilled water and heating water.
2. Two-pipe systems are either constant volume flow or variable volume flow systems.
3. Direct Return Systems. Critical to provide proper balancing devices (balancing valves or flow control devices).
4. Reverse Return Systems. Generally limited to small systems, simplifies balancing.

T. Three-Pipe Systems (Obsolete):

1. Separate chilled water and heating water supply piping, common return piping used to circulate chilled water and heating water.

U. Four-Pipe Systems:

1. Separate supply and return piping (2 separate systems) used to circulate chilled water and heating water.
2. Four-pipe systems are either constant volume flow or variable volume flow systems.
3. Direct Return Systems. Critical to provide proper balancing devices (balancing valves or flow control devices).
4. Reverse Return Systems. Generally limited to small systems, simplifies balancing.

V. Ring or Loop Type Systems:

1. Piping systems which are laid out to form a loop with the supply and return mains parallel to each other.
2. Constant volume flow or variable volume flow systems.
3. Provide flexibility for future additions and provide service reliability.
4. Can be designed with better diversity factors.
5. During shutdown for emergency or scheduled repairs, maintenance, or modifications, loads, especially critical loads, can be fed from other direction or leg.
6. Isolation valves must be provided at critical junctions and between all major lateral connections so mains can be isolated and flow rerouted.
7. Flows and pressure distribution have to be estimated by trial and error or by computer.

W. Constant Volume Flow Systems:

1. Direct Connected Terminals. Flow created by main pump through 3-way valves.
2. Indirect Connected Terminals. Flow created by a separate pump with bypass and without output controls.
   a. Permits variable volume flow systems.
   b. Subcircuits can be operated with high pump heads without penalizing the main pump.
   c. Requires excess flow in the main circulating system.
3. Constant volume flow systems are limited to:
   a. Small systems with a single boiler or chiller.

b. More than 1 boiler system if boilers are firetube or firebox boilers.
c. Two chiller systems if chillers are connected in series.
d. Small low temperature heating water systems with 10 to 20°F. delta T.
e. Small chilled water systems with 7 to 10°F. delta T.
f. Condenser water systems.
g. Large chilled water and heating water systems with primary/secondary pumping systems, constant flow primary circuits.

4. Constant volume flow systems not suited to:
   a. Multiple watertube boiler systems.
   b. Parallel chiller systems.
   c. Parallel boiler systems.
5. Constant volume flow systems are generally energy inefficient.

X. Variable Volume Flow Systems:

1. At partial load, the variable volume flow system return temperatures approach the temperature in the secondary medium.
2. Significantly higher pressure differentials occur at part load and must be considered during design unless variable speed pumps are provided.

Y. Primary/Secondary/Tertiary Systems (PST Systems):

1. PST Systems decouple system circuits hydraulically, thereby making control, operation, and analysis of large systems less complex.
2. Secondary (Tertiary) pumps should always discharge into secondary (tertiary) circuits away from the common piping.
3. Cross-Over Bridge: Cross-over bridge is the connection between the primary (secondary) supply main and the primary (secondary) return main. Size cross-over bridge at a pressure drop of 1–4 Ft./100 Ft.
4. Common Piping: Common piping (sometimes called bypass piping) is the length of piping common to both the primary and secondary circuit flow paths and the secondary and tertiary circuit flow paths. Common piping is the interconnection between the primary and secondary circuits and the secondary and tertiary circuits. The common piping is purposely designed to an extremely low or negligible pressure drop and is generally only 6″ to 24″ long maximum. By designing for an extremely low pressure drop, the common piping ensures hydraulic isolation of the secondary circuit from the primary circuit and the tertiary circuit from the secondary circuit.
5. Extend common pipe size a minimum of 8 diameters upstream and a minimum of 4 diameters downstream when primary flow rate is considerably less than secondary flow rate (i.e., primary pipe size is smaller than secondary pipe size—use larger pipe size) to prevent any possibility of "jet flow." Common piping (bypass piping) in primary/secondary systems or secondary/tertiary systems should be a minimum of 10 pipe diameters in length and the same size as the larger of the two piping circuits.
6. A 1-Pipe Primary System uses one pipe for supply and return. The secondary circuits are in series. Therefore, this system supplies a different supply water temperature to each secondary circuit, and the secondary circuits must be designed for this temperature change.
7. A 2-Pipe Primary System uses two pipes, one for supply and one for return with a cross-over bridge connecting the two. The secondary circuits are in parallel. Therefore, this system supplies the same supply water temperature to each secondary circuit.

19.02 Steam Piping Systems

A. Steam Pipe Sizing (See Appendix C):

1. Low Pressure:
   a. Low Pressure Steam: 0–15 psig.
   b. 0.2–3 psi Total System Pressure Drop Max.
   c. ⅛–½ psi/100 Ft.
2. Medium Pressure:
   a. Medium Pressure Steam: 16–100 psig.
   b. 3–10 psi Total System Pressure Drop Max.
   c. ½–2 psi/100 Ft.
3. High Pressure:
   a. High Pressure Steam: 101–300 psig.
   b. 10–60 psi Total System Pressure Drop Max.
   c. 2–5 psi/100 Ft.
4. Steam Velocity:
   a. 15,000 FPM Maximum.
   b. 6,000–12,000 FPM Recommended.
   c. Low Pressure Systems: 4,000–6,000 FPM.
   d. Medium Pressure Systems: 6,000–8,000 FPM.
   e. High Pressure Systems: 10,000–15,000.
5. Friction Loss Estimate:
   a. 2.0 × System Length (Ft.) × Friction Rate (Ft./100 Ft.).
6. Standard Steel Pipe Sizes—½″, ¾″, 1″, 1¼″, 1½″, 2″, 2½″, 3″, 4″, 6″, 8″, 10″, 12″, 14″, 16″, 18″, 20″, 24″, 30″, 36″, 42″, 48″, 54″, 60″, 72″, 84″, 96″.
7. Total pressure drop in the steam system should not exceed 20% of the total maximum steam pressure at the boiler.
8. Steam condensate liquid to steam volume ratio is 1:1600 at 0 psig.
9. Flash Steam. Flash steam is formed when hot steam condensate under pressure is released to a lower pressure; the temperature drops to the boiling point of the lower pressure, causing some of the condensate to evaporate forming steam. Flash steam occurs whenever steam condensate experiences a drop in pressure and thus produces steam at the lower pressure.
   a. Low pressure steam systems flash steam is negligible and can be generally be ignored.
   b. Medium and high pressure steam systems flash steam is important to utilize and consider when sizing condensate piping.
   c. Flash Steam Recovery Requirements:
      1) To utilize flash steam recovery the condensate must be at a reasonably high pressure (medium and high pressure steam systems) and the traps supplying the condensate must be capable of operating with the back pressure of the flash steam system.
      2) There must be a use or demand for the flash steam at the reduced pressure. Demand for steam at the lower pressure should be greater than the supply of flash steam. The demand for steam should occur at the same time as the flash steam supply.
      3) The steam equipment should be in close proximity to the flash steam source to minimize installation and radiation losses and to fully take advantage of the flash steam recovery system. Flash steam recovery systems are especially advantageous when steam is utilized at multiple pressures within the facility and the distribution systems are already in place.

10. Saturated Steam:
    a. Saturated Steam. Saturated steam is steam that is in equilibrium with the liquid at a given pressure. One pound of steam has a volume of 26.8 Cu.Ft. at atmospheric pressure (0 psig).
    b. Dry Saturated Steam. Dry steam is steam which has been completely evaporated and contains no liquid water in the form of mist or small droplets. Steam systems which produce a dry steam supply are superior to systems which produce a wet steam supply.
    c. Wet Saturated Steam. Wet steam is steam which has not been completely evaporated and contains water in the form of mist or small droplets. Wet steam has a heat content substantially lower than dry steam.
    d. Superheated Steam. Superheated steam is dry saturated steam that is heated, which increases the temperature without increasing the system pressure.
11. Steam Types:
    a. Plant Steam. Steam produced in a conventional boiler system using softened and chemically treated water.
    b. Filtered Steam. Plant steam which has been filtered to remove solid particles (no chemical removal).
    c. Clean Steam. Steam produced in a clean steam generator using distilled, de-ionized, reverse-osmosis, or ultra-pure water.
    d. Pure Steam. Steam produced in a clean steam generator using distilled or de-ionized pyrogen free water, normally defined uncondensed water for injection.
12. Steam Purity versus Steam Quality:
    a. Steam Purity. A qualitative measure of steam contamination caused by dissolved solids, volatiles, or particles in vapor, or by tiny water droplets that may remain in the steam following primary separation in the boiler.
    b. Steam Quality. The ratio of the weight of dry steam to the weight of dry saturated steam and entrained water [Example: 0.95 quality refers to 95 parts steam (95%) and 5 parts water (5%)].

B. Steam Condensate Pipe Sizing (See Appendix C):

1. Steam Condensate Pipe Sizing Criteria Limits:
    a. Pressure Drop: 1⁄16–1.0 Psig/100 Ft.
    b. Velocity. Liquid Systems: 150 Ft./Min. Max.
    c. Velocity. Vapor Systems: 5000 Ft./Min. Max.
2. Recommended Steam Condensate Pipe Sizing Criteria:
    a. Low Pressure Systems:
        1) Pressure Drop: ⅛–¼ Psig/100 Ft.
        2) Velocity. Vapor Systems: 2,000 to 3,000 feet per minute.
    b. Medium Pressure Systems:
        1) Pressure Drop: ⅛–¼ Psig/100 Ft.
        2) Velocity. Vapor Systems: 2,000 to 3,000 feet per minute.
    c. High Pressure Systems:
        1) Pressure Drop: ¼–½ Psig/100 Ft.
        2) Velocity. Vapor Systems: 3,000 to 4,000 feet per minute.
3. Wet Returns: Return pipes contain only liquid, no vapor. Wet condensate returns connect to the boiler below the water line so that the piping is always flooded.
4. Dry Returns: Return pipes contain saturated liquid and saturated vapor (most common). Dry condensate returns connect to the boiler above the waterline so that the piping is not flooded and must be pitched in the direction of flow. Dry condensate returns often carry steam, air, and condensate.

5. Open Returns: Return system is vented to atmosphere and condensate lines are essentially at atmospheric pressure (gravity flow lines).
6. Closed Returns: Return system is not vented to atmosphere.
7. Steam traps and steam condensate piping should be selected to discharge at 4 times the condensate rating of air handling heating coils and 3 times the condensate rating of all other equipment for system start-up.

C. Steam and Steam Condensate System Design and Pipe Installation Guidelines:

1. Minimum recommended steam pipe size is ¾ inch. Minimum recommended steam condensate pipe size is 1 inch.
2. Locate all valves, strainers, unions, and flanges so that they are accessible. All valves (except control valves) and strainers should be full size of pipe before reducing size to make connections to equipment and controls. Union and/or flanges should be installed at each piece of equipment, in bypasses and in long piping runs (100 feet or more), to permit disassembly for alteration and repairs.
3. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7′-0″ above floor level and chain should extend to 5′-0″ to 7′-0″ above floor level.
4. All valves should be installed so that valve remains in service when equipment or piping on equipment side of valve is removed.
5. Locate all flow measuring devices in accessible locations with straight section of pipe upstream (10 pipe diameters) and downstream (5 pipe diameters) of device or as recommended by manufacturer.
6. Provide vibration isolators for all piping supports connected to and within 50 feet of isolated equipment, except at base elbow supports and anchor points, throughout mechanical equipment rooms, and for supports of steam mains within 50 feet of boiler or pressure reducing valves.
7. Pitch steam piping downward in direction of flow ¼″ per 10 Ft. (1″ per 40 Ft.) minimum.
8. Where length of branch lines are less than 8 feet, pitch branch lines downward toward mains ½″ per foot minimum.
9. Connect all branch lines to the top of steam mains (45 degree preferred, 90 degree acceptable).
10. Steam piping should be installed with eccentric reducers (flat on bottom) to prevent accumulation of condensate in the pipe and thus increasing the risk of water hammer.
11. Drip leg collection points on steam piping should be the same size as the steam piping to prevent steam condensate from passing over the drip leg and increasing the risk of water hammer. The drip leg collection point should be a minimum of 12 inches long including a minimum 6 inch long dirt leg with the steam trap outlet above the dirt leg.
12. Pitch all steam return lines downward in the direction of condensate flow ½″ per 10 Ft. minimum.
13. Drip legs must be installed at all low points, downfed runouts to all equipment, end of mains, bottom of risers, and ahead of all pressure regulators, control valves, isolation valves and expansion joints.
14. On straight runs with no natural drainage points, install drip legs at intervals not exceeding 200 feet where pipe is pitched downward in the direction of steam flow and a maximum of 100 feet where the pipe is pitched up so that condensate flow is opposite of steam flow.
15. Steam traps used on steam mains and branches shall be minimum ¾″ size.
16. When elevating steam condensate to an overhead return main, it requires 1 psi to elevate condensate 2 Ft. Try to avoid elevating condensate.
17. Control of steam systems with more than 2 million Btuh's should be accomplished with 2 or more control valves (see steam PRVs).

18. Double valves should be installed on the supply side of equipment for isolating steam systems, above 40 psig, with a drain between these valves to visually confirm isolation. The reason for double valving of systems is to ensure isolation because of the large pressure differentials which occur when the system is opened for repairs. Double valve all the following:
    a. Equipment.
    b. Drains.
    c. Vents.
    d. Gauges.
    e. Instrumentation.
19. Steam and steam condensate in a steam system should be maintained at a pH of approximately 8 to 9. A pH of 7 is neutral; below 7 is acid; above 7 is alkaline.
20. Provide stop check valve (located closest to the boiler) and isolation valve with a drain between these valves on the steam supply connections to all steam boilers.
21. Provide steam systems with warm-up valves for in service start-up as shown in the following table. This will allow operators to warm these systems slowly and to prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when they are only opened a small amount in an attempt to control system warm-up speed.

Bypass and Warming Valves

MAIN VALVE NOMINAL PIPE SIZE	NOMINAL PIPE SIZE	
	SERIES A WARMING VALVES	SERIES B BYPASS VALVES
4	1/2	1
5	3/4	$1\frac{1}{4}$
6	3/4	$1\frac{1}{4}$
8	3/4	$1\frac{1}{2}$
10	1	$1\frac{1}{2}$
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:
1. **Series A covers steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**
2. **Series B covers lines conveying gases or liquids where by-passing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

22. Steam System Warming Valve Procedure:
    a. Slowly open the warming supply valve to establish flow and to warm the system.
    b. Once the system pressure and temperature have stabilized, then proceed with the following items listed below, one at a time:
        1) Slowly open the main supply valve.
        2) Close the warming supply valve.
23. Steam System Warm-up Procedure:
    a. Steam system start-up should not exceed 120°F. temperature rise per hour, but boiler or heat exchanger manufacture limitations should be consulted.
    b. It is recommended that no more than a 25°F. temperature rise per hour be used when warming steam systems. Slow warming of the steam system allows for system piping, supports, hangers, and anchors to keep up with system expansion.
    c. Low pressure steam systems (15 psig and less) should be warmed slowly at 25°F. temperature rise per hour until system design pressure is reached.
    d. Medium and high pressure steam systems (above 15 psig) should be warmed slowly at 25°F. temperature rise per hour until 250°F-15 psig system temperature-pressure is reached. At this temperature-pressure the system should be permitted to settle for at least 8 hours or more (preferably overnight). The temperature-pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 120 psig or system design pressure in 25 psig pressure increments; allow the system to settle for an hour before increasing the pressure to the next increment. When the system reaches 120 psig and the design pressure is above 120 psig, the system should be allowed to settle for at least 8 hours or more (preferably overnight). The pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 300 psig or system design pressure in 25 psig pressure increments; allow the system to settle for an hour before increasing the pressure to the next increment.

D. Low Pressure Steam Pipe Materials:

1. 2″ and Smaller:
    a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
       Fittings: Black Cast Iron Screw Fittings, 125 lb., *ANSI/ASME B16.4*
       Joints: Pipe Threads, General Purpose (American) *ANSI/ASME B1.20.1*
2. 2½″ thru 10″:
    a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B
       Fittings: Steel Butt-Welding Fittings, 125 lb., *ANSI/ASME B16.9*
       Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*
3. 12″ and Larger:
    a. Pipe: Black Steel Pipe, *ASTM A53,* ⅜″ wall, Type E or S, Grade B
       Fittings: Steel Butt-Welding Fittings, 125 lb., *ANSI/ASME B16.9*
       Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*

E. Low Pressure Steam Condensate Pipe Materials:

1. 2″ and Smaller:
    a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B
       Fittings: Black Cast Iron Screw Fittings, 250 lb., *ANSI/ASME B16.4*
       Joints: Pipe Threads, General Purpose (American) *ANSI/ASME B1.20.1*

2. 2½″ and Larger:
   a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B
      Fittings: Steel Butt-Welding Fittings, 250 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*

F. Medium and High Pressure Steam and Steam Condensate Pipe:

1. 1½″ and Smaller:
   a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B
      Fittings: Forged Steel Socket-Weld, 300 lb., *ANSI B16.11*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*
   b. Pipe: Carbon Steel Pipe, *ASTM A106, Schedule 80,* Grade B
      Fittings: Forged Steel Socket-Weld, 300 lb., *ANSI B16.11*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*
2. 2″ and Larger:
   a. Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B
      Fittings: Steel Butt-Welding Fittings, 300 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*
   b. Pipe: Carbon Steel Pipe, *ASTM A106, Schedule 80,* Grade B
      Fittings: Steel Butt-Welding Fittings, 300 lb., *ANSI/ASME B16.9*
      Joints: Welded pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9*

G. Pipe Testing:

1. 1.5 × System Working Pressure.
2. 100 Psi Minimum.

H. Steam Pressure Reducing Valves (PRV):

1. PRV Types:
   a. Direct Acting:
      1) Low Cost.
      2) Limited ability to respond to changing load and pressure.
      3) Suitable for systems with low flow requirements.
      4) Suitable for systems with constant loads.
      5) Limited control of downstream pressure.
   b. Pilot-Operated:
      1) Close control of downstream pressure over a wide range of upstream pressures.
      2) Suitable for systems with varying loads.
      3) Ability to respond to changing loads and pressures.
      4) Types:
         a) Pressure-Operated-Pilot.
         b) Temperature-Pressure-Operated-Pilot.
2. Use multiple stage reduction where greater than 100 psig reduction is required or where greater than 50 psig reduction is required to deliver a pressure less than 25 psig operating pressure or when intermediate steam pressure is required.
3. Use multiple PRVs where system steam capacity exceeds 2″ PRV size, when normal operation calls for 10% of design load for sustained periods, or when there are two distinct load requirements (i.e., summer/winter). Provide number of PRV's to suit project.
   a. If system capacity for a single PRV exceeds 2″ PRV size but is not larger than 4″ PRV size, use 2 PRVs with ⅓ and ⅔ capacity split.
   b. If system capacity for a single PRV exceeds 4″ PRV size, use 3 PRV's with 25%, 25%, and 50% or 15%, 35%, and 50% capacity split to suit project.

4. Smallest PRV to be no greater than ⅓ of system capacity. Maximum size PRV to be 4″ (6″ when 4″ PRV will require more than 3 valves per stage).
5. PRV bypass to be 2 pipe sizes smaller than largest PRV.
6. Provide 10 pipe diameters from PRV inlet to upstream header.
7. Provide 20 pipe diameters from PRV outlet to downstream header.
8. Maximum Pipe Velocity Upstream and Downstream of PRV:
   a. 8″ and Smaller: 10,000 FPM.
   b. 10″ and Larger: 8,000 FPM.
   c. Where low sound levels are required reduce velocities by 25% to 50%.
   d. If outlet velocity exceeds those listed above, use noise suppressor.
9. Avoid abrupt changes in pipe size. Use concentric reducers.
10. Limit pipe diameter changes to two pipe sizes per stage of expansion.

I. Safety Relief Valves:

1. The safety relief valve must be capable of handling the volume of steam as determined by the high pressure side of the largest PRV or the bypass, whichever is greater.
2. Use multiple safety relief valves if the capacity of a 4″ safety relief valve is exceeded. Each valve must have a separate connection to the pipeline.
3. Safety, Relief, and Safety Relief Valve testing is dictated by the Insurance Underwriter.

J. Steam Traps:

1. Steam Trap Types:
   a. A steam trap is a self-actuated valve that closes in the presence of steam and opens in the presence of steam condensate or non-condensible gases.
   b. Thermostatic Traps: React to differences in temperature between steam and cooled condensate. Condensate must be subcooled for the trap to operate properly. Thermostatic traps work best in drip and tracing service and where steam temperature and pressure are constant and predictable.
      1) Liquid Expansion Thermostatic Trap.
      2) Balanced Pressure Thermostatic Trap:
         a) Balanced pressure traps change their actuation temperature automatically with changes in steam pressure. Balanced pressure traps are used in application where system pressure varies.
         b) During start-up and operation, this trap discharges air and other non-condensibles very well. This trap is often used as a stand-alone air vent in steam systems.
         c) The balanced pressure trap will cause condensate to back up in the system.
      3) Bimetal Thermostatic Trap:
         a) Bimetal traps are rugged and resist damage from steam system events such as water hammer, freezing, superheated steam, and vibration.
         b) Bimetal traps cannot compensate for steam system pressure changes.
         c) Bimetal traps have a slow response time to changing process pressure and temperature conditions.
      4) Bellows Thermostatic Trap.
      5) Capsule Thermostatic Trap.
   c. Mechanical Traps: Operate by the difference in density between steam and condensate (buoyancy operated).
      1) Float & Thermostatic Traps:
         a) Process or modulating applications—will work in almost any application—heat exchangers, coils, humidifiers, etc.

b) Simplest type of mechanical trap
c) The F&T trap is the only trap that provides continuous, immediate, and modulating condensate discharge.
d) A thermostat valve is open when cold or when below saturation (steam) temperature to allow air to bleed out during system start-up and operation. The valve closes when the system reaches steam temperature.

2) Bucket Traps.
3) Inverted Bucket Traps:

a) Work best in applications with constant load and constant pressure—drips.
b) When the inverted bucket is filled with steam, it rises and closes the discharge valve preventing the discharge of steam. When the inverted bucket is filled with condensate, it drops opening the valve and discharging the condensate.
c) Inverted bucket traps are poor at removal of air and other non-condensible gases.

d. Kinetic Traps: Rely on the difference in flow characteristics of steam and condensate and the pressure created by flash steam.

1) Thermodynamic Traps:

a) Thermodynamic traps work best in drip and tracing service.
b) Thermodynamic traps can remove air and other non-condensibles during start-up only if the system pressures are increased slowly; because of this thermodynamic traps often require a separate air vent.
c) These traps snap open and snap shut and the sound can be annoying if used in noise sensitive areas.
d) The thermodynamic trap is rugged because is has only one moving part and is resistant to water hammer, superheated steam, freezing, and vibration.

2) Impulse or Piston Traps.
3) Orifice Traps.

2. Steam Trap Selection:

a. HVAC equipment steam traps should be selected to discharge three to four times the condensate rating of the equipment for system start-up.
b. Boiler header steam traps should be selected to discharge 3 to 5 times the condensate carryover rating of the boilers (typically 10%).
c. Steam main piping steam traps should be selected to discharge 2 to 3 times the condensate generated during the start-up mode caused by radiation losses.
d. Steam branch piping steam traps should be selected to discharge 3 times the condensate generated during the start-up mode caused by radiation losses.
e. Use float and thermostatic (F&T) traps for all steam supplied equipment.

1) Thermostatic traps may be used for steam radiators, steam finned tube, and other non-critical equipment, in lieu of F&T traps.
2) A combination of an inverted bucket trap and an F&T trap in parallel, with F&T trap installed above inverted bucket trap, may be used, in lieu of F&T traps.

f. Use inverted bucket traps for all pipeline drips.

3. Steam Trap Functions:

a. Steam traps allow condensate to flow from the heat exchanger or other device to minimize fouling, prevent damage, and to allow the heat transfer process to continue.
b. Steam traps prevent steam escape from the heat exchanger or other device.
c. Steam traps vent air or other non-condensible gases to prevent corrosion and allow heat transfer.

4. Common Steam Trap Problems:

a. Steam Leakage: Like all valves the steam trap seat is subject to damage, corrosion, and/or erosion. When the trap seat is damaged, the valve will not seal; thus, the steam trap will leak live steam.

b. Air Binding: Air, carbon dioxide, hydrogen, and other non-condensible gases trapped in a steam system will reduce heat transfer and can defeat steam trap operation.
c. Insufficient Pressure Difference: Steam traps rely on a positive pressure difference between the upstream steam pressure and the downstream condensate pressure to discharge condensate. When this is not maintained, the discharge of condensate is impeded.
    1) Overloading of the condensate return system is one cause: too much back pressure.
    2) Steam pressure that is too low is another cause.
d. Dirt: Steam condensate often contains dirt, particles of scale and corrosion, and other impurities from the system that can erode and damage the steam traps. Strainers should always be placed upstream of the steam traps to extend life.
e. Freezing: Freezing is normally only a problem when the steam system is shut down or idles and liquid condensate remains in the trap.
f. Noise: Thermodynamic traps are generally the only trap that produces noise when it operates. All other traps operate relatively quietly.
g. Maintenance: Steam traps, as with all valves, must be maintained. Most steam traps can be maintained in-line without removing the body from the connecting piping.

5. Steam Trap Characteristics are given in the following table.

Steam Trap Comparison

CHARACTERISTIC	STEAM TRAP TYPE		
	INVERTED BUCKET	FLOAT & THERMOSTATIC	LIQUID EXPANSION THERMOSTATIC
Method of Operation	Intermittent, Condensate drainage is continuous, discharge is intermittent	Continuous	Intermittent
No Load	Small Dribble	No Action	No Action
Light Load	Intermittent	Usually Continuous but May Cycle at High Pressures	Continuous, Usually Dribble Action
Normal Load	Intermittent	Usually Continuous but May Cycle at High Pressures	May Blast at High Pressures
Full or Overload	Continuous	Continuous	Continuous
Energy Conservation	Excellent	Good	Fair
Resistance to Wear	Excellent	Good	Fair
Corrosion Resistance	Excellent	Good	Good
Resistance to Hydraulic Shock	Excellent	Poor	Poor
Vents Air and CO_2 at Steam Temperature	Yes	No	No
Ability to Vent Air at Very Low Pressure (1/4 Psig)	Poor	Excellent	Good
Ability to Handle Start-up Air Loads	Fair	Excellent	Excellent
Operation Against Back Pressure	Excellent	Excellent	Excellent
Resistance to Damage from Freezing, Cast Iron Trap not Recommended	Good	Poor	Good
Ability to Purge System	Excellent	Fair	Good
Performance on Very Light Loads	Excellent	Excellent	Excellent
Responsiveness to Slugs of Condensate	Immediate	Immediate	Delayed
Ability to Handle Dirt	Excellent	Poor	Fair
Comparative Physical Size	Large	Large	Small
Ability to Handle Flash Steam	Fair	Poor	Poor

Steam Trap Comparison

CHARACTERISTIC	STEAM TRAP TYPE		
	INVERTED BUCKET	FLOAT & THERMOSTATIC	LIQUID EXPANSION THERMOSTATIC
Usual Mechanical Failure Mode	Open	Closed with Air Vent Open	Open or Closed Depending on Design
Subcooling	No	No	Yes
Venting	Fair	Excellent	Excellent
Seat Pressure Rating	Yes	Yes	N/A
Advantages	Rugged	Continuous condensate discharge	Utilizes sensible heat of condensate
	Tolerates water hammer without damage	Handles rapid pressure changes	Allows discharge of non-condensibles at startup to the set point temperature
		High non-condensible capacity	Not affected by superheated steam, water hammer, or vibration
			Resists freezing
Disadvantages	Discharges non-condensibles slowly (additional air vent required)	Float can be damaged by water hammer	Element subject to corrosion damage
	Level of condensate can freeze, damaging the trap body	Level of condensate in chamber can freeze, damaging float and body	Condensate backs up into the drain line and/or process
	Must have water seal to operate - subject to loosing prime	Some thermostatic air vent designs are susceptible to corrosion	
	Pressure fluctuations and superheated steam can cause loss of water seal		
Recommended Services	Continuous operation where non-condensible venting is not critical and rugged construction is important	Heat exchangers with high and variable heat transfer rates	Ideal for tracing used for freeze protection
		When condensate pump is required	Freeze protection - water and condensate lines and traps
		Batch processes that require frequent startup of an air filled system	Non-critical temperature control of heated tanks

Steam Trap Comparison

CHARACTERISTIC	STEAM TRAP TYPE		
	BALANCED PRESSURE THERMOSTATIC	BIMETAL THERMOSTATIC	THERMODYNAMIC
Method of Operation	Intermittent	Intermittent	Intermittent
No Load	No Action	No Action	No Action
Light Load	Continuous, Usually Dribble Action	Continuous, Usually Dribble Action	Intermittent
Normal Load	May Blast at High Pressures	May Blast at High Pressures	Intermittent
Full or Overload	Continuous	Continuous	Continuous
Energy Conservation	Fair	Fair	Poor
Resistance to Wear	Fair	Fair	Poor
Corrosion Resistance	Good	Good	Excellent
Resistance to Hydraulic Shock	Good	Good	Excellent
Vents Air and CO_2 at Steam Temperature	No	No	No
Ability to Vent Air at Very Low Pressure (1/4 Psig)	Good	Good	Not Recommended for Low Pressure Applications
Ability to Handle Start-up Air Loads	Excellent	Excellent	Poor
Operation Against Back Pressure	Excellent	Excellent	Poor
Resistance to Damage from Freezing, Cast Iron Trap not Recommended	Good	Good	Good
Ability to Purge System	Good	Good	Excellent
Performance on Very Light Loads	Excellent	Excellent	Poor
Responsiveness to Slugs of Condensate	Delayed	Delayed	Delayed
Ability to Handle Dirt	Fair	Fair	Poor
Comparative Physical Size	Small	Small	Small
Ability to Handle Flash Steam	Poor	Poor	Poor

Steam Trap Comparison

CHARACTERISTIC	STEAM TRAP TYPE		
	BALANCED PRESSURE THERMOSTATIC	BIMETAL THERMOSTATIC	THERMODYNAMIC
Usual Mechanical Failure Mode	Open or Closed Depending on Design	Open or Closed Depending on Design	Open, Dirt can cause to fail closed
Subcooling	Yes	Yes	No
Venting	Excellent	Excellent	Fair
Seat Pressure Rating	N/A	N/A	N/A
Advantages	Small and lightweight	Small and Lightweight	Rugged, withstands corrosion, water hammer, high pressure, and superheated steam
	Maximum discharge of non-condensibles at startup	Maximum discharge of non-condensibles at startup	Handles wide pressure range
	Unlikely to freeze	Unlikely to freeze and unlikely to be damaged if it does freeze	Compact and simple
		Rugged; Withstands corrosion, water hammer, high pressure, and superheated steam	Audible operations warns when repair is needed
Disadvantages	Some types of damage by water hammer, corrosion, and superheated steam	Responds slowly to load and pressure changes	Poor operation with very low pressure steam or high back pressure
	Condensate backs up into the drain line and/or process	More condensate backup than Balance Pressure Thermostatic Trap	Requires slow pressure buildup to remove air at startup to prevent air binding
		Back pressure changes operating characteristics	Noisy operation
Recommended Services	Batch processing requiring rapid discharge of non-condensibles at startup	Drip legs on constant-pressure steam mains	Steam main drips, tracers
	Drip legs on steam mains and tracing	Installations subject to ambient conditions below freezing	Constant-pressure, constant-load applications
	Installations subject to ambient conditions below freezing		Installations subject to ambient conditions below freezing

6. Steam Trap Inspection
   a. Method #1 is shown in the following table:

TRAP FAILURE RATE	STEAM TRAP INSPECTION FREQUENCY
OVER 10%	EVERY 2 MONTHS
5 TO 10%	EVERY 3 MONTHS
LESS THAN 5%	EVERY 6 MONTHS

b. Method #2 is shown in the following table:

SYSTEM PRESSURE	STEAM TRAP INSPECTION FREQUENCY
0 TO 30 PSIG	ANNUALLY
30 TO 100 PSIG	SEMI-ANNUALLY
100 TO 250 PSIG	QUARTERLY OR MONTHLY
OVER 250 PSIG	MONTHLY OR WEEKLY

19.03 Refrigerant Systems and Piping

A. Refrigeration System Design Considerations:

1. Refrigeration Load and System Size:
   a. Conduction Heat Gains, Sensible.
   b. Radiation Heat Gains, Sensible.
   c. Convection/Infiltration Heat Gains, Sensible and Latent.
   d. Internal Heat Gains, Lights, People, Equipment.
   e. Product Load, Sensible and Latent.
2. Part Load Performance, Minimum vs Maximum Load.
3. Piping Layout and Design:
   a. Assure proper refrigerant flow to feed evaporators.
   b. Size piping to limit excessive pressure drop and temperature rise and to minimize first cost.
   c. Assure proper lubricating oil flow to compressors and protect compressors for loss of lubricating oil flow.
   d. To prevent liquid (oil or refrigerant) from entering the compressors.
   e. Maintain a clean and dry system.
   f. To prevent refrigeration system leaks.
4. Refrigerant type selection and refrigerant limitations.
5. System operation, partial year or year round regardless of ambient conditions.
6. Load variations during short time periods.
7. Evaporator frost control.
8. Oil management under varying load conditions.
9. Heat exchange method.
10. Secondary coolant selection.
11. Installed cost, operating costs, maintenance costs, system efficiency and system simplicity.
12. Safe operation for building inhabitants.
13. Operating pressure and pressure ratios, single stage vs. two stage vs. multi-staged.
14. Special electrical requirements.

B. Refrigerant Pipe Design Criteria:

1. Halocarbon Refrigerants:
   a. Liquid Lines (Condensers to Receivers)—100 FPM or Less.

b. Liquid Lines (Receivers to Evaporator)—300 FPM or Less.
c. Compressor Suction Line—900 to 4,000 FPM.
d. Compressor Discharge Line—2,000 to 3,500 FPM.
e. Defrost Gas Supply Lines—1,000 to 2,000 FPM.
f. Condensate Drop Legs—150 FPM or Less.
g. Condensate Mains—100 FPM or less.
h. Pressure loss due to refrigerant liquid risers is 0.5 psi per foot of lift.
i. Liquid lines should be sized to produce a pressure drop due to friction that corresponds to a 1°F. to 2°F. change in saturation temperature or less.
j. Discharge and suction lines should be sized to produce a pressure drop due to friction that corresponds to a 2°F. change in saturation temperature or less.
k. Pump suction pipe sizing should be 2.5 fps maximum. Oversizing of pump suction piping should be limited to one pipe size.

2. Standard Steel Pipe Sizes: ½″, ¾″, 1″, 1¼″, 1½″, 2″, 2½″, 3″, 4″, 6″, 8″, 10″, 12″, 14″, 16″, 18″, 20″.
3. Standard Copper Pipe Sizes: ⅜″, ½″, ⅝″, ¾″, ⅞″, 1″, 1⅛″, 1¼″, 1⅜″, 1½″, 1⅝″, 2″, 2⅛″, 2½″, 2⅝″, 3″, 3⅛″, 3⅝″, 4″, 4⅛″, 6″, 8″, 10″, 12″.
4. Ammonia Refrigerant:
   a. Liquid lines should be sized for 2.0 Psi/100 Ft. of equivalent pipe length or less. Liquid lines should be sized for a 3:1, 4:1 or 5:1 overfeed ratio (4:1 recommended).
   b. Suction lines should be sized for 0.25, 0.5 or 1.0°F./100 Ft. of equivalent pipe length.
   c. Discharge lines should be sized for 1.0°F./100 Ft. of equivalent pipe length.
   d. Pump suction pipe sizing should be 3.0 fps maximum. Oversizing of pump suction piping should be limited to one pipe size.
   e. Cooling Water Flow Rate: 0.1 GPM/Ton.

C. Halocarbon Refrigerant Pipe Materials:

1. Pipe: Type "L (ACR)" Copper Tubing, *ASTM B280,* Hard Drawn.
   Fittings: Wrought Copper Solder Joint Fittings, *ANSI/ASME B16.22.*
   Joints: Classification BAg-1 (silver) AWS A5.8 Brazed-Silver Alloy brazing. Brazing shall be conducted using a brazing flux. Do not use an acid flux.

D. Ammonia Refrigerant Pipe Materials:

1. Liquid Lines:
   a. 1½″ and Smaller: Schedule 80 minimum
   b. 2″ to 6″: Schedule 40 minimum
   c. 8″ and Larger: Schedule 30 minimum
2. Suction, Discharge, and Vapor Lines
   a. 1½″ and Smaller: Schedule 80 minimum
   b. 2″ to 6″: Schedule 40 minimum
   c. 8″ and Larger: Schedule 30 minimum
3. Fittings:
   a. Couplings, elbows, tees, and unions for threaded piping systems must constructed of forged steel with a pressure rating of 300 psi.
   b. Welding fitting must match weight of pipe.
   c. Low pressure side piping, vessels, and flanges should be designed for 150 psi.
   d. High pressure side piping, vessels, and flanges should be designed for 250 psi if the system is water or evaporative cooled and 300 psi if the system is air cooled.
4. Joints:
   a. 1¼″ pipe and smaller may be threaded although, welded systems are superior.
   b. 1½″ pipe and larger must be welded.

5. Recommended Low Pressure Side Piping Requirements:
   a. 1¼″ and Smaller:
      Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B or Carbon Steel
      Pipe, *ASTM A106, Schedule 80,* Type S, Grade B.
      Fittings: Forged Steel Threaded Fittings, 3,000 Lb.
      Joints: Pipe Threads, General Purpose (American) *ANSI/ASME B1.20.1*
      OR
      Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B or Carbon Steel
      Pipe, *ASTM A106, Schedule 80,* Type S, Grade B.
      Fittings: Forged Steel Socket Weld, 150 Lb. *ANSI B16.11.*
      Joints: Welded Pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   b. 1½″:
      Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B or Carbon Steel
      Pipe, *ASTM A106, Schedule 80,* Type S, Grade B.
      Fittings: Forged Steel Socket Weld, 150 Lb. *ANSI B16.11.*
      Joints: Welded Pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   c. 2″ and Larger:
      Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B or Carbon Steel
      Pipe, *ASTM A106, Schedule 40,* Type S, Grade B.
      Fittings: Steel Butt-Welding Fittings, 150 Lb., *ANSI/ASME B16.9.*
      Joints: Welded Pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

6. Recommended High Pressure Side Piping Requirements:
   a. 1¼″ and Smaller:
      Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B or Carbon Steel
      Pipe, *ASTM A106, Schedule 80,* Type S, Grade B.
      Fittings: Forged Steel Threaded Fittings, 3,000 Lb.
      Joints: Pipe Threads, General Purpose (American) *ANSI/ASME B1.20.1*
      OR
      Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B or Carbon Steel
      Pipe, *ASTM A106, Schedule 80,* Type S, Grade B.
      Fittings: Forged Steel Socket Weld, 300 Lb. *ANSI B16.11.*
      Joints: Welded Pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   b. 1½″:
      Pipe: Black Steel Pipe, *ASTM A53, Schedule 80,* Type E or S, Grade B or Carbon Steel
      Pipe, *ASTM A106, Schedule 80,* Type S, Grade B.
      Fittings: Forged Steel Socket Weld, 300 Lb. *ANSI B16.11.*
      Joints: Welded Pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*
   c. 2″ and Larger:
      Pipe: Black Steel Pipe, *ASTM A53, Schedule 40,* Type E or S, Grade B or Carbon Steel
      Pipe, *ASTM A106, Schedule 40,* Type S, Grade B.
      Fittings: Steel Butt-Welding Fittings, 300 Lb., *ANSI/ASME B16.9.*
      Joints: Welded Pipe, *ANSI/AWS D1.1* and *ANSI/ASME Sec. 9.*

E. Refrigerant Piping Installation:

1. Slope piping 1 percent in direction of oil return.
2. Install horizontal hot gas discharge piping with ½″ per 10 feet downward slope away from the compressor.
3. Install horizontal suction lines with ½″ per 10 feet downward slope to the compressor, with no long traps or dead ends which may cause oil to separate from the suction gas and return to the compressor in damaging slugs.
4. Liquid lines may be installed level.
5. Provide line size liquid indicators in main liquid line leaving condenser or receiver. Install moisture-liquid indicators in liquid lines between filter dryers and thermostatic expansion valves and in liquid line to receiver.
6. Provide line size strainer upstream of each automatic valve. Provide shutoff valve on each side of strainer.
7. Provide permanent filter dryers in low temperature systems and systems using hermetic compressors.
8. Provide replaceable cartridge filter dryers with three valve bypass assembly for solenoid valves that is adjacent to receivers.
9. Provide refrigerant charging valve connections in liquid line between receiver shutoff valve and expansion valve.
10. Normally only refrigerant suction lines are insulated, but liquid lines should be insulated where condensation will become a problem and hot gas lines should be insulated where personal injury from contact may pose a problem.
11. Refrigerant lines should be installed a minimum of 7′6″ feet above the floor.

F. Refrigerant Properties:

1. Halocarbon refrigerants absorb 40–80 Btuhs/Lb. and ammonia absorbs 500–600 Btuhs/Lb.
2. Ammonia refrigeration systems require smaller piping than halocarbon refrigeration systems for the same pressure drop and capacity.
3. Human or living tissue contact with many refrigerants in their liquid state can cause instant freezing, frostbite, solvent defatting or dehydration, and/or caustic or acid burns.
4. Leak detectors are essential for all halocarbon refrigerants because they are generally heavier than air, are odorless, and can cause suffocation due to oxygen depravation. Ammonia is lighter than air and has a distinctive and unmistakable odor.
5. Ammonia Properties:
   a. Refrigerant Grade Ammonia:
      99.98% Ammonia Minimum.
      0.015% Water Maximum.
      3 ppm Oil Maximum.
      0.2 ml/g Non-Condensable Gases.
   b. Agricultural Grade Ammonia:
      99.5% Ammonia Minimum.
      0.5% Water Maximum.
      0.2% Water Minimum.
      5 ppm Oil Maximum.

c. Ammonia Limitations are shown in the following table:

Concentration of Ammonia in the Air	Limitations/Symptoms
4 ppm	Detectable by human sense of smell.
25 ppm	Maximum ACGIH Permissible Exposure Limit (PEL). Maximum European Government Limit
30 - 35 ppm	Uncomfortable - breathing support desired or required. Common level around ammonia print machines. Maximum recommended exposure 15 minutes (ACGIH).
50 ppm	Maximum OSHA & NIOSH Permissible Exposure Limit (PEL).
100 ppm	Noticeable irritation to the eyes, throat, and mucous membranes.
400 ppm	Mucous membranes may be destroyed with prolonged contact with ammonia. No serious health threat with infrequent and less than 1 hour exposures.
500 ppm	Immediate Danger to Life and Health (IDLH) Limit.
700 ppm	Significant eye irritation.
1,700 ppm	Convulsive coughing occurs. Fatal after short exposures of less than one half hour.
2,500 ppm	Exposure in as short a time as 30 minutes is dangerous. Affects show up several days later - pulmonary edema (water in the lungs).
5,000 ppm and Above	Immediate hazard to life due to suffocation. Full face respiratory protection is required including eyes. Causes respiratory spasm, strangulation, and asphyxia - no exposure permissible.
15,000 ppm and Above	Full body protection required - ammonia reacts with body perspiration to form a caustic solution that attacks the skin causing burns and blisters.
160,000 - 270,000 ppm	Flammable in air at 68°F.
15.5% by Volume	Lower Flammability Limit (LFL) also referred to Lower Explosive Limit (LEL)

6. Refrigerant physical properties are shown in the following table:

REFRIGERANT PHYSICAL PROPERTIES								
REFRIGERANT		ASHRAE STD 15 GROUP NO.	MOLECULAR MASS	BOILING POINT AT 14.7 PSIA °F.	FREEZING POINT °F.	CRITICAL		
NO.	NAME					TEMP. °F.	PRESS. PSIA	VOLUME FT³/LB.
R-11	---	A1	137.38	74.87	-168.0	388.4	639.5	0.0289
R-12	---	A1	120.93	-21.62	-252.0	233.6	596.9	0.0287
R-13	---	A1	104.47	-114.60	-294.0	83.9	561.0	0.0277
R-13B1	---	A1	148.93	-71.95	-270.0	152.6	575.0	0.0215
R-14	---	A1	88.01	-198.30	-299.0	-50.2	543.0	0.0256
R-22	---	A1	86.48	-41.36	-256.0	204.8	721.9	0.0305
R-40	---	B2	50.49	-11.60	-144.0	289.6	968.7	0.0454
R-113	---	A1	187.39	117.63	-31.0	417.4	498.9	0.0278
R-114	---	A1	170.94	38.80	-137.0	294.3	473.0	0.0275
R-115	---	A1	154.48	-38.40	-159.0	175.9	457.6	0.0261
R-123	---	B1	152.93	82.17	-160.9	362.8	532.9	---
R-134a	---	A1	102.03	-15.08	-141.9	214.0	589.8	0.0290
R-142b	---	A2	100.50	14.40	-204.0	278.8	598.0	0.0368
R-152a	---	A2	66.05	-13.00	-178.6	236.3	652.0	0.0439
R-170	ETHANE	A3	30.07	-127.85	-297.0	90.0	709.8	0.0830
R-290	PROPANE	A3	44.10	-43.73	-305.8	206.3	617.4	0.0728
R-C318	---	A1	200.04	21.50	-42.5	239.6	403.6	0.0258
R-500	---	A1	99.31	-28.30	-254.0	221.9	641.9	0.0323
R-502	---	A1	111.63	-49.80	---	179.9	591.0	0.0286
R-503	---	A1	87.50	-127.60	---	67.1	607.0	0.0326
R-600	BUTANE	A3	58.13	31.10	-217.3	305.6	550.7	0.0702
R-600a	ISOBUTANE	A3	58.13	10.89	-255.5	275.0	529.1	0.0725
R-611	---	B2	60.05	89.20	-146.0	417.2	870.0	0.0459
R-717	AMMONIA	B2	17.03	-28.00	-107.9	271.4	1657.0	0.0680
R-744	CARBON DIOXIDE	A1	44.01	-109.20	-69.9	87.9	1070.0	0.0342
R-764	SULFUR DIOXIDE	B1	64.07	14.00	-103.9	315.5	1143.0	0.0306
R-1150	ETHYLENE	A3	28.05	-154.7	-272.0	48.8	742.2	0.0700
R-1270	PROPYLENE	A3	42.09	-53.86	-301.0	197.2	670.3	0.0720

REFRIGERANT TYPE	ENERGY ABSORPTION RATE BTU/LB.				
	40°F.	20°F.	0°F.	-20°F.	-40°F.
R-11	80.863	82.507	84.126	85.732	87.335
R-12	64.649	66.953	69.098	71.116	73.038
R-22	86.503	90.344	93.891	97.193	100.296
R-123	76.787	78.078	79.167	80.162	81.340
R-134a	84.011	87.589	90.925	94.063	97.050
R-502	61.687	65.069	68.101	70.795	73.162
R-717 AMMONIA	535.936	552.858	568.692	583.540	597.482

19.04 Glycol Solution Systems

A. Glycol System Design Considerations:

1. HVAC system glycol applications should use an industrial grade ethylene glycol (phosphate based) or propylene glycol (phosphate based) with corrosion inhibitors without fouling. Specify glycol to have ZERO silicate content.
2. Automobile antifreeze solutions should *NOT* be used for HVAC systems because they contain silicates to protect aluminum engine parts. But these silicates found in automobile antifreeze causes fouling in HVAC systems.
3. Consider having the antifreeze dyed to facilitate leak detection.
4. Glycol systems should be filled with a high quality water, preferably distilled or deionized (deionized recommended) water, or filled with pre-diluted solutions of industrial grade glycol. Water should have less than 25 ppm of chloride and sulfate, and less than 50 ppm of hard water ions (Ca++, Mg++). City water is treated with chlorine, which is corrosive.
5. Automatic makeup water systems should be avoided to prevent system contamination or system dilution. A low level liquid alarm should be used in lieu of an automatic fill line.
6. Systems should be clean with little or no corrosion.
7. Industrial grade glycol will last up to 20 years in a system if properly maintained.
8. Propylene glycol should be used where low oral toxicity is important or where incidental contact with drinking water is possible.
9. Expansion tank sizing is critical to the design of glycol systems. The design should allow for a glycol level of about two-thirds full during operation. Glycol will expand about 6 percent.
10. Water quality should be analyzed at each site for careful evaluation of the level of corrosion protection required.
11. Foaming of a glycol system is usually caused by air entrainment, improper expansion tank design, contamination by organics (oil, gas) or solids, or improper system operation. Foaming will reduce heat transfer and aggravate cavitation corrosion.
12. A buffering agent should be added to maintain fluid alkalinity, minimize acidic corrosive attack, and counteract fluid degradation. Proper buffering agents will reduce fluid maintenance, extend fluid life, and be less sensitive to contamination.

13. A non-absorbent bypass filter, of the sock or cartridge variety, should be installed in each glycol system.
14. An annual chemical analysis should be conducted to determine the glycol content, oxidative degradation, foaming agent concentration, inhibitor concentration, buffer concentration, freezing point, and pH, reserve alkalinity.

ETHYLENE GLYCOL CHARACTERISTICS	PROPYLENE GLYCOL CHARACTERISTICS
MORE EFFECTIVE FREEZE POINT DEPRESSION	LESS EFFECTIVE FREEZE POINT DEPRESSION
BETTER HEAT TRANSFER EFFICIENCY	LOWER HEAT TRANSFER EFFICIENCY
LOWER VISCOSITY	HIGHER VISCOSITY
LOW FLAMMABILITY	LOW FLAMMABILITY
LOW CHEMICAL OXYGEN DEMAND - MORE FRIENDLY TO THE ENVIRONMENT	HIGH CHEMICAL OXYGEN DEMAND - LESS FRIENDLY TO THE ENVIRONMENT
BIODEGRADES IN A REASONABLE PERIOD OF TIME - 10 TO 20 DAYS COMPLETELY	GREATER RESISTANCE TO COMPLETE BIODEGRADATION - MORE THAN 20 DAYS
NON-CARCINOGENIC	NON-CARCINOGENIC
HIGHER LEVEL OF ACUTE (SHORT TERM) AND CHRONIC (LONG TERM) TOXICITY TO HUMANS AND ANIMALS WHEN TAKEN ORALLY - TARGETS THE KIDNEY	LOWER LEVEL OF ACUTE (SHORT TERM) AND CHRONIC (LONG TERM) TOXICITY TO HUMANS AND ANIMALS WHEN TAKEN ORALLY
MILD EYE IRRITANT	MILD EYE IRRITANT
LESS IRRITATING TO THE SKIN	MORE IRRITATING TO THE SKIN
NO ADVERSE REPRODUCTIVE EFFECTS IN LIFETIME OR THREE GENERATION STUDIES	NO ADVERSE REPRODUCTIVE EFFECTS IN LIFETIME OR THREE GENERATION STUDIES
AT HIGH CONCENTRATIONS DURING PREGNANCY, WILL CAUSE BIRTH DEFECTS AND TOXIC TO THE FETUS	AT THE SAME CONCENTRATIONS DURING PREGNANCY, WILL NOT CAUSE BIRTH DEFECTS
RELATIVELY NON-TOXIC TO SEWAGE MICROORGANISMS NEEDED FOR BIODEGRADATION AND TO AQUATIC LIFE	RELATIVELY NON-TOXIC TO SEWAGE MICROORGANISMS NEEDED FOR BIODEGRADATION AND TO AQUATIC LIFE

Ethylene Glycol

% GLYCOL SOLUTION	TEMPERATURE °F.		SPECIFIC HEAT	SPECIFIC GRAVITY (1)	EQUATION FACTOR
	FREEZE POINT	BOILING POINT			
0	+32	212	1.00	1.000	500
10	+26	214	0.97	1.012	491
20	+16	216	0.94	1.027	483
30	+4	220	0.89	1.040	463
40	-12	222	0.83	1.055	438
50	-34	225	0.78	1.067	416
60	-60	232	0.73	1.079	394
70	<-60	244	0.69	1.091	376
80	-49	258	0.64	1.101	352
90	-20	287	0.60	1.109	333
100	+10	287+	0.55	1.116	307

Propylene Glycol

% GLYCOL SOLUTION	TEMPERATURE °F.		SPECIFIC HEAT	SPECIFIC GRAVITY (1)	EQUATION FACTOR
	FREEZE POINT	BOILING POINT			
0	+32	212	1.000	1.000	500
10	+26	212	0.980	1.008	494
20	+19	213	0.960	1.017	488
30	+8	216	0.935	1.026	480
40	-7	219	0.895	1.034	463
50	-28	222	0.850	1.041	442
60	<-60	225	0.805	1.046	421
70	<-60	230	0.750	1.048	393
80	<-60	230+	0.690	1.048	362
90	<-60	230+	0.645	1.045	337
100	<-60	230+	0.570	1.040	296

Note for ethylene and propylene glycol tables

1. Specific gravity with respect to water at 60°F.

19.05 Air Conditioning (AC) Condensate Piping

A. AC Condensate Flow:

1. Range: 0.02–0.08 GPM/Ton
2. Average: 0.04 GPM/Ton
3. Unitary Packaged AC Equipment: 0.006 GPM/Ton
4. Air Handling Units (100% outside Air): 0.100 GPM/1,000 CFM
5. Air Handling Units (50% Outdoor Air): 0.065 GPM/1,000 CFM

6. Air Handling Units (25% Outdoor Air): 0.048 GPM/1,000 CFM
7. Air Handling Units (15% Outdoor Air): 0.041 GPM/1,000 CFM
8. Air Handling Units (0% Outdoor Air): 0.030 GPM/1,000 CFM

B. AC Condensate Pipe Sizing

1. Minimum Pipe Sizes are given in the following table.

AC TONS	MINIMUM DRAIN SIZE
0 -20	1"
21 - 40	1-1/4"
41 - 60	1-1/2"
61 - 100	2"
101 - 250	3"
251 & LARGER	4"

2. Pipe size shall not be smaller than drain pan outlet. Minimum size below grade and below ground floor shall be 2½″ (4″ Allegheny Co., PA). Drain shall have slope of not less than ⅛″ per foot.
3. Some localities require AC condensate to be discharged to storm sewers, some require AC condensate to be discharged to sanitary sewers, and some permit AC condensate to be discharged to either storm or sanitary sewers. Verify pipe sizing and discharge requirements with local authorities and codes.

19.06 Valves

A. Valve Types:

1. Balancing Valves:
   a. Duty: Balancing, Shutoff (Manual or Automatic).
   b. A valve specially designed for system balancing.
2. Ball Valves Full Port:
   a. Duty: Shutoff.
   b. A valve with a spherical shaped internal flow device which rotates open and closed to permit flow or to obstruct flow through the valve. The valve goes from full open to full close in a quarter turn. The opening in the spherical flow device is the same size or close to the same size as the pipe.
3. Ball Valves, Reduced Port:
   a. Duty: Balancing, Shutoff.
   b. A valve with a spherical shaped internal flow device which rotates open and closed to permit flow or to obstruct flow through the valve. The valve goes from full open to full close in a quarter turn. The opening in the spherical flow device is smaller than the pipe size.
4. Butterfly Valves:
   a. Duty: Shutoff, Balancing.

   b. A valve with a disc shaped internal flow device which rotates open and closed to permit flow or to obstruct flow through the valve. The valve goes from full open to full close in a quarter turn.
5. Check Valves:
   a. Duty: Control Flow Direction.
   b. A valve which is opened by the flow of fluid in one direction and which closes automatically to prevent flow in the reverse direction. (Types: Ball, Disc, Globe, Piston, Stop, Swing).
6. Gate Valves:
   a. Duty: Shutoff.
   b. A valve with a wedge or gate shaped internal flow device which moves on an axis perpendicular to the direction of flow.
7. Globe Valves:
   a. Duty: Throttling.
   b. A valve with a disc or plug which moves on an axis perpendicular to the valve seat.
8. Plug Valves:
   a. Duty: Shutoff, Balancing.
   b. A valve with a cylindrical or conical shaped internal flow device which rotates open and closed to permit flow or obstruct flow through the valve. The valve goes from full open to full close in a quarter turn.
9. Control Valves. Control valves are mechanical devices used to control flow of steam, water, gas, and other fluids.
   a. 2-Way. Temperature Control, Modulate Flow to Controlled Device, Variable Flow System.
   b. 3-Way Mixing. Temperature Control, Modulate Flow to Controlled Device, Constant Flow System; 2 inlets and 1 outlet.
   c. 3-Way Diverting. Used to Divert Flow; generally cannot modulate flow—2 position: 1 inlet and 2 outlets.
   d. Quick Opening Control Valves: Quick opening control valves produce wide free port area with relatively small percentage of total valve stem stroke. Maximum flow is approached as the valve begins to open.
   e. Linear Control Valves: Linear control valves produce free port areas that are directly related to valve stem stroke. Opening and flow are related in direct proportion.
   f. Equal Percentage Control Valves: Equal percentage control valves produce an equal percentage increase in the free port area with each equal increment of valve stem stroke. Each equal increment of opening increases flow by an equal percentage over the previous value (most common HVAC control valve).
   g. Control valves are normally smaller than line size unless used in 2-position applications (open/closed).
   h. Control valves should normally be sized to provide 20 to 60% of the total system pressure drop.
      1) Water system control valves should be selected with a pressure drop equal to 2–3 times the pressure drop of the controlled device.

         OR

         Water system control valves should be selected with a pressure drop equal to 10 Ft. or the pressure drop of the controlled device, whichever is greater.

         OR

         Water system control valves for constant flow systems should be sized to provide 25% of the total system pressure drop.

         OR

Water system control valves for variable flow systems should be sized to provide 10% of the total system pressure drop or 50% of the total available system pressure.

2) Steam control valves should be selected with a pressure drop equal to 75% of inlet steam pressure.

10. Specialty Valves:
    Triple Duty Valves: Combination Check, Balancing, and Shutoff.
    Backflow Preventer: Prevent Contamination of Domestic Water System. For HVAC applications use reduced pressure backflow preventers.
11. Valves used for balancing need not be line size. Balancing valves should be selected for midrange of its adjustment.

B. Valve Terms:

1. Actuator. A mechanical, hydraulic, electric, or pneumatic device or mechanism used to operate a valve.
2. Adjustable Travel Stop. A mechanism used to limit the internal flow device travel.
3. Back Face. The side of the flange opposite the gasket.
4. Blind Flange. A flange with a sealed end to provide a pressure tight closure of a flanged opening.
5. Body. The pressure containing shell of a valve or fitting with ends for connection to the piping system.
6. Bonnet. A valve body component which contains an opening for the stem. The bonnet may be bolted (Bolted Bonnet), threaded (Threaded Bonnet), or a union (Union Bonnet).
7. Bronze Mounted. The seating surfaces of the valve are made of brass or bronze.
8. Butt Welding Joints. A joint made to pipes, valves, and fittings with ends adapted for welding by abutting the ends and welding them together.
9. Chainwheel. A manual actuator which uses a chain-driven wheel to turn the valve flow device by turning the stem, handwheel, or gearing.
10. Cock. A form of a plug valve.
11. Cold Working Pressure. Maximum pressure at which a valve or fitting is allowed to operate at ambient temperature.
12. Concentric Reducer. A reducer in which both of the openings are on the same centerline.
13. Eccentric Reducer. A reducer with the small end off center.
14. Elbow, Long Radius. An elbow with a centerline turning radius of 1½ times the nominal size of the elbow.
15. Elbow, Short Radius. An elbow with a centerline turning radius of 1 times the nominal size of the elbow.
16. Face-to-Face Dimension. The dimension from the face of the inlet to the face of the outlet of the valve or fitting.
17. Female End. Internally threaded portion of a pipe, valve, or fitting.
18. Flanged Joint. A joint made with an annular collar designed to permit a bolted connection.
19. Grooved Joint. A joint made with a special mechanical device using a circumferential groove cut into or pressed into the pipes, valves, and fittings to retain a coupling member.
20. Handwheel. The valve handle shaped in the form of a wheel.
21. Inside Screw. The screw mechanism which moves the internal flow device is located within the valve body.
22. Insulating Unions (Dielectric Unions). Used in piping systems to prevent dissimilar metals from coming into direct contact with each other (See Galvanic Action Paragraph).

23. Male End. Externally threaded portion of pipes, valves, or fittings.
24. Memory Stop. A device which allows for the repeatable operation of a valve at a position other than full open or full closed, often used to set or mark a balance position.
25. Nipple. A short piece of pipe with boths ends externally threaded.
26. Nominal Pipe Size (NPS). Standard pipe size but not necessarily the actual dimension.
27. Non-Rising Stem. When the valve is operated, the stem does not rise through the bonnet; the internal flow device rises on the stem.
28. Outside Screw and Yoke (OS&Y). The valve packing is located between the stem threads and the valve body. The valve has a threaded stem which is visible.
29. Packing. A material that seals around the movable penetration of the valve stem.
30. Rising Stem. When the valve is operated, the stem rises through the bonnet and the internal flow device is moved up or down by the moving stem.
31. Safety-Relief Valves. A valve which automatically relieves the system pressure when the internal pressure exceeds a set value. Safety-relief valves may operate on pressure only or on a combination pressure and temperature.
    a. Safety Valve. An automatic pressure relieving device actuated by the static pressure upstream of the valve and characterized by full opening pop action. A safety valve is used primarily for gas or vapor service.
    b. Relief Valve. An automatic pressure relieving device actuated by the static pressure upstream of the valve which opens further with the increase in pressure over the opening pressure. A relief valve is used primarily for liquid service.
    c. Safety Relief Valve. An automatic pressure actuated relieving device suitable for use either as a safety valve or relief valve, depending on application.
    d. Safety, Relief, and Safety Relief Valve testing is dictated by the Insurance Underwriter.
32. Seat. The portion of the valve which the internal flow device presses against to form a tight seal for shutoff.
33. Slow Opening Valve. A valve which requires at least five 360 degree turns of the operating mechanism to change from fully closed to fully open.
34. Socket Welding Joint. A joint made with a socket configuration to fit the ends of the pipes, valves, or fittings and then fillet welded in place.
35. Soldered Joint. A joint made with pipes, valves, or fittings in which the joining is accomplished by soldering or brazing.
36. Stem. A device which operates the internal flow control device.
37. Threaded Joint. A joint made with pipes, valves, or fittings in which the joining is accomplished by threading the components.
38. Union. A fitting which allows the assembly or disassembly of the piping system without rotating the piping.

C. Valve Abbreviations

TE	Threaded End
FE	Flanged End
SE	Solder End
BWE	Butt Weld End
SWE	Socket Weld End
TB	Threaded Bonnet
BB	Bolted Bonnet
UB	Union Bonnet
TC	Threaded Cap
BC	Bolted Cap
UC	Union Cap

IBBM	Iron Body, Bronze Mounted
DI	Ductile Iron
SB	Silver Brazed
DD	Double Disc
SW	Solid Wedge Disc
RWD	Resilient Wedge Disc
FW	Flexible Wedge
HW	Handwheel
NRS	Non-Rising Stem
RS	Rising Stem
OS&Y	Outside Screw & Yoke
ISNRS	Inside Screw NRS
ISRS	Inside Screw RS
FF	Flat Face
RF	Raised Face
HF	Hard Faced
MJ	Mechanical Joint
RJ	Ring Type Joint
F&D	Face and Drilled Flange
CWP	Cold Working Pressure
OWG	Oil, Water, Gas, Pressure
SWP	Steam Working Pressure
WOG	Water, Oil, Gas, Pressure
WWP	Water Working Pressure
FTTG	Fitting
FLG	Flange
DWV	Drainage-Wast-Vent Fitting
NPS	Nominal Pipe Size
IPS	Iron Pipe Size
NPT	National Standard Pipe Thread Taper

19.07 Expansion Loops (See Chapter 5 and Appendix D)

A. L-Bends. Anchor Force = 500 Lbs./Dia. Inch.

B. Z-Bends. Anchor Force = 200–500 Lbs./Dia. Inch.

C. U-Bends. Anchor Force = 200 Lbs./Dia. Inch.

D. Locate anchors at beam locations, and avoid anchor locations at steel bar joists if at all possible.

19.08 Strainers

A. Strainers shall be full line size.

B. Water Systems:

1. Strainer Type:
   a. 2″ and Smaller: “Y” Type
   b. 2½″ to 16″: Basket Type
   c. 18″ and Larger: Multiple Basket Type

2. Strainer Perforation Size:
   a. 4″ and Smaller: 0.057″ Dia. Perforations
   b. 5″ and Larger: 0.125″ Dia. Perforations
   c. Double perforation diameter for condenser water systems.

C. Steam Systems:

1. Strainer Type: "Y" Type
2. Strainer Perforation Size:
   a. 2″ and Smaller: 0.033″ Dia. Perforations
   b. 2½″ and Smaller: 3⁄64″ Dia. Perforations

D. Strainer Pressure Drops, Water Systems: Pressure drops listed below are based on the GPM and pipe sizing of 4.0 Ft./100 Ft. pressure drop or 10 Ft./Sec. velocity:

1. 1½″ and Smaller (Y-Type & Basket Type):
   a. Pressure Drop < 1.0 PSI, 2.31 Ft. H_2O
2. 2″–4″ (Y-Type & Basket Type):
   a. Pressure Drop ≅ 1.0 PSI, 2.31 Ft. H_2O
3. 5″ and Larger:
   a. Y-Type Pressure Drop ≅ 1.5 PSI, 3.46 Ft. H_2O
   b. Basket Type Pressure Drop ≅ 1.0 PSI, 2.31 Ft. H_20

19.09 Expansion Tanks and Air Separators

A. Minimum (Fill) Pressure:

1. Height of System + 5 to 10 psi OR 5–10 psi, whichever is greater.

B. Maximum (System) Pressure:

1. 150 Lb. Systems: 45–125 psi
2. 250 Lb. Systems: 125–225 psi

C. System Volume Estimate:

1. 12 Gal./Ton
2. 35 Gal./BHP

D. Connection Location:

1. Suction Side of Pump(s).
2. Suction side of Primary Pumps when used in Primary/Secondary/Tertiary Systems. An alternate location in Primary/Secondary/Tertiary Systems with a single secondary circuit may be the suction side of the secondary pumps.

E. Expansion Tank Design Considerations:

1. Solubility of Air in Water. The amount of air water can absorb and hold in solution is temperature and pressure dependant. As temperature increases, maximum solubility decreases, and as pressure increases, maximum solubility increases. Therefore, expansion tanks are generally connected to the suction side of the pump (lowest pressure point).
2. Expansion tank sizing. If due to space or structural limitations the expansion tank must be undersized, the minimum expansion tank size should be capable of handling at least ½ of the system expansion volume. With less than this capacity, system start-up

becomes a tedious and extremely sensitive process. If the expansion tank is undersized, an automatic drain should be provided and operated by the control system in addition to the manual drain. Size both the manual and automatic drains to enable a quick dump of a water logged tank (especially critical with undersized tanks) within the limits of the nitrogen fill speed and system pressure requirements.

3. System Volume Changes:
   a. System start-up and shutdown results in the largest change in system volume.
   b. System volume expansion and contraction must be evaluated at full load and partial load. Variations caused by load changes are described below:
      1) In constant flow systems, heating water return temperatures rise and chilled water temperatures drop as load decreases until at no load the return temperature is equal to the supply temperature. Heating systems expand and cooling systems contract at part load.
      2) In variable flow systems, heating water return temperatures drop and chilled water return temperatures rise as load decreases until at no load the return temperature equals the temperature in the secondary medium. Heating systems contract and cooling systems expand at part load.
4. Expansion tanks are used to accept system volume changes, and a gas cushion (usually air or nitrogen) pressure is maintained by releasing the gas from the tank and readmitting the gas into the tank as the system water expands and contracts, respectively. Expansion tanks are used where constant pressurization in the system must be maintained.
5. Cushion tanks are used in conjunction with expansion tanks and are limited in size. As system water expands, pressure increases in the cushion tank until reaching the relief point, at which time it discharges to a lower pressure expansion tank. As the system water contracts, pressure decreases in the cushion tank until reaching a low limit, at which time the pump starts and pumps the water from the low pressure expansion tank to the cushion tank, thus increasing the pressure. Cushion tank relief and makeup flow rates are based on the initial expansion of a heating system or the initial contraction of a cooling system during start-up, because this will be the largest change in system volume for either system.
6. Compression tanks build their own pressure through the thermal expansion of the system contents. Compression tanks are not recommended on medium or high temperature heating water systems.
7. When expansion tank level transmitters are provided for building automation control systems, the expansion tank level should be provided from the level transmitter with local readout at the expansion tank, compression tank, or cushion tank. Also provide a sight glass or some other means of visually verifying level in tank and accuracy of transmitter.
8. When expansion tank pressure transmitters are provided for building automation control systems, the expansion tank pressure should be provided from the pressure transmitter with local readout at the expansion tank, compression tank, or cushion tank. Also provide pressure gauge at tank to verify transmitter.
9. Nitrogen relief from expansion, cushion, or compression tank must be vented to outside (noise when discharging is quite deafening). Vent can be tied into the vent off of the blowdown separator. Also need to provide nitrogen pressure monitoring and alarms and manual nitrogen relief valves.
10. Expansion tank sizing can be simplified using the tables and their respective corrections factors that follow. These tables can be especially helpful for preliminary sizing.
    a. Low-temperature systems. Tables on pages 199–203.
    b. Medium-temperature systems. Tables on pages 204–208.
    c. High-temperature systems. Tables on pages 209–213.

F. Air Separators

1. Air separators shall be full line size.

Expansion Tank Sizing, Low Temperature Systems

TANK SIZED EXPRESSED AS A PERCENTAGE OF SYSTEM VOLUME				
MAXIMUM SYSTEM TEMPERATURE °F.	EXPANSION TANK TYPE			
	CLOSED TANK	OPEN TANK	DIAPHRAGM TANK	
			TANK VOLUME	ACCEPTANCE VOLUME
100	2.21	1.37	1.32	0.59
110	3.08	1.87	1.83	0.82
120	3.71	2.24	2.21	0.99
130	4.81	2.87	2.86	1.28
140	5.67	3.37	3.37	1.51
150	6.77	3.99	4.03	1.80
160	7.87	4.61	4.68	2.10
170	9.20	5.36	5.48	2.45
180	10.53	6.11	6.27	2.81
190	11.87	6.86	7.06	3.16
200	13.20	7.61	7.86	3.52
210	14.77	----	8.79	3.93
220	16.34	----	9.72	4.35
230	17.90	----	10.66	4.77
240	19.71	----	11.73	5.25
250	21.51	----	12.80	5.73

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 10 Psig.
3. Table based on maximum operating pressure: 30 Psig.
4. For initial and maximum pressures different from those listed above, multiply tank size only (not Acceptance Volume) by correction factors contained in the Low Temperature System Correction Factor Tables below.

Closed Expansion Tank Sizing, Low Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	5	10	15	20	25	30	35	40	45	50
5	1.76	1.06	0.83	0.71	0.64	0.59	0.56	0.53	0.51	0.50
10	2.66	1.55	1.18	**1.00**	0.89	0.82	0.76	0.72	0.69	0.67
15	3.73	2.14	1.60	1.34	1.18	1.07	0.99	0.94	0.89	0.86
20	4.99	2.81	2.08	1.72	1.50	1.36	1.25	1.17	1.11	1.06
25	6.43	3.57	2.62	2.15	1.86	1.67	1.53	1.43	1.35	1.29
30	8.05	4.43	3.22	2.62	2.26	2.02	1.84	1.71	1.61	1.53
35	9.85	5.37	3.88	3.14	2.69	2.39	2.18	2.02	1.89	1.80
40	11.83	6.41	4.60	3.70	3.16	2.80	2.54	2.35	2.20	2.07
45	13.99	7.54	5.39	4.31	3.66	3.23	2.93	2.70	2.52	2.37
50	16.34	8.75	6.23	4.96	4.21	3.70	3.34	3.07	2.86	2.69
55	18.86	10.06	7.13	5.66	4.78	4.20	3.78	3.46	3.22	3.02
60	21.57	11.46	8.09	6.41	5.40	4.72	4.24	3.88	3.60	3.37
65	24.46	12.95	9.11	7.20	6.05	5.28	4.73	4.32	4.00	3.75
70	27.53	14.53	10.20	8.03	6.73	5.87	5.25	4.78	4.42	4.13
75	30.77	16.20	11.34	8.91	7.45	6.48	5.79	5.27	4.86	4.54
80	34.21	17.96	12.55	9.84	8.21	7.13	6.36	5.78	5.33	4.96
85	37.82	19.81	13.81	10.81	9.01	7.81	6.95	6.31	5.81	5.41
90	41.61	21.75	15.13	11.83	9.84	8.52	7.57	6.86	6.31	5.87
95	45.59	23.79	16.52	12.89	10.71	9.25	8.22	7.44	6.83	6.35
100	49.74	25.91	17.97	13.99	11.61	10.02	8.89	8.04	7.37	6.84

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 10 Psig.
3. Table based on maximum operating pressure: 30 Psig.

Closed Expansion Tank Sizing, Low Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	55	60	65	70	75	80	85	90	95	100
5	0.48	0.47	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.43
10	0.65	0.63	0.62	0.61	0.59	0.59	0.58	0.57	0.56	0.56
15	0.83	0.80	0.78	0.77	0.75	0.74	0.73	0.72	0.71	0.70
20	1.03	0.99	0.96	0.94	0.92	0.90	0.89	0.87	0.86	0.85
25	1.24	1.19	1.16	1.13	1.10	1.08	1.06	1.04	1.02	1.00
30	1.47	1.41	1.37	1.33	1.29	1.26	1.24	1.21	1.19	1.17
35	1.71	1.65	1.59	1.54	1.50	1.46	1.43	1.40	1.37	1.35
40	1.98	1.89	1.82	1.77	1.71	1.67	1.63	1.59	1.56	1.53
45	2.26	2.16	2.07	2.00	1.94	1.89	1.84	1.80	1.76	1.73
50	2.55	2.44	2.34	2.26	2.18	2.12	2.06	2.01	1.97	1.93
55	2.86	2.73	2.62	2.52	2.44	2.36	2.30	2.24	2.19	2.14
60	3.19	3.04	2.91	2.80	2.70	2.62	2.54	2.48	2.42	2.36
65	3.54	3.36	3.21	3.09	2.98	2.88	2.80	2.72	2.65	2.59
70	3.90	3.70	3.53	3.39	3.27	3.16	3.06	2.98	2.90	2.83
75	4.27	4.05	3.87	3.71	3.57	3.45	3.34	3.24	3.16	3.08
80	4.67	4.42	4.21	4.04	3.88	3.75	3.63	3.52	3.43	3.34
85	5.08	4.81	4.58	4.38	4.21	4.06	3.92	3.81	3.70	3.61
90	5.51	5.21	4.95	4.73	4.54	4.38	4.23	4.10	3.99	3.88
95	5.95	5.62	5.34	5.10	4.89	4.71	4.55	4.41	4.28	4.17
100	6.41	6.05	5.74	5.48	5.26	5.06	4.88	4.73	4.59	4.46

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 10 Psig.
3. Table based on maximum operating pressure: 30 Psig.

Diaphragm Expansion Tank Sizing, Low Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	5	10	15	20	25	30	35	40	45	50
5	2.21	1.33	1.04	0.89	0.80	0.74	0.70	0.67	0.64	0.62
10	2.66	1.55	1.18	**1.00**	0.89	0.82	0.76	0.72	0.69	0.67
15	3.11	1.78	1.33	1.11	0.98	0.89	0.83	0.78	0.74	0.71
20	3.55	2.00	1.48	1.22	1.07	0.96	0.89	0.84	0.79	0.76
25	4.00	2.22	1.63	1.34	1.16	1.04	0.95	0.89	0.84	0.80
30	4.45	2.45	1.78	1.45	1.25	1.11	1.02	0.95	0.89	0.85
35	4.89	2.67	1.93	1.56	1.34	1.19	1.08	1.00	0.94	0.89
40	5.34	2.89	2.08	1.67	1.43	1.26	1.15	1.06	0.99	0.94
45	5.79	3.12	2.23	1.78	1.52	1.34	1.21	1.12	1.04	0.98
50	6.24	3.34	2.38	1.89	1.61	1.41	1.27	1.17	1.09	1.03
55	6.68	3.57	2.53	2.01	1.69	1.49	1.34	1.23	1.14	1.07
60	7.13	3.79	2.68	2.12	1.78	1.56	1.40	1.28	1.19	1.12
65	7.58	4.01	2.82	2.23	1.87	1.64	1.47	1.34	1.24	1.16
70	8.03	4.24	2.97	2.34	1.96	1.71	1.53	1.39	1.29	1.21
75	8.47	4.46	3.12	2.45	2.05	1.79	1.59	1.45	1.34	1.25
80	8.92	4.68	3.27	2.57	2.14	1.86	1.66	1.51	1.39	1.29
85	9.37	4.91	3.42	2.68	2.23	1.93	1.72	1.56	1.44	1.34
90	9.82	5.13	3.57	2.79	2.32	2.01	1.79	1.62	1.49	1.38
95	10.26	5.36	3.72	2.90	2.41	2.08	1.85	1.67	1.54	1.43
100	10.71	5.58	3.87	3.01	2.50	2.16	1.91	1.73	1.59	1.47

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 10 Psig.**
3. **Table based on maximum operating pressure: 30 Psig.**

Diaphragm Expansion Tank Sizing, Low Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	55	60	65	70	75	80	85	90	95	100
5	0.61	0.59	0.58	0.57	0.56	0.56	0.55	0.55	0.54	0.54
10	0.65	0.63	0.62	0.61	0.59	0.59	0.58	0.57	0.56	0.56
15	0.69	0.67	0.65	0.64	0.62	0.61	0.60	0.60	0.59	0.58
20	0.73	0.71	0.69	0.67	0.65	0.64	0.63	0.62	0.61	0.60
25	0.77	0.74	0.72	0.70	0.68	0.67	0.66	0.64	0.63	0.63
30	0.81	0.78	0.76	0.73	0.71	0.70	0.68	0.67	0.66	0.65
35	0.85	0.82	0.79	0.77	0.74	0.73	0.71	0.69	0.68	0.67
40	0.89	0.86	0.82	0.80	0.77	0.75	0.74	0.72	0.71	0.69
45	0.93	0.89	0.86	0.83	0.80	0.78	0.76	0.74	0.73	0.71
50	0.97	0.93	0.89	0.86	0.83	0.81	0.79	0.77	0.75	0.74
55	1.01	0.97	0.93	0.89	0.86	0.84	0.81	0.79	0.78	0.76
60	1.06	1.00	0.96	0.92	0.89	0.87	0.84	0.82	0.80	0.78
65	1.10	1.04	1.00	0.96	0.92	0.89	0.87	0.84	0.82	0.80
70	1.14	1.08	1.03	0.99	0.95	0.92	0.89	0.87	0.85	0.83
75	1.18	1.12	1.06	1.02	0.98	0.95	0.92	0.89	0.87	0.85
80	1.22	1.15	1.10	1.05	1.01	0.98	0.95	0.92	0.89	0.87
85	1.26	1.19	1.13	1.08	1.04	1.01	0.97	0.94	0.92	0.89
90	1.30	1.23	1.17	1.12	1.07	1.03	1.00	0.97	0.94	0.92
95	1.34	1.27	1.20	1.15	1.10	1.06	1.02	0.99	0.96	0.94
100	1.38	1.30	1.24	1.18	1.13	1.09	1.05	1.02	0.99	0.96

Notes:
1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 10 Psig.
3. Table based on maximum operating pressure: 30 Psig.

Expansion Tank Sizing, Medium Temperature Systems

TANK SIZED EXPRESSED AS A PERCENTAGE OF SYSTEM VOLUME				
MAXIMUM SYSTEM TEMPERATURE °F.	EXPANSION TANK TYPE			
	CLOSED TANK	OPEN TANK	DIAPHRAGM TANK	
			TANK VOLUME	ACCEPTANCE VOLUME
250	263.25	----	18.02	5.73
260	285.30	----	19.53	6.21
270	310.23	----	21.24	6.75
280	335.16	----	22.95	7.29
290	360.08	----	24.65	7.83
300	387.88	----	26.56	8.44
310	415.67	----	28.46	9.04
320	443.47	----	30.36	9.65
330	474.13	----	32.46	10.32
340	504.80	----	34.56	10.98
350	538.33	----	36.86	11.71

Notes:
1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 200 Psig.
3. Table based on maximum operating pressure: 300 Psig.
4. For initial and maximum pressures different from those listed above, multiply tank size only (not Acceptance Volume) by correction factors contained in the Medium Temperature System Correction Factor Tables below.

Closed Expansion Tank Sizing, Medium Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	10	20	30	40	50	60	70	80	90	100
30	0.36	0.21	0.16	0.14	0.13	0.12	0.11	0.10	0.10	0.10
40	0.52	0.30	0.23	0.19	0.17	0.15	0.14	0.14	0.13	0.13
50	072	0.41	0.30	0.25	0.22	0.20	0.18	0.17	0.16	0.16
60	0.94	0.52	0.39	0.32	0.28	0.25	0.23	0.21	0.20	0.19
70	1.19	0.66	0.48	0.39	0.34	0.30	0.28	0.26	0.24	0.23
80	1.47	0.80	0.58	0.47	0.41	0.36	0.33	0.31	0.29	0.27
90	1.78	0.97	0.70	0.56	0.48	0.43	0.39	0.36	0.34	0.32
100	2.12	1.14	0.82	0.66	0.56	0.49	0.45	0.41	0.39	0.36
110	2.49	1.34	0.95	0.76	0.64	0.57	0.51	0.47	0.44	0.41
120	2.88	1.54	1.09	0.87	0.74	0.65	0.58	0.54	0.50	0.47
130	3.31	1.76	1.25	0.99	0.83	0.73	0.66	0.60	0.56	0.52
140	3.77	2.00	1.41	1.11	0.94	0.82	0.73	0.67	0.62	0.58
150	4.26	2.25	1.58	1.25	1.05	0.91	0.82	0.75	0.69	0.65
160	4.78	2.52	1.76	1.39	1.16	1.01	0.90	0.82	0.76	0.71
170	5.32	2.80	1.96	1.54	1.28	1.11	0.99	0.90	0.83	0.78
180	5.90	3.09	2.16	1.69	1.41	1.22	1.09	0.99	0.91	0.85
190	6.50	3.40	2.37	1.85	1.54	1.34	1.19	1.08	0.99	.92
200	7.14	3.73	2.59	2.02	1.68	1.45	1.29	1.17	1.08	**1.00**
210	7.81	4.07	2.82	2.20	1.83	1.58	1.40	1.27	1.16	1.08
220	8.50	4.42	3.06	2.39	1.98	1.71	1.51	1.37	1.25	1.16
230	9.22	4.79	3.32	2.58	2.13	1.84	1.63	1.47	1.35	1.25
240	9.98	5.18	3.58	2.78	2.30	1.98	1.75	1.58	1.44	1.34
250	10.76	5.58	3.85	2.98	2.47	2.12	1.87	1.69	1.54	1.43
260	11.57	5.99	4.13	3.20	2.64	2.27	2.00	1.80	1.65	1.52

Notes:
1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 200 Psig.
3. Table based on maximum operating pressure: 300 Psig.

Closed Expansion Tank Sizing, Medium Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	110	120	130	140	150	160	170	180	190	200
30	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08
40	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.10	0.10
50	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13
60	0.19	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.15
70	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18
80	0.26	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.21
90	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.24
100	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.28	0.27	0.27
110	0.39	0.38	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30
120	0.44	0.42	0.41	0.39	0.38	0.37	0.36	0.35	0.34	0.33
130	0.50	0.47	0.45	0.44	0.42	0.41	0.40	0.39	0.38	0.37
140	0.55	0.52	0.50	0.48	0.47	0.45	0.44	0.43	0.42	0.41
150	0.61	0.58	0.55	0.53	0.51	0.49	0.48	0.47	0.46	0.44
160	0.67	0.63	0.61	0.58	0.56	0.54	0.52	0.51	0.50	0.48
170	0.73	0.69	0.66	0.63	0.61	0.59	0.57	0.55	0.54	0.53
180	0.80	0.76	0.72	0.69	0.66	0.64	0.62	0.60	0.58	0.57
190	0.87	0.82	0.78	0.75	0.72	0.69	0.67	0.65	0.63	0.61
200	0.94	0.89	0.84	0.81	0.77	0.74	0.72	0.70	0.68	0.66
210	1.01	0.96	0.91	0.87	0.83	0.80	0.77	0.75	0.73	0.71
220	1.09	1.03	0.97	0.93	0.89	0.86	0.83	0.80	0.78	0.75
230	1.17	1.10	1.04	1.00	0.95	0.92	0.88	0.85	0.83	0.81
240	1.25	1.18	1.12	1.06	1.02	0.98	0.94	0.91	0.88	0.86
250	1.33	1.26	1.19	1.13	1.08	1.04	1.00	0.97	0.94	0.91
260	1.42	1.34	1.27	1.20	1.15	1.10	1.06	1.03	0.99	0.96

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 200 Psig.
3. Table based on maximum operating pressure: 300 Psig.

Diaphragm Expansion Tank Sizing, Medium Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	10	20	30	40	50	60	70	80	90	100
30	1.74	1.03	0.79	0.67	0.60	0.55	0.52	0.50	0.48	0.46
40	2.06	1.19	0.90	0.75	0.67	0.61	0.57	0.54	0.51	0.49
50	2.37	1.35	1.00	0.83	0.73	0.66	0.61	0.57	0.55	0.52
60	2.69	1.50	1.11	0.91	0.79	0.71	0.66	0.61	0.58	0.56
70	3.01	1.66	1.21	0.99	0.86	0.77	0.70	0.65	0.62	0.59
80	3.33	1.82	1.32	1.07	0.92	0.82	0.75	0.69	0.65	0.62
90	3.64	1.98	1.43	1.15	0.98	0.87	0.79	0.73	0.69	0.65
100	3.96	2.14	1.53	1.23	1.05	0.93	0.84	0.77	0.72	0.68
110	4.28	2.30	1.64	1.31	1.11	0.98	0.88	0.81	0.76	0.71
120	4.60	2.46	1.74	1.39	1.17	1.03	0.93	0.85	0.79	0.75
130	4.92	2.62	1.85	1.47	1.24	1.08	0.97	0.89	0.83	0.78
140	5.23	2.78	1.96	1.55	1.30	1.14	1.02	0.93	0.86	0.81
150	5.55	2.93	2.06	1.63	1.36	1.19	1.07	0.97	0.90	0.84
160	5.87	3.09	2.17	1.71	1.43	1.24	1.11	1.01	0.93	0.87
170	6.19	3.25	2.27	1.79	1.49	1.30	1.16	1.05	0.97	0.90
180	6.50	3.41	2.38	1.86	1.56	1.35	1.20	1.09	1.01	0.94
190	6.82	3.57	2.49	1.94	1.62	1.40	1.25	1.13	1.04	0.97
200	7.14	3.73	2.59	2.02	1.68	1.45	1.29	1.17	1.08	**1.00**
210	7.46	3.89	2.70	2.10	1.75	1.51	1.34	1.21	1.11	1.03
220	7.78	4.05	2.80	2.18	1.81	1.56	1.38	1.25	1.15	1.06
230	8.09	4.21	2.91	2.26	1.87	1.61	1.43	1.29	1.18	1.10
240	8.41	4.36	3.02	2.34	1.94	1.67	1.47	1.33	1.22	1.13
250	8.73	4.52	3.12	2.42	2.00	1.72	1.52	1.37	1.25	1.16
260	9.05	4.68	3.23	2.50	2.06	1.77	1.56	1.41	1.29	1.19

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 200 Psig.**
3. **Table based on maximum operating pressure: 300 Psig.**

Diaphragm Expansion Tank Sizing, Medium Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	110	120	130	140	150	160	170	180	190	200
30	0.45	0.44	0.43	0.42	0.41	0.41	0.40	0.40	0.39	0.39
40	0.48	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.40
50	0.50	0.49	0.48	0.46	0.45	0.45	0.44	0.43	0.43	0.42
60	0.53	0.52	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.44
70	0.56	0.54	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45
80	0.59	0.57	0.55	0.53	0.52	0.51	0.49	0.48	0.48	0.47
90	0.62	0.60	0.57	0.56	0.54	0.53	0.51	0.50	0.49	0.48
100	0.65	0.62	0.60	0.58	0.56	0.55	0.53	0.52	0.51	0.50
110	0.68	0.65	0.62	0.60	0.58	0.57	0.55	0.54	0.53	0.52
120	0.71	0.67	0.65	0.62	0.60	0.59	0.57	0.56	0.54	0.53
130	0.74	0.70	0.67	0.65	0.62	0.61	0.59	0.57	0.56	0.55
140	0.76	0.73	0.70	0.67	0.65	0.63	0.61	0.59	0.58	0.56
150	0.79	0.75	0.72	0.69	0.67	0.64	0.63	0.61	0.59	0.58
160	0.82	0.78	0.74	0.71	0.69	0.66	0.64	0.63	0.61	0.60
170	0.85	0.81	0.77	0.74	0.71	0.68	0.66	0.64	0.63	0.61
180	0.88	0.83	0.79	0.76	0.73	0.70	0.68	0.66	0.64	0.63
190	0.91	0.86	0.82	0.78	0.75	0.72	0.70	0.68	0.66	0.64
200	0.94	0.89	0.84	0.81	0.77	0.74	0.72	0.70	0.68	0.66
210	0.97	0.91	0.87	0.83	0.79	0.76	0.74	0.71	0.69	0.67
220	1.00	0.94	0.89	0.85	0.81	0.78	0.76	0.73	0.71	0.69
230	1.02	0.97	0.92	0.87	0.84	0.80	0.78	0.75	0.73	0.71
240	1.05	0.99	0.94	0.90	0.86	0.82	0.79	0.77	0.74	0.72
250	1.08	1.02	0.96	0.92	0.88	0.84	0.81	0.79	0.76	0.74
260	1.11	1.05	0.99	0.94	0.90	0.86	0.83	0.80	0.78	0.75

Notes:

1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 200 Psig.**
3. **Table based on maximum operating pressure: 300 Psig.**

Expansion Tank Sizing, High Temperature Systems

TANK SIZED EXPRESSED AS A PERCENTAGE OF SYSTEM VOLUME				
MAXIMUM SYSTEM TEMPERATURE °F.	EXPANSION TANK TYPE			
	CLOSED TANK	OPEN TANK	DIAPHRAGM TANK	
			TANK VOLUME	ACCEPTANCE VOLUME
350	1,995.03	----	47.71	11.71
360	2,119.30	----	50.68	12.44
370	2,243.58	----	53.65	13.17
380	2,378.48	----	56.88	13.96
390	2,524.02	----	60.36	14.82
400	2,669.56	----	63.84	15.67
410	2,815.10	----	67.32	16.53
420	2,981.90	----	71.31	17.51
430	3,138.07	----	75.04	18.42
440	3,315.51	----	79.29	19.46
450	3,492.95	----	83.53	20.51

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 600 Psig.
3. Table based on maximum operating pressure: 800 Psig.
4. For initial and maximum pressures different from those listed above, multiply tank size only (not Acceptance Volume) by correction factors contained in the High Temperature System Correction Factor Tables below.

Closed Expansion Tank Sizing, High Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	20	40	60	80	100	120	140	160	180	200
160	0.68	0.37	0.27	0.22	0.19	0.17	0.16	0.15	0.14	0.13
180	0.83	0.46	0.33	0.27	0.23	0.20	0.19	0.17	0.16	0.15
200	1.01	0.55	0.39	0.32	0.27	0.24	0.22	0.20	0.19	0.18
220	1.19	0.64	0.46	0.37	0.31	0.28	0.25	0.23	0.22	0.20
240	1.40	0.75	0.53	0.43	0.36	0.32	0.29	0.26	0.25	0.23
260	1.62	0.86	0.61	0.49	0.41	0.36	0.32	0.30	0.28	0.26
280	1.85	0.98	0.70	0.55	0.46	0.41	0.37	0.33	0.31	0.29
300	2.10	1.11	0.78	0.62	0.52	0..46	0.41	0.37	0.35	0.32
320	2.37	1.25	0.88	0.69	0.58	0.51	0.45	0.41	0.38	0..36
340	2.65	1.40	0.98	0.77	0.64	0.56	0.50	0.46	0.42	0.39
360	2.95	1.55	1.08	0.85	0.71	0.62	0.55	0.50	0.46	0.43
380	3.27	1.71	1.19	0.94	0.78	0.68	0.60	0.55	0.50	0.47
400	3.60	1.88	1.31	1.02	0.85	0.74	0.66	0.59	0.55	0.51
420	3.95	2.06	1.43	1.12	0.93	0.80	0.71	0.65	0.59	0.55
440	4.31	2.25	1.56	1.21	1.01	0.87	0.77	0.70	0.64	0.59
460	4.69	2.44	1.69	1.31	1.09	0.94	0.83	0.75	0.69	0.64
480	5.08	2.64	1.83	1.42	1.17	1.01	0.90	0.81	0.74	0.69
500	5.50	2.85	1.97	1.53	1.26	1.09	0.96	0.87	0.79	0.73
520	5.92	3.07	2.12	1.64	1.36	1.17	1.03	0.93	0.85	0.78
540	6.37	3.29	2.27	1.76	1.45	1.25	1.10	0.99	0.90	0.84
560	6.82	3.53	2.43	1.88	1.55	1.33	1.17	1.05	0.96	0.89
580	7.30	3.77	2.59	2.00	1.65	1.41	1.25	1.12	1.02	0.94
600	7.79	4.02	2.76	2.13	1.75	1.50	1.32	1.19	1.08	**1.00**
620	8.30	4.28	2.93	2.26	1.86	1.59	1.40	1.26	1.15	1.06
640	8.82	4.54	3.11	2.40	1.97	1.69	1.48	1.33	1.21	1.12
660	9.36	4.81	3.30	2.54	2.09	1.78	1.57	1.41	1.28	1.18
680	9.91	5.10	3.49	2.69	2.20	1.88	1.65	1.48	1.35	1.24
700	10.49	5.39	3.69	2.84	2.33	1.99	1.74	1.56	1.42	1.31

Notes:
1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 600 Psig.
3. Table based on maximum operating pressure: 800 Psig.

Closed Expansion Tank Sizing, High Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	220	240	260	280	300	320	340	360	380	400
160	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10
180	0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12
200	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13
220	0.19	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.15
240	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17
260	0.25	0.24	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.19
280	0.28	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20
300	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22
320	0.34	0.32	0.31	0.29	0.28	0.27	0.27	0.26	0.25	0.25
340	0.37	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.27
360	0.40	0.38	0.37	0.35	0.34	0.32	0.31	0.31	0.30	0.29
380	0.44	0.42	0.40	0.38	0.37	0.35	0.34	0.33	0.32	0.31
400	0.48	0.45	0.43	0.41	0.39	0.38	0.37	0.36	0.35	0.34
420	0.52	0.49	0.46	0.44	0.43	0.41	0.40	0.38	0.37	0.36
440	0.56	0.53	0.50	0.48	0.46	0.44	0.42	0.41	0.40	0.39
460	0.60	0.56	0.54	0.51	0.49	0.47	0.45	0.44	0.43	0.41
480	0.64	0.60	0.57	0.55	0.52	0.50	0.49	0.47	0.45	0.44
500	0.69	0.65	0.61	0.58	0.56	0.54	0.52	0.50	0.48	0.47
520	0.73	0.69	0.65	0.62	0.59	0.57	0.55	0.53	0.51	0.50
540	0.78	0.73	0.69	0.66	0.63	0.61	0.58	0.56	0.54	0.53
560	0.83	0.78	0.74	0.70	0.67	0.64	0.62	0.60	0.58	0.56
580	0.88	0.83	0.78	0.74	0.71	0.68	0.65	0.63	0.61	0.59
600	0.93	0.87	0.83	0.78	0.75	0.72	0.69	0.66	0.64	0.62
620	0.98	0.92	0.87	0.83	0.79	0.76	0.73	0.70	0.68	0.66
640	1.04	0.97	0.92	0.87	0.83	0.80	0.76	0.74	0.71	0.69
660	1.10	1.03	0.97	0.92	0.88	0.84	0.80	0.77	0.75	0.72
680	1.15	1.08	1.02	0.97	0.92	0.88	0.84	0.81	0.78	0.76
700	1.21	1.14	1.07	1.01	0.87	0.92	0.89	0.85	0.82	0.80

Notes:

1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 600 Psig.
3. Table based on maximum operating pressure: 800 Psig.

Diaphragm Expansion Tank Sizing, High Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	20	40	60	80	100	120	140	160	180	200
160	2.39	1.32	0.96	0.78	0.67	0.60	0.55	0.51	0.48	0.46
180	2.64	1.44	1.04	0.84	0.72	0.64	0.59	0.54	0.51	0.48
200	2.88	1.56	1.12	0.90	0.77	0.68	0.62	0.57	0.54	0.51
220	3.13	1.69	1.21	0.97	0.82	0.73	0.66	0.61	0.57	0.53
240	3.37	1.81	1.29	1.03	0.87	0.77	0.69	0.64	0.59	0.56
260	3.62	1.93	1.37	1.09	0.92	0.81	0.73	0.67	0.62	0.58
280	3.86	2.05	1.45	1.15	0.97	0.85	0.76	0.70	0.65	0.61
300	4.11	2.18	1.53	1.21	1.02	0.89	0.80	0.73	0.67	0.63
320	4.35	2.30	1.61	1.27	1.07	0.93	0.83	0.76	0.70	0.66
340	4.60	2.42	1.70	1.33	1.12	0.97	0.87	0.79	0.73	0.68
360	4.84	2.55	1.78	1.40	1.17	1.01	0.90	0.82	0.76	0.71
380	5.09	2.67	1.86	1.46	1.21	1.05	0.94	0.85	0.78	0.73
400	5.34	2.79	1.94	1.52	1.26	1.09	0.97	0.88	0.81	0.75
420	5.58	2.91	2.02	1.58	1.31	1.13	1.01	0.91	0.84	0.78
440	5.83	3.04	2.11	1.64	1.36	1.18	1.04	0.94	0.87	0.80
460	6.07	3.16	2.19	1.70	1.41	1.22	1.08	0.97	0.89	0.83
480	6.32	3.28	2.27	1.76	1.46	1.26	1.11	1.00	0.92	0.85
500	6.56	3.40	2.35	1.82	1.51	1.30	1.15	1.04	0.95	0.88
520	6.81	3.53	2.43	1.89	1.56	1.34	1.18	1.07	0.97	0.90
540	7.05	3.65	2.52	1.95	1.61	1.38	1.22	1.10	1.00	0.93
560	7.30	3.77	2.60	2.01	1.66	1.42	1.25	1.13	1.03	0.95
580	7.55	3.90	2.68	2.07	1.71	1.46	1.29	1.16	1.06	0.98
600	7.79	4.02	2.76	2.13	1.75	1.50	1.32	1.19	1.08	**1.00**
620	8.04	4.14	2.84	2.19	1.80	1.54	1.36	1.22	1.11	1.02
640	8.28	4.26	2.92	2.25	1.85	1.58	1.39	1.25	1.14	1.05
660	8.53	4.39	3.01	2.32	1.90	1.63	1.43	1.28	1.17	1.07
680	8.77	4.51	3.09	2.38	1.95	1.67	1.46	1.31	1.19	1.10
700	9.02	4.63	3.17	2.44	2.00	1.71	1.50	1.34	1.22	1.12

Notes:
1. **Table based on initial temperature: 50°F.**
2. **Table based on initial pressure: 600 Psig.**
3. **Table based on maximum operating pressure: 800 Psig.**

Diaphragm Expansion Tank Sizing, High Temperature System Correction Factors

INITIAL PRESSURE PSIG	PRESSURE INCREASE - PSIG INITIAL PRESSURE + PRESSURE INCREASE = MAXIMUM OPERATING PRESSURE									
	220	240	260	280	300	320	340	360	380	400
160	0.44	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.36	0.35
180	0.46	0.44	0.43	0.42	0.40	0.39	0.39	0.38	0.37	0.36
200	0.49	0.47	0.45	0.43	0.42	0.41	0.40	0.39	0.38	0.38
220	0.51	0.49	0.47	0.45	0.44	0.43	0.41	0.41	0.40	0.39
240	0.53	0.51	0.49	0.47	0.45	0.44	0.43	0.42	0.41	0.40
260	0.55	0.53	0.50	0.49	0.47	0.46	0.44	0.43	0.42	0.41
280	0.57	0.55	0.52	0.50	0.49	0.47	0.46	0.45	0.44	0.43
300	0.60	0.57	0.54	0.52	0.50	0.49	0.47	0.46	0.45	0.44
320	0.62	0.59	0.56	0.54	0.52	0.50	0.49	0.47	0.46	0.45
340	0.64	0.61	0.58	0.56	0.54	0.52	0.50	0.49	0.47	0.46
360	0.66	0.63	0.60	0.57	0.55	0.53	0.52	0.50	0.49	0.48
380	0.69	0.65	0.62	0.59	0.57	0.55	0.53	0.51	0.50	0.49
400	0.71	0.67	0.64	0.61	0.58	0.56	0.54	0.53	0.51	0.50
420	0.73	0.69	0.66	0.63	0.60	0.58	0.56	0.54	0.53	0.51
440	0.75	0.71	0.67	0.64	0.62	0.59	0.57	0.56	0.54	0.52
460	0.78	0.73	0.69	0.66	0.63	0.61	0.59	0.57	0.55	0.54
480	0.80	0.75	0.71	0.68	0.65	0.63	0.60	0.58	0.57	0.55
500	0.82	0.77	0.73	0.70	0.67	0.64	0.62	0.60	0.58	0.56
520	0.84	0.79	0.75	0.71	0.68	0.66	0.63	0.61	0.59	0.57
540	0.86	0.81	0.77	0.73	0.70	0.67	0.65	0.62	0.60	0.59
560	0.89	0.83	0.79	0.75	0.72	0.69	0.66	0.64	0.62	0.60
580	0.91	0.85	0.81	0.77	0.73	0.70	0.67	0.65	0.63	0.61
600	0.93	0.87	0.73	0.78	0.75	0.72	0.69	0.66	0.64	0.62
620	0.95	0.89	0.84	0.80	0.76	0.73	0.70	0.68	0.66	0.64
640	0.98	0.92	0.86	0.82	0.78	0.75	0.72	0.69	0.67	0.65
660	1.00	0.94	0.88	0.84	0.80	0.76	0.73	0.71	0.68	0.66
680	1.02	0.96	0.90	0.85	0.81	0.78	0.75	0.72	0.69	0.67
700	1.04	0.98	0.92	0.87	0.83	0.79	0.76	0.73	0.71	0.68

Notes:
1. Table based on initial temperature: 50°F.
2. Table based on initial pressure: 600 Psig.
3. Table based on maximum operating pressure: 800 Psig.

19.10 Galvanic Action

A. Galvanic action results from the electrochemical variation in the potential of metallic ions. If two metals of different potentials are placed in an electrolytic medium (i.e., water), the one with the higher potential will act as an anode and will corrode. The metal with the lower potential, being the cathode, will be unchanged. The greater the separation of the two metals on the chart below, the greater the speed and severity of the corrosion. The list below is in order of their anodic-cathodic characteristics (i.e., metals listed below will corrode those listed above, for example, copper will corrode steel).

Magnesium Alloys
Alclad 3S
Aluminum Alloys
Low-Carbon Steel
Cast Iron
Stainless Steel, Type 410
Stainless Steel, Type 430
Stainless Steel, Type 404
Stainless Steel, Type 304
Stainless Steel, Type 316
Hastelloy A
Lead-Tin Alloys
Brass
Copper
Bronze
90/10 Copper-Nickel
70/30 Copper-Nickel
Inconel
Silver
Stainless Steel (passive)
Monel
Hastelloy C
Titanium

19.11 Piping System Installation Hierarchy (Easiest to Hardest to Install)

A. Natural Gas, Medical Gases, and Laboratory Gases, Easiest to Install.

B. Chilled Water, Heating Water, Domestic Cold and Hot Water Systems, and other Closed HVAC and Plumbing Systems.

C. Steam and Steam Condensate.

D. Refrigeration Piping Systems.

E. Sanitary Systems, Storm Water Systems, AC Condensate Systems, Hardest to Install.

19.12 *ASME B31 Piping Code* Comparison

ASME B31 Piping Code Comparison

ITEM	POWER PIPING ASME B31.1 - 1998	PROCESS PIPING ASME B31.3 - 1996	BUILDING SERVICES PIPING ASME B31.9 - 1996
Application	Power & Auxiliary Piping for Electric Generating Stations, Industrial and Institutional Plants, Central & District Heating/Cooling Plants, and Geothermal Heating Systems.	Petroleum Refineries, Chemical, Pharmaceutical, Textile, Paper, Semiconductor, and Cryogenic Plants.	Industrial, Institutional, Commercial, and Public Buildings and Multi-Unit Residences.
Services	Systems include, but are not limited to, Steam, Water, Oil, Gas, and Air.	Systems include, but are not limited to, raw, intermediate, and finished chemicals, petroleum products, gas, steam air water, fluidized solids, refrigerants, and cryogenic fluids.	Systems include, but are not limited to, water for heating and cooling, condensing water, steam or other condensate, other nontoxic liquids, steam, vacuum, other nontoxic, nonflammable gases, and combustible liquids including fuel oil.
General Limitations	This Code does not apply to building services piping within the property limits or buildings of industrial and institutional facilities which is in the scope of ASME B31.9 except that piping beyond the limitations of material, size, temperature, pressure, and service specified in ASME B31.9 shall conform to the requirements of ASME B31.1. This Code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code (BPVC) Section I.	This code excludes piping systems for internal gauge pressures above zero but less than 15 psig provided the fluid is nonflammable, nontoxic, and not damaging to human tissue and its temperature is from -20 °F through 366 °F This Code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code Section I and boiler external piping which is required to conform to ASME B31.1.	This Code prescribes requirements for the design, materials, fabrication, installation, inspection, examination, and testing of piping systems for building services. It includes piping systems in the building or within the property limits. This Code excludes power boilers in accordance with the ASME Boiler and Pressure Vessel Code Section I and boiler external piping which is required to conform to ASME B31.1.

ASME B31 Piping Code Comparison

ITEM	POWER PIPING ASME B31.1 - 1998	PROCESS PIPING ASME B31.3 - 1996	BUILDING SERVICES PIPING ASME B31.9 - 1996
Pipe Size Limitations	No Limit	No Limit	Carbon Steel - 30" OD Nominal Pipe Size and 0.5" Wall (30" XS Steel Pipe) Copper - 12" Nominal Pipe Size Stainless Steel - 12" OD Nominal Pipe Size and 0.5" Wall
Pressure Limitations	No Limit	No Limit	Steam & Condensate - 150 Psig Liquids - 350 Psig Vacuum - 1 Atmosphere External Pressure Compressed Air & Gas - 150 Psig
Temperature Limitations	No Limit	No Limit	Steam & Condensate - 366 °F. Maximum (150 Psig) Other Gases & Vapors - 200 °F Maximum Non-Flammable Liquids - 250 °F Maximum Minimum Temperature All Services - 0 °F
Bypass Requirements	All bypasses must be in accordance with MSS-SP-45. Pipe weight shall be minimum Schedule 80.	Bypasses not addressed - recommend following B31.1	Bypasses not addressed - recommend following B31.1

ASME B31 Piping Code **Comparison**

ITEM	POWER PIPING ASME B31.1 - 1998	PROCESS PIPING ASME B31.3 - 1996	BUILDING SERVICES PIPING ASME B31.9 - 1996
Class I Boiler Systems - ASME BPVC Section I	Boiler External Piping is governed by ASME B31.1 All other piping may be governed by this Code within the limitations of the Code.	Boiler External Piping is governed by ASME B31.1 All other piping may be governed by this Code within the limitations of the Code.	Boiler External Piping is governed by ASME B31.1 All other piping may be governed by this Code within the limitations of the Code.
Class IV Boiler Systems - ASME BPVC Section IV	All piping, including boiler external piping, may be governed by this Code within the limitations of the Code.	All piping, including boiler external piping, may be governed by this Code within the limitations of the Code.	All piping, including boiler external piping, may be governed by this Code within the limitations of the Code.

Class I Boiler Systems

1. Class I Steam Boiler Systems are constructed for Working Pressures above 15 Psig.
2. Class I Hot Water Boiler Systems are constructed for Working Pressures above 160 Psig and/or Working Temperatures above 250 °F.

Class IV Boiler Systems

1. Class IV Steam Boiler Systems are constructed with a maximum Working Pressure of 15 Psig.
2. Class IV Hot Water Boiler Systems are constructed with a maximum Working Pressure of 160 Psig and a maximum Working Temperature of 250 °F.

Class I Boiler External Piping

1. Steam Boiler Piping - ASME Code piping is required from the boiler through the 1st stop check valve to the 2nd Stop Valve.
2. Steam Boiler Feedwater Piping - ASME Code piping is required from the boiler through the 1st stop valve to the check valve for single boiler feedwater installations and from the boiler through the 1st stop valve and through the check valve to the 2nd stop valve at the feedwater control valve for multiple boiler installations.
3. Steam Boiler Bottom Blowdown Piping - ASME Code Piping is required from the boiler through the 1st stop valve to the 2nd stop valve.
4. Steam Boiler Surface Blowdown Piping - ASME Code Piping is required from the boiler to the 1st stop valve.
5. Steam & Hot Water Boiler Drain Piping - ASME Code Piping is required from the boiler through the 1st stop valve to the 2nd stop valve.
6. Hot Water Boiler Supply and Return Piping - ASME Code piping is required from the boiler through the 1st stop check valve to the 2nd Stop Valve on both the supply and return piping.

Class IV Boiler External Piping

1. All Class IV Boiler External Piping is governed by the respective piping system code.

ASME B31 Piping Code Comparison

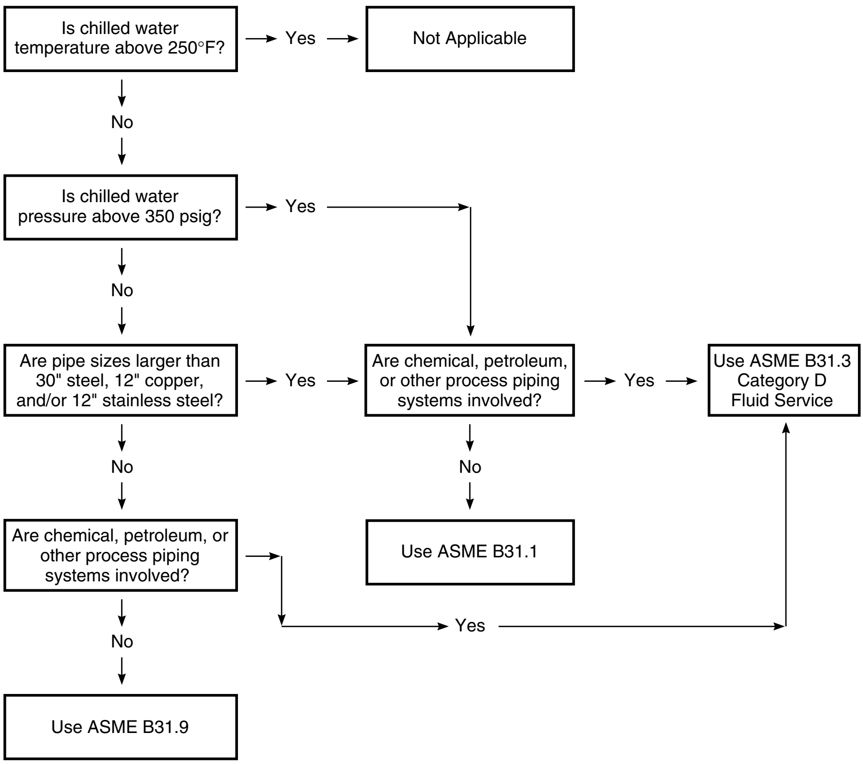
ITEM	POWER PIPING ASME B31.1 - 1998	PROCESS PIPING ASME B31.3 - 1996	BUILDING SERVICES PIPING ASME B31.9 - 1996
Piping Classifications	No Classifications required by this Code. The Code deals with and governs all piping under its jurisdiction the same.		No Classifications required by ths Code. The Code deals with and governs all piping under its jurisdiction the same.
Low Temp Chilled Water (0 - 40 °F)		D	
Chilled Water (40 - 60 °F)		D	
Condenser Water (60 - 110 °F)		D	
Low Temp Heating Water (110 - 250 °F)		N	
High Temp Heating Water (250 - 450 °F)		N - Except Boiler Ext. Piping B31.1 applicable	
Low Press. Steam (15 Psig and Less)		N	
High Press. Steam (Above 15 Psig)		N - Except Boiler Ext. Piping B31.1 applicable	
Hydrostatic Pressure Testing	Test Medium - Water, unless subject to freezing	Test Medium - Water, unless subject to freezing	Test Medium - Water, unless subject to freezing
	Boiler External Piping - ASME BPVC Section I	N/A	N/A
	Nonboiler External Piping - 1.5 times the design pressure but not to exceed max. allowable system pressure for a minimum of 10 minutes.	Category D or N Fluid Service - 1.5 times the design pressure but not to exceed max. allowable system pressure for a minimum of 10 minutes.	Nonboiler External Piping - 1.5 times the design pressure but not to exceed max. allowable system pressure for a minimum of 10 minutes.
	All Other Services - 1.5 times the design pressure but not to exceed max. allowable system pressure fo a minimum of 10 minutes.		All Other Services - 1.5 times the design pressure but not to exceed max. allowable system pressure fo a minimum of 10 minutes.

ASME B31 Piping Code Comparison

ITEM	POWER PIPING ASME B31.1 - 1998	PROCESS PIPING ASME B31.3 - 1996	BUILDING SERVICES PIPING ASME B31.9 - 1996
Examination, Inspection, and Testing Requirements	The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the Owner. Class I Steam & Hot Water Systems - Nondestructive testing and visual examinations are required by this Code. Percentage and types of tests performed must be agreed upon. Class IV Steam & Hot Water Systems - Visual examination only. All other Services - Visual examination only. If more rigorous examination or testing is required, it must be mutually agreed upon.	The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the Owner. Category D Fluid Service - Visual Examination Category N Fluid Service - Visual Examination, 5% Random Examination of components, fabrication, welds, and installation. Random radiographic or ultrasonic testing of 5% of circumferential butt welds. If more rigorous examination or testing is required, it must be mutually agreed upon.	The degree of examination, inspection, and testing, and the acceptance standards must be mutually agreed upon by the manufacturer, fabricator, erector, or contractor and the Owner. All Services - Visual Examinations. If more rigorous examination or testing is required, it must be mutually agreed upon.
Nondestructive Testing	Radiographic Ultrasonic Eddy Current Liquid Penetrant Magnetic Particle Hardness Tests	Radiographic Ultrasonic Eddy Current Liquid Penetrant Magnetic Particle Hardness Tests	Radiographic Ultrasonic Eddy Current Liquid Penetrant Magnetic Particle Hardness Tests

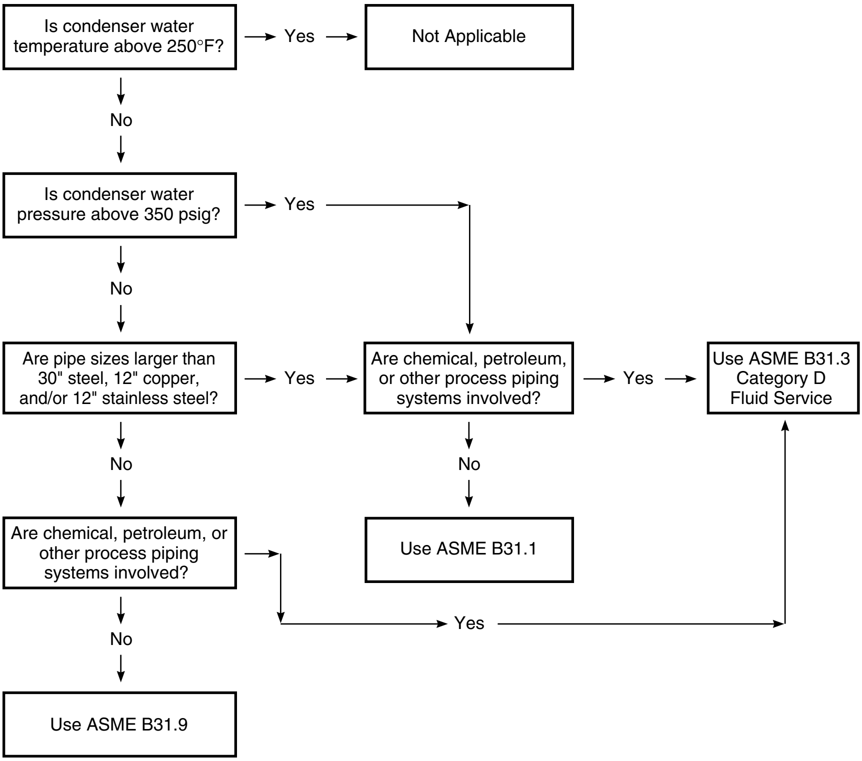
ASME B31 Chilled Water System Decision Diagram

Chilled Water Systems (0–60°F.)



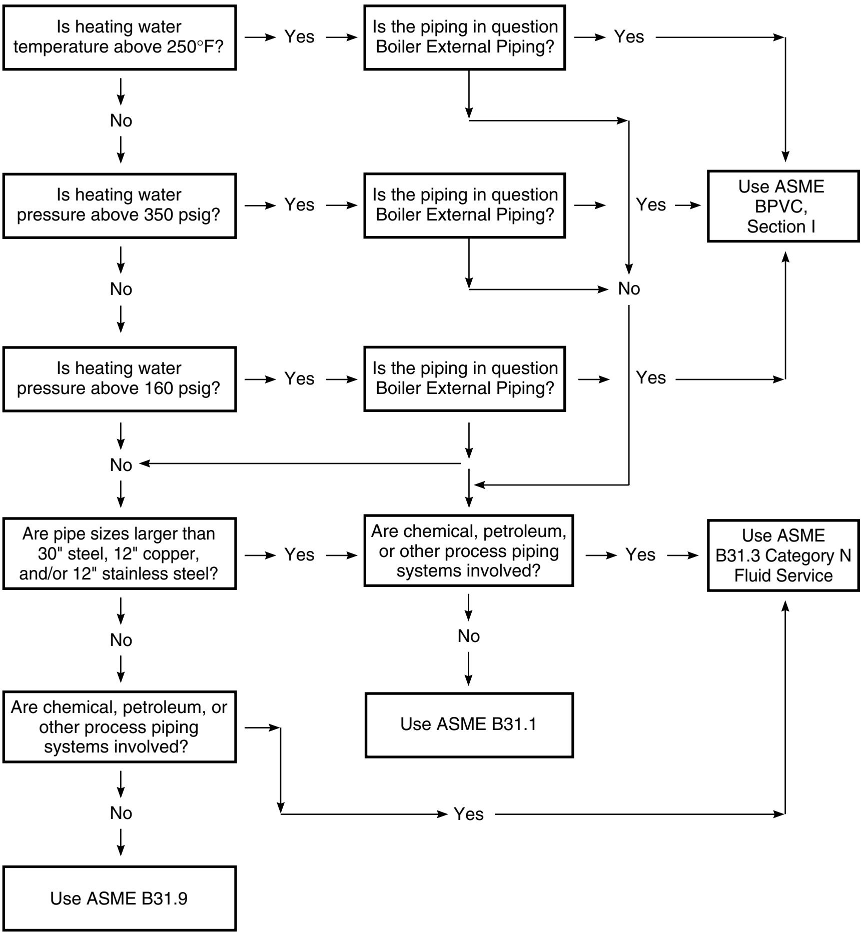
ASME B31 Condenser Water System Decision Diagram

Condenser Water Systems (60–110°F.)



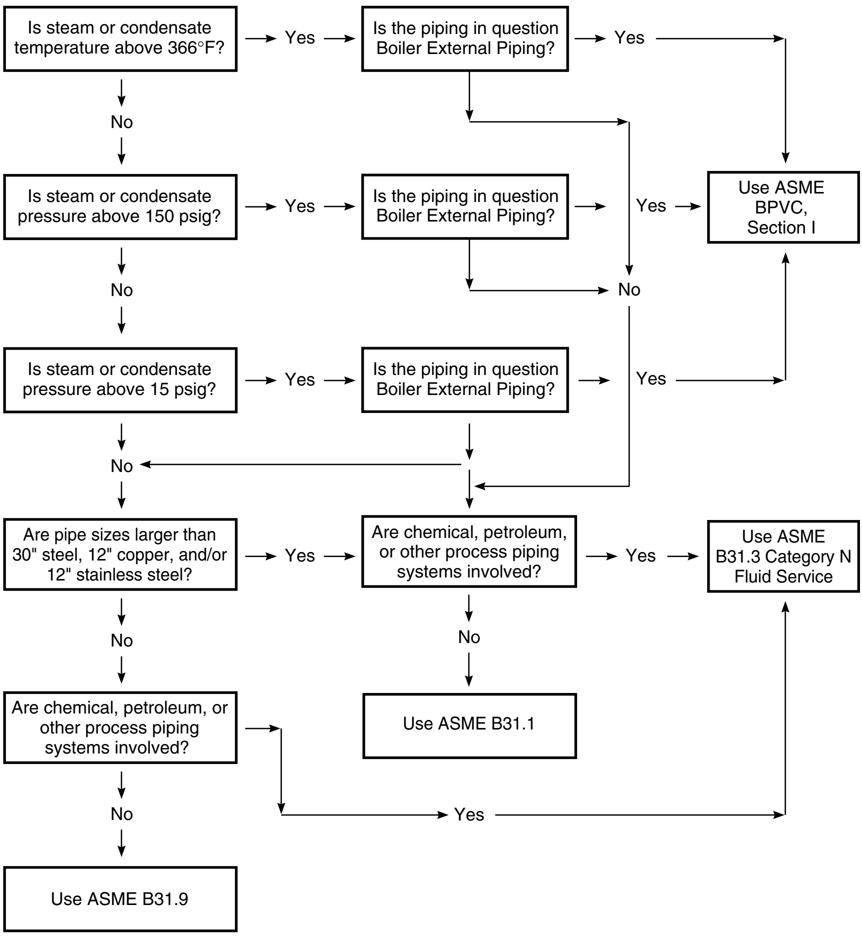
ASME B31 Heating Water System Decision Diagram

Heating Water Systems (110–450°F.)



ASME B31 Steam & Condensate System Decision Diagram

Steam & Steam Condensate Systems (0–300 PSIG)



PART 20

Central Plant Equipment

20.01 Air Handling Units, Air Conditioning Units, Heat Pumps

A. Definitions:

1. Air Handling Units (AHU): AHUs contain fans, filters, coils, and other items but do not contain refrigeration compressors.
2. Air Conditioning Units (ACU): ACUs are AHUs that contain refrigeration compressors.
3. Heat Pumps: Heat pumps are ACUs with refrigeration systems capable of providing heat to the space as well as cooling.

B. Air Handling Unit Types:

1. Packaged AHUs:
   a. 800–50,000 CFM.
   b. 0–9″ SP.
   c. ¼–100 Hp.
2. Factory Fabricated AHUs:
   a. 1,000–125,000 CFM.
   b. 0–13″ SP.
   c. ¼–500 Hp.
   d. Shipping limiting factor, 2 to 3 times more expensive than packaged AHUs.
3. Field Fabricated AHUs:
   a. 10,000–804,000 CFM.
   b. 0–14″ SP.
   c. 2–2500 Hp.
   d. Fan size limiting factor.

C. Packaged Equipment, All Spaces:

1. 300–500 CFM/Ton @ 20°F. ΔT.
2. 400 CFM/Ton ± 20% @ 20°F. ΔT.

D. Water Source Heat Pumps:

1. Water Heat Rejection:
   a. 2.0–3.0 GPM/Ton @ 15–10°F. ΔT.
   b. 3.0 GPM/Ton @ 10°F. ΔT recommended.
2. 85–95°F. Condenser Water Temperature.
3. 60–90°F. Heat Pump Water Loop Temperatures:
   a. Winter design: 60°F.
   b. Summer design: 90°F.
4. Cooling Tower, Evap. Cooler Sizing:
   a. 1.4 × Block Cooling Load.
5. Supplemental Heater Sizing:
   a. 0.75 × Block Heating Load.

E. Geothermal Source Heat Pumps:

1. Efficiencies:
   a. Average: 3.5–4.7 COP; 12–16 EER
   b. High: 5.3–5.9 COP; 18–20 EER
2. Vertical wells used for heat transfer are the most common system type in lieu of horizontal heat transfer sites.
3. Length of heat exchanger pipe required:
   a. Range: 130 Ft/Ton–175 Ft./Ton
   b. Average: 150 Ft./Ton

4. 20°F.–110°F. Heat Pump Water Loop Temperatures.
5. If system is sized to meet cooling requirements, supplemental heat will not be required.
6. If system is sized to meet heating requirements, supplemental cooling tower will be required.
7. Pipe spacing:
   a. Commercial: 15′ × 15′ Center to Center Grid
   b. Residential: 10′ × 10′ Center to Center Grid

F. Air Handling Unit Fans:

1. ½°F. temperature rise for each 1″ S.P. from fan heat.
2. See Section on fans for more information.
3. Return air system with more than ½″ pressure drop should have return air fan. A return air fan is also required if you intend to use an economizer and still maintain the space under a neutral or a negative pressure.

G. Economizers:

1. Water side economizers take advantage of low condenser water temperature to either precool entering air, assist in mechanical cooling, or to provide total system cooling.
2. Air side economizers take advantage of cool outdoor air to either assist in mechanical cooling or to provide total system cooling.
   a. Dry Bulb.
   b. Enthalpy.

H. System Types:

1. VAV Systems:
   a. Fans selected for 100% Block Airflow.
   b. Normal Operation 60–80% Block Airflow.
   c. Minimum Airflow 30–40% Block Airflow.
2. Constant Volume Reheat Systems:
   a. Fans selected and operated at 100% Sum of Peak Airflow.
3. Dual Duct Systems:
   a. Cold Deck designed for 100% of Sum of Peak Airflow.
   b. Hot Deck designed for 75–90% of Sum of Peak Airflow.
   c. Fans selected and operated at 100% of Sum of Peak Airflow.
4. Dual Duct VAV Systems:
   a. Cold Deck designed for 100% of Block Airflow.
   b. Hot Deck designed for 75–90% of Block Airflow.
   c. Fans selected for 100% Block Airflow.
   d. Normal Operation 60–80% Block Airflow.
   e. Minimum Airflow 30–40% Block Airflow.
5. Single Zone and Multizone Systems:
   a. Cold Deck designed for 100% of Sum of Peak Airflow.
   b. Hot Deck designed for 75–90% of Sum of Peak Airflow.
   c. Fans selected and operated at 100% of Sum of Peak Airflow.

I. Clearance Requirements:

1. Minimum recommended clearance around air handling units and similar equipment is 24 inches on non-service side and 36 inches on service side. Maintain minimum clearance for coil pull as recommended by the equipment manufacturer; this is generally equal to the width of the air handling unit. Maintain minimum clearance as required to open access and control doors on air handling units for service, maintenance, and inspection.

2. Mechanical room locations and placement must take into account how large air handling units and similar equipment can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

20.02 Coils

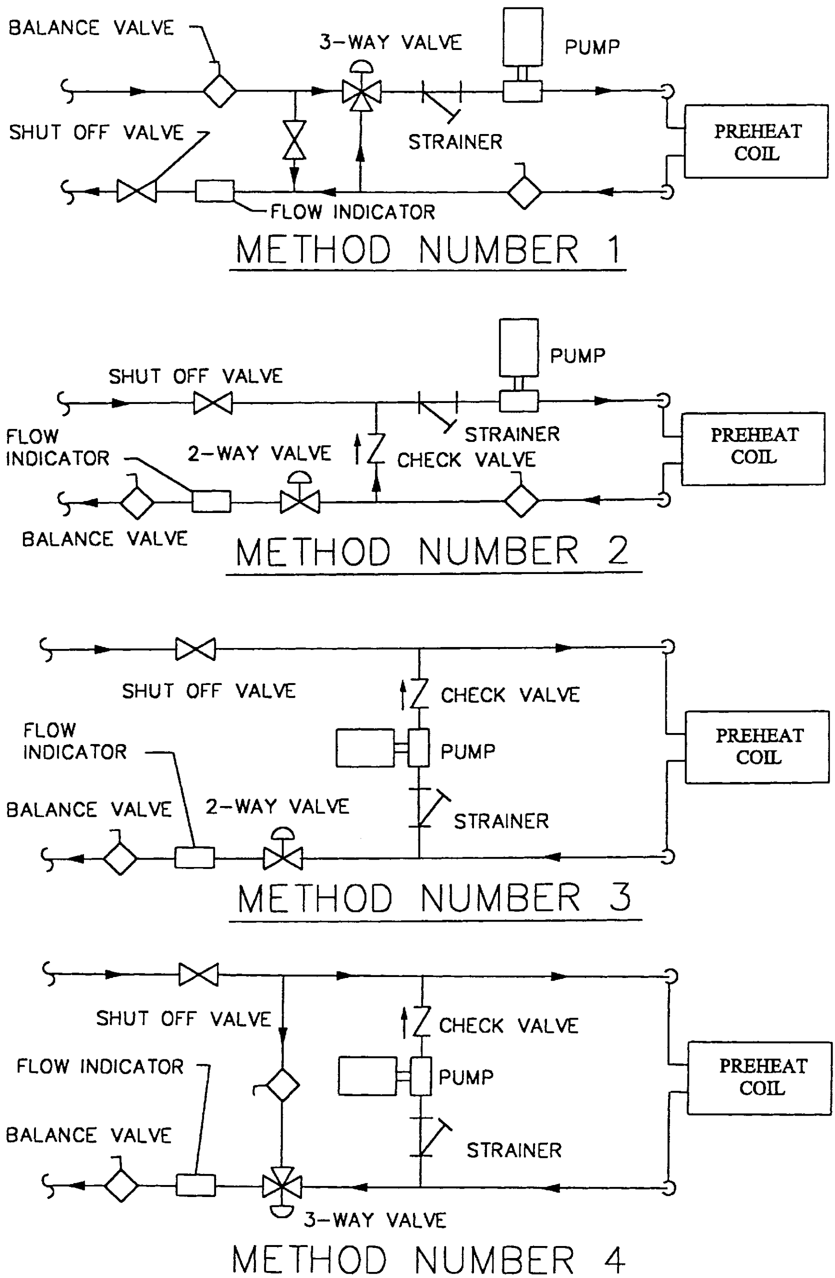
A. General:

1. Field erected and factory assembled air handling unit coils should be arranged for removal from upstream side without dismantling supports. Provide galvanized structural steel supports for all coils (except the lowest coil) in banks over two coils high to permit independent removal of any coil.
2. When air handling units are used to supply makeup air (100% OA) for smoke control/smoke management systems, water coil freeze up must be considered. Some possible solutions are listed below:
   a. Provide preheat coil in AHU to heat the air from outside design temperature to 45–50°F.
   b. Provide control of system to open all water coil control valves serving smoke control/smoke management systems to full open and circulate water through the coils.
   c. Elect not to provide freeze protection with Owner concurrence in the event a fire or other emergency occurs on a cold day. Also many emergency situations are fairly short in duration. A follow-up letter should also be written.
3. Select water coils with tube velocities high enough at design flow so that tube velocities do not end up in the laminar flow region when the flow is reduced in response low load conditions. Tube velocities become critical with units designed for 100 percent outside air at low loads near 32°F. Higher tube velocity selection results in a higher water pressure drop for the water coil. Sometimes a trade-off between pressure drop and low load flows must be evaluated.
4. It is best to use water coils with same end connections to reduce flow imbalances caused by differences in velocity head.
5. In horizontal water coil headers, supply water flow should be downward and return water flow should be upward for proper air venting.
6. Water Coil Flow Patterns:
   a. Multiple Path, Parallel Flow, Grid Type Coil.
   b. Series Flow, Serpentine Coil.
   c. Series and Parallel Flow.

B. Water and Steam Coils:

1. Preheat:
   a. Concurrent Air/Water or Steam Flow.
   b. Freeze Protection:
      1) Face and Bypass Dampers.
      2) IFB Coils.
      3) Preheat Pumps (Primary/Secondary System).
2. Cooling, Heating, Reheat:
   a. Counter Air/Water or Steam Flow.
3. Cooling Coil Face Velocity:
   a. 450–550 FPM Range.
   b. 500 FPM Recommended.
   c. 450 FPM Preferred.
4. Preheat, Heating and Reheat Coil Face Velocity:
   a. 500–900 FPM Range.

b. 600–700 FPM Recommended.
c. 600 FPM Preferred.
d. Use preheat coil whenever mixed air temperature (outside air and return air) is below 40°F.



PREHEAT COIL PIPING DIAGRAMS

C. Refrigerant Coils:

1. Cooling:
   a. Counter Air/Water Flow.
2. Cooling Coil Face Velocity:
   a. 450–550 FPM Range.
   b. 500 FPM Recommended.
   c. 450 FPM Preferred.

D. Weight and Volume of Water in Standard Water Coils:

1. Weight of Water in the Tubes:

$W_{WT} = 0.966$ Lbs./Row Sq.Ft. × No. of Rows × Face Area of Coil

2. Total Weight of Water in Coil:

$W_{WC} = W_{WT} + W_{WH}$

3. Total Weight of Water Coils:

$W_T = W_C + W_{WC}$

4. Volume of Water in Coil:

$V = W_{WC} \times 0.12$

W_{WT} = Water Weight in the Tubes (Pounds)
W_{WH} = Water Weight in the Headers/U-bends, from Table (Pounds)
W_{WC} = Water Weight in the Coil (Pounds)
W_C = Dry Coil Weight (Pounds)
W_T = Total Weight of the Coil (Pounds)
V = Volume of the Coil (Gallons)

Weight of Water in Coil Heaters and U-Bends

FINNED WIDTH	NUMBER OF ROWS						
	1	2	3	4	5	6	8
6"	0.75	1.75	---	---	---	---	---
9"	1.00	2.75	---	---	---	---	---
12"	1.50	3.26	3.84	4.04	4.75	4.94	7.61
18"	2.75	3.94	4.82	5.07	6.21	8.70	13.10
24"	3.85	5.28	6.50	6.86	8.37	11.61	17.60
30"	4.72	8.66	10.12	10.50	12.48	16.52	24.00
33"	5.21	9.50	11.09	11.58	13.54	17.99	26.10
36"	---	16.34	19.58	22.82	26.06	29.30	32.55
42"	---	18.95	22.73	26.51	30.29	34.07	37.85
48"	---	21.55	25.88	30.20	34.52	38.84	43.16

E. Coil Pressure Drop

1. Air Pressure Drop (Water, Steam, Refrigerant Coils) is given in the following table:

NUMBER OF ROWS	FACE VELOCITY (Fpm)						
	450	500	550	600	700	800	900
1	0.05-0.15	0.05-0.18	0.08-0.20	0.08-0.25	0.12-0.30	0.15-0.40	0.17-0.50
2	0.10-0.35	0.11-0.50	0.15-0.50	0.16-0.60	0.20-0.80	0.25-0.90	0.32-0.90
4	0.20-0.70	0.22-0.90	0.28-1.00	0.33-1.20	0.40-1.50	0.50-1.80	0.65-1.70
6	0.30-1.10	0.35-1.30	0.45-1.50	0.50-1.70	0.65-2.30	0.75-2.80	1.00-2.70
8	0.40-1.50	0.45-1.75	0.60-2.00	0.60-2.40	0.85-3.00	1.00-3.70	1.30-3.70
10	0.50-1.75	0.60-2.25	0.70-2.50	0.80-3.00	1.10-3.80	1.30-4.50	1.70-4.50

Notes for Air Pressure Drop Table:

1. **Lower pressure drop is for 70 Fins/Ft.**
2. **Higher pressure drop is for 170 Fins/Ft.**
3. **Pressure drops in in. W.G.**

2. Water Pressure Drop is given in the following table:

FINNED WIDTH	FINNED LENGTH											
	12	24	36	48	60	72	84	96	108	120	132	144
12	0.11 8.77	0.13 10.1	0.14 11.6	0.15 13.1	0.16 14.6	0.17 16.2	0.18 17.7	0.19 19.2	0.20 20.7	0.21 22.2	0.22 23.7	0.23 25.2
18	0.07 6.31	0.09 7.65	0.10 9.16	0.11 10.7	0.12 12.2	0.13 13.7	0.14 15.2	0.15 16.7	0.16 18.2	0.17 19.7	0.18 21.2	0.19 22.3
24	0.09 8.21	0.11 9.55	0.12 11.1	0.13 12.6	0.14 14.1	0.15 15.6	0.16 17.1	0.17 18.6	0.18 20.1	0.19 21.7	0.20 23.2	0.21 24.7
30	0.12 10.3	0.14 11.6	0.15 13.2	0.16 14.7	0.17 16.2	0.18 17.7	0.19 19.2	0.20 20.7	0.21 22.2	0.22 23.7	0.23 25.3	0.24 26.8
33	0.15 11.4	0.17 12.7	0.18 14.2	0.19 15.7	0.20 17.2	0.21 18.7	0.22 20.2	0.23 21.8	0.24 23.3	0.25 24.8	0.26 26.3	0.27 27.8
36	0.17 13.2	0.19 14.5	0.20 16.1	0.21 17.5	0.22 19.0	0.23 20.5	0.24 22.1	0.25 23.6	0.26 25.1	0.27 26.6	0.28 28.1	0.29 29.6
42	0.20 14.7	0.22 16.1	0.23 17.5	0.24 19.1	0.25 20.6	0.26 22.1	0.27 23.6	0.28 25.1	0.29 26.6	0.30 28.1	0.31 29.6	0.32 31.1
48	0.22 16.4	0.24 17.8	0.25 19.3	0.26 20.8	0.27 22.3	0.28 23.8	0.29 25.3	0.30 26.8	0.31 28.3	0.32 29.8	0.33 31.3	0.34 32.9

Notes for Water Pressure Drop Table:

1. **Pressure drops in FT H_2O/Row.**
2. **Top row is based on water velocity of 1.0 FPS.**
3. **Bottom row is based on water velocity of 8.0 FPS.**
4. **Water Velocity (FPS) = (GPM × 1.66)/Finned Width.**
5. **Based on W type coil.**

F. Electric Coils:

1. Open Coils: Use when personnel contact is not a concern. It is the most common type of electric coil used in HVAC applications.
   a. Air Pressure Drops:
      1) 400 FPM–900 FPM 0.01–0.10″ WG

b. Minimum Velocity:
   1) 400 FPM 6 KW/Sq.Ft. of Duct
   2) 500 FPM 8 KW/Sq.Ft. of Duct
   3) 600 FPM 10 KW/Sq.Ft. of Duct
   4) 700 FPM 12 KW/Sq.Ft. of Duct
   5) 800 FPM 14 KW/Sq.Ft. of Duct
   6) 900 FPM 16 KW/Sq.Ft. of Duct
   7) Manufacturer's literature should be consulted.

2. Finned Tubular Coils: Use when personnel contact is a concern.
   a. Air Pressure Drops:
      1) 400 FPM–900 FPM 0.02–0.20″ WG
   b. Minimum Velocity:
      1) 400 FPM 6 KW/Sq.Ft. of Duct
      2) 500 FPM 9 KW/Sq.Ft. of Duct
      3) 600 FPM 12 KW/Sq.Ft. of Duct
      4) 700 FPM 15 KW/Sq.Ft. of Duct
      5) 800 FPM 17 KW/Sq.Ft. of Duct
      6) 900 FPM 20 KW/Sq.Ft. of Duct
      7) Manufacturer's literature should be consulted.

20.03 Filters

A. Flat or Panel Filters:

1. Efficiency: 20–35%
2. Face Velocity: 500 FPM
3. Initial Pressure Drop: 0.25″ WG
4. Final Pressure Drop: 0.50″ WG
5. Nominal Sizes
   a. 1″ Thick: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 16 × 25; 16 × 20
   b. 2″ Thick: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24
6. Test Method: *ASHRAE 52-76, Atmospheric*

B. Pleated Media Filters

1. Efficiency:
   a. 25–35%
   b. 60–65%
   c. 80–85%
   d. 90–95%
2. Face Velocity: 500 FPM
3. Initial Pressure Drop
   a. 25–35%: 0.25–0.45″ WG
   b. 60–65%: 0.50″ WG
   c. 80–85%: 0.60″ WG
   d. 90–95%: 0.70″ WG
4. Final Pressure Drop
   a. 25–35%: 1.20″ WG
   b. 60–65%: 1.20″ WG

c. 80–85%: 1.20″ WG
d. 90–95%: 1.20″ WG

5. Nominal Sizes
   a. Thicknesses
      1) 25–35%: 1; 2; 4;
      2) 60–65%: 4; 6; 12;
      3) 80–85%: 4; 6; 12;
      4) 90–95%: 4; 6; 12;
   b. Face Sizes
      1) 25–35%: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24
      2) 60–65%: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24
      3) 80–85%: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24
      4) 90–95%: 24 × 24; 20 × 25; 20 × 24; 20 × 20; 18 × 24; 16 × 25; 16 × 20; 12 × 24
6. Test Method: *ASHRAE 52-76, Atmospheric*

C. Bag Filters:

1. Efficiency:
   a. 40–45%
   b. 50–55%
   c. 60–65%
   d. 80–85%
   e. 90–95%
2. Face Velocity: 500 FPM
3. Initial Pressure Drop:
   a. 40–45%: 0.25″ WG
   b. 50–55%: 0.35″ WG
   c. 60–65%: 0.40″ WG
   d. 80–85%: 0.50″ WG
   e. 90–95%: 0.60″ WG
4. Final Pressure Drop
   a. 40–45%: 1.00″ WG
   b. 50–55%: 1.00″ WG
   c. 60–65%: 1.00″ WG
   d. 80–85%: 1.00″ WG
   e. 90–95%: 1.00″ WG
5. Nominal Sizes
   a. Thicknesses
      1) 40–45%: 12; 15
      2) 50–55%: 21; 22; 30; 37
      3) 60–65%: 21; 22; 30; 37
      4) 80–85%: 21; 22; 30; 37
      5) 90–95%: 21; 22; 30; 37
   b. Face Sizes
      1) 40–45%: 24 × 24; 24 × 20; 20 × 25; 20 × 24; 20 × 20; 16 × 25; 16 × 20; 12 × 24
      2) 50–55%: 24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24
      3) 60–65%: 24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24
      4) 80–85%: 24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24
      5) 90–95%: 24 × 24; 24 × 20; 20 × 24; 20 × 20; 12 × 24
6. Test Method: *ASHRAE 52-76, Atmospheric*

D. HEPA (High Efficiency Particulate Air) Filters:

1. Efficiency: 99.97% for 0.3 micron particles and larger
2. Face Velocity: 250 FPM Maximum
3. Initial Pressure Drop:
   a. 95%: 0.50″ WG
   b. 99.97–99.995%: 1.00″ WG
4. Final Pressure Drop:
   a. 95%: 2.00″ WG
   b. 99.97–99.995%: 3.00″ WG
5. Nominal Sizes
   a. Thicknesses: 3; 5; 6; 12
   b. Face Sizes: 8 × 8; 12 × 12; 12 × 24; 16 × 20; 20 × 20; 24 × 12; 24 × 24; 24 × 30; 24 × 36; 24 × 48; 24 × 60; 24 × 72; 30 × 24; 30 × 30; 30 × 36; 30 × 48; 30 × 60; 30 × 72; 36 × 24; 36 × 30; 36 × 36; 36 × 48; 36 × 60; 36 × 72
6. Test Method: D.O.P. or Polystyrene Latex (PSL) Spheres (PSL preferred)

E. ULPA (Ultra Low Penetrating Air) Filters:

1. Efficiency: 99.9997% for 0.12 micron particles and larger
2. Face Velocity: 250 Fpm Maximum
3. Initial Pressure Drop
   a. 99.997–99.9999%: 1.00″ WG
4. Final Pressure Drop
   a. 99.997–99.9999%: 3.00″ WG
5. Nominal Sizes
   a. Thicknesses: 3; 5; 6; 12
   b. Face Sizes: 8 × 8; 12 × 12; 12 × 24; 16 × 20; 20 × 20; 24 × 12; 24 × 24; 24 × 30; 24 × 36; 24 × 48; 24 × 60; 24 × 72; 30 × 24; 30 × 30; 30 × 36; 30 × 48; 30 × 60; 30 × 72; 36 × 24; 36 × 30; 36 × 36; 36 × 48; 36 × 60; 36 × 72
6. Test Method: D.O.P. or Polystyrene Latex (PSL) Spheres (PSL preferred)

F. Roll Filters:

1. Efficiency: 20–25%
2. Face Velocity: 500 FPM
3. Initial Pressure Drop
   a. 20%: 0.20″ WG
4. Final Pressure Drop
   a. 20%: 0.45″ WG
5. Nominal Sizes
   a. Thicknesses: 2
   b. Face Sizes
      1) Height: 5′-0″ to 15′-0″ by increments of 4″
      2) Width: 3′-0″ to 30′-0″ by increments of 1′-0″
6. Test Method: *ASHRAE 52-76, Atmospheric*

G. Carbon Filters:

1. Front/Back Access:
   a. Face Velocity: 500 FPM
      1) Pressure Drop: 0.35–0.45″ WG

2) Nominal Sizes
 24 × 24 × 24: 90 Lbs. of carbon per 2,000 CFM
 24 × 12 × 24: 45 Lbs. of carbon per 1,000 CFM
3) Tray Size: 24 × 24
b. Face Velocity: 250 FPM
1) Pressure Drop: 0.30–0.40″ WG
2) Nominal Sizes:
 24 × 24 × 8: 30 Lbs. of carbon per 1,000 CFM
 24 × 24 × 8: 15 Lbs. of carbon per 500 CFM
3) Tray Size: 24 × 8
2. Side Access:
a. Face Velocity: 500 FPM
1) Pressure Drop: 0.35–0.45″ WG
2) Nominal Sizes
 24 × 24 × 24: 108 Lbs. of carbon per 2,000 CFM
3) Tray Size: 12 × 24
3.Test Method: *ASHRAE 52-76, Atmospheric*

H. Electronic Air Cleaners:

1. Efficiency: 30–40%
2. Face Velocity: 625 FPM
3. Initial Pressure Drop:
 a. 90%: 0.26″ WG
4. Final Pressure Drop:
 a. 90%: 0.50″ WG
5. Nominal Sizes:
 a. Thicknesses: 2′-0″ to 4′-0″
 b. Face Sizes
  1) Height: 2′-4″ to 15′-8″ by increments of 4″
  2) Width: 2′-8″ to 18′-8″ by increments of 1′-0″
6.Test Method: *ASHRAE 52-76, Atmospheric*

I. Filter Removal Capabilities:

1. Fine Mode < 2.5 microns.
2. Coarse Mode ≥ 2.5 microns.
3. Respirable < 10.0 microns.
4. Nonrespirable ≥ 10.0 microns.

J. Filter Design Factors:

1. Degree of Air Cleanliness Required.
2. Particulate/Contaminate Size and Form (Solid or Aerosols).
3. Concentration.
4. Cost (Initial and Maintenance).
5. Space Requirements.
6. Pressure Loss/Energy Use.

K. Filter Characteristics

1. Efficiency. Ability of the filter to remove particulates/contaminates.
2. Airflow resistance. Static pressure drop of the filters.

3. Dust Holding Capacity. Amount of particulates/contaminates the filter will hold before efficiency drops drastically.

L. Filter Classes:

1. Class 1 Filters: Filters that, when clean, do not contribute fuel when attacked by flame and emit only neglible amounts of smoke.
2. Class 2 Filters: Filters that, when clean, burn moderately when attacked by flame or emit moderate amounts of smoke, or both.
3. However, dust, trapped by filters, will support combustion and will produce smoke more than the filter itself.

M. Filter Test Methods:

1. ASHRAE "Test Dust." ASHRAE test dust is composed of 72% standardized air cleaner test dust, fine; 23% powdered carbon; and 5% cotton linters.
2. Arrestance Test:
   a. Uses ASHRAE Test Dust.
   b. Tests the ability of the filter to remove the larger atmospheric dust particles.
   c. Measures the concentration of the dust leaving the filter.
3. Atmospheric Dust Spot Efficiency Test:
   a. Measures the change in light transmitted by HEPA filter media targets.
   b. Intermittent Flow Method. Airflow upstream and downstream of the tested filter is drawn through separate target filters. Upstream airflow is intermittently drawn and the downstream airflow is continuously drawn. The test takes more time for higher efficiency filters.
   c. Constant Flow Method. Airflow upstream and downstream of the tested filter is drawn through separate target filters at a constant flow. Test takes the same time for high and low efficiency filters.
4. Dust Holding Capacity Test. The amount of dust held by the filter when filter pressure drop reaches its maximum or final pressure drop or when arrestance tests drop below 85% for two consecutive readings or below 75% for one reading.
5. DOP (Di-Octyl Phthalate) Test:
   a. High Efficiency Filter Tests (HEPA and ULPA).
   b. DOP or BEP (Bis-[2-Ethylhexyl] Phthalate) Test aerosols are used.
   c. A cloud of DOP or BEP is passed through the test filter and the amount passing through the filter is measured by light scattering photometer.
6. Polystyrene Latex (PSL) Spheres Test:
   a. High Efficiency Filter Tests (HEPA and ULPA).
   b. Filter media thickness 20 mil.
   c. Media is tested at 10.5 feet per minute with PSL.
   d. Filters are tested at 70 to 100 feet per minute.
   e. PSL test material is selected to allow 90 percent of the mean size to be between 0.1 and 0.3 microns.
   f. The minimum number of PSL particles in the filter test challenge will be a minimum of 10 million particles per cubic foot.
   g. Particle test challenge is monitored in accordance with Institute of Environmental Sciences (IES) standards *IES-RP-C001* for HEPA filters and *IES-RP-C007* for ULPA filters.
7. Leak Scan Tests:
   a. Used with HEPA and ULPA Filters.
   b. DOP Test is used while scanning the face of the filter for air leakage through or around the filters.
8. Particle Size Tests. No standard exists; depends heavily on the type of aerosol used.

20.04 Chillers

A. Chiller Types:

1. Centrifugal:
   a. 200 Tons and Larger.
   b. 0.55–0.85 KW/Ton.
   c. 4.14–6.39 COP.
   d. Turndown Ratio, 100% to 10%.
2. Reciprocating:
   a. 200 Tons and Smaller.
   b. 0.90–1.30 KW/Ton.
   c. 2.70–3.90 COP.
   d. Turndown Ratio, Staged or Stepped based on number of cylinders and unloading control.
3. Rotary Screw:
   a. 50–1100 Tons.
   b. 1.00–1.50 KW/Ton.
   c. 2.34–3.50 COP.
   d. Turndown Ratio, 100% to 25%.
4. Absorption (Steam or Hot Water):
   a. 100 Tons and Larger.
   b. 18,750 Btuh/Ton; 0.64 COP 1-Stage.
   c. 12,250 Btuh/Ton; 0.98 COP 2-Stage.
   d. Turndown Ratio, 100% to 10%.
5. Absorption (Gas or Oil):
   a. 100 Tons and Larger.
   b. 11,720 Btuh/Ton; 1.02 COP Gas.
   c. 12,440 Btuh/Ton; 0.96 COP Oil.
   d. Turndown Ratio, 100% to 10%.

B. Chiller Motor Types:

1. Hermetic Chillers/Motors:
   a. Motors are refrigerant cooled.
   b. Motor heat absorbed by the refrigerant must be removed by the condenser cooling medium (air or water).
   c. $TONS_{COND} = TONS_{EVAP} \times 1.25$
      $= 12{,}000$ Btu/Hr. Ton $\times 1.25 = 15{,}000$ Btu/Hr. Ton.
      Therefore, motor heat gain is approximately 3,000 Btu/Hr. Ton.
2. Open Chillers/Motors:
   a. Motors are air cooled.
   b. Motor heat is rejected directly to the space. Therefore, the space HVAC system must remove approximately 3,000 Btu/Hr. Ton of motor heat gain.
3. In either case the chillers must remove the 3,000 Btu/Hr. Ton of heat generated by the motors; the only difference is the method by which it is accomplished.

C. Chiller Terms:

1. Refrigeration Effect: The refrigeration effect is the amount of heat absorbed by the refrigerant in the evaporator.
2. Heat of Rejection: The heat of rejection is the amount of heat rejected by the refrigerant in the condenser, which includes compressor heat.

3. Subcooling: Subcooling is the cooling of the refrigerant below the temperature in which it condenses. Subcooling the liquid refrigerant will increase the refrigeration effect of the system will be increased.
4. Superheating: Superheating is the heating of the refrigerant above the temperature in which it evaporates. Superheating the refrigerant by the evaporator is part of the system design to prevent a slug of liquid refrigerant from entering the compressor and causing damage.
5. Coefficient of Performance (COP): The coefficient of performance is defined as the refrigeration effect (Btu/Hr.) divided by the work of the compressor (Btu/Hr.). Another way to define COP is Btu Output divided by Btu Input. COP is equal to EER divided by 3.413.
6. Energy Efficiency Ratio (EER): The energy efficiency ratio is defined as the refrigeration effect (Btu/Hr.) divided by the work of the compressor (Watts). Another way to define EER is the Btu Output divided by the Watts Input. The EER is equal to 3.413 times the COP.
7. pH Chart: Pressure/Enthalpy chart is a graphic representation of the properties of a specific refrigerant with the pressure on the vertical axis and the enthalpy on the horizontal axis. The graph is used and is helpful in visualizing the changes that occur in a refrigeration cycle.
8. Integrated Part Load Value (IPLV) ARI Specified Conditions. Acceptable tolerances for specified conditions are ±5%.
9. Application Part Load Value (APLV) Engineer Specified Conditions (Real World Conditions). Acceptable tolerances for specified conditions are ± 5%.
10. Rupture Disc. Relief device on low pressure machines.
11. Relief Valve. Relief device on high pressure machines.
12. Pumpdown. Refrigerant pumped to condenser for storage.
13. Pumpout. Refrigerant pumped to separate storage vessel. Use pumpout type storage when reasonable size and number of portable storage containers cannot be moved into the building.
14. Purge Unit. Removes air from the refrigeration machine, required on low pressure machines only.
15. Prevac. Device that prevents air from entering refrigeration machine, and it is used to leak test the refrigeration machine, required on low pressure machines only.
16. Factory Run Tests. 1,500 tons and smaller; most manufacturers can provide.
    a. Certified Test. Certify Performance—Full Load and/or Part Load—IPLV, and/or APLV.
    b. Witnessed Tests:
        1) Generic. Any chiller the manufacturer produces of the same size and characteristics.
        2) Specific. The specific chiller required by the customer.
17. Hot Gas Bypass. Low limit to suction pressure of compressor. Hot gas bypass is beneficial on DX systems and generally not beneficial on chilled water systems, except when tight temperature tolerances are required for a manufacturing process. Chillers specified with both hot gas bypass and low ambient temperature control will result in the hot gas bypass increasing the low ambient temperature operating point of the chiller (decrease ability for chiller to operate at low ambient conditions).

D. Basic Refrigeration Cycle Terminology:

1. Compressor. Mechanical device where the refrigerant is compressed from a lower pressure and lower temperature to a higher pressure and higher temperature.
2. Hot Gas Piping. Refrigerant piping from the compressor discharge to the compressor suction, to the evaporator outlet, or to the evaporator inlet or from the compressor discharge and the condenser outlet to the compressor suction.
3. Condenser. Heat exchanger where the system heat is rejected and the refrigerant condenses into a liquid.

4. Liquid Piping. Refrigerant piping from the condenser outlet to the evaporator inlet.
5. Evaporator. Heat exchanger where the system heat is absorbed and the refrigerant evaporates into a gas.
6. Suction Piping. Refrigerant piping from the evaporator outlet to the compressor suction inlet.
7. Thermal Expansion Valve. Pressure and temperature regulation valve, located in the liquid line, which is responsive to the superheat of the vapor leaving the evaporator coil.

E. Chiller Energy Saving Techniques:

1. Constant Speed Chillers. For each 1°F. increase in chilled water temperature, chiller efficiency increases 1.0 to 2.0 percent.
2. Variable Speed Chillers. For each 1°F. increase in chilled water temperature, chiller efficiency increases 2.0 to 4.0 percent.
3. For each 1°F. decrease in condenser water temperature, chiller efficiency increases 1.0 to 2.0 percent.

F. Evaporator / Chilled Water System:

1. Leaving Water Temperature (LWT): 42–46°F.
2. 10–20°F. ΔT.
3. 2.4 GPM/Ton @ 10°F. ΔT.
4. 2.0 GPM/Ton @ 12°F. ΔT.
5. 1.5 GPM/Ton @ 16°F. ΔT.
6. 1.2 GPM/Ton @ 20°F. ΔT.
7. 5,000 Btuh/GPM @ 10°F. ΔT.
8. 6,000 Btuh/GPM @ 12°F. ΔT.
9. 8,000 Btuh/GPM @ 16°F. ΔT.
10. 10,000 Btuh/GPM @ 20°F. ΔT.
11. ARI Evaporator Fouling Factor: 0.00010 Btu/Hr.Ft^2.°F.
12. Chilled Water Flow Range: Chiller Design Flow ±10%.
13. Chiller Tube Velocity for Variable Flow Chilled Water:
    a. Minimum Flow: 3.0 FPS
    b. Maximum Flow: 12.0 FPS

G. Condenser / Condenser Water Systems:

1. Entering Water Temperature (EWT): 85°F.
2. ΔT Range: 10–20°F.
3. Normal ΔT: 10°F.
4. 3.0 GPM/Ton @ 10°F. ΔT.
5. 2.5 GPM/Ton @ 12°F. ΔT.
6. 2.0 GPM/Ton @ 15°F. ΔT.
7. 1.5 GPM/Ton @ 20°F. ΔT.
8. 5,000 Btuh/GPM @ 10°F. ΔT.
9. 6,000 Btuh/GPM @ 12°F. ΔT.
10. 7,500 Btuh/GPM @ 15°F. ΔT.
11. 10,000 Btuh/GPM @ 20°F. ΔT.
12. ARI Condenser Fouling Factor: 0.00025 Btu/Hr.Ft^2.°F.

H. Chilled Water Storage Systems:

1. 10°F. ΔT.
    a. 19.3 Cu.FT./Ton Hr.
    b. 623.1 Btu/Cu.Ft.; 83.3 Btu/Gal.

2. 12°F. ΔT:
   a. 16.1 Cu.Ft./Ton Hr.
   b. 747.7 Btu/Cu.Ft.; 100.0 Btu/Gal.
3. 16°F. ΔT:
   a. 12.4 Cu.Ft./Ton Hr.
   b. 996.9 Btu/Cu.Ft.; 133.3 Btu/Gal.

I. Ice Storage Systems:

1. 144 Btu/Lb. @ 32°F. + 0.48 Btu/Lb. for each 1°F. below 32°F.
2. 3.2 Cu.Ft./Ton Hr.
3. Only the latent heat capacity of ice should be used when designing ice storage systems.

J. Water Cooled Condensers:

1. Entering Water Temperature (EWT): 85°F.
2. Leaving Water Temperature (LWT): 95°F.
3. 3.0 GPM/Ton @ 10°F. ΔT.
4. For each 1°F. decrease in condenser water temperature, chiller efficiency increases 1 to 1.2 percent.

K. Refrigerant Estimate–Split Systems:

1. Total 3.0 Lbs./Ton.
2. Equipment 2.0 Lbs./Ton.
3. Piping 1.0 Lbs./Ton.

L. Chilled Water System Makeup Connection: Minimum connection size shall be 10% of largest system pipe size or 1″, whichever is greater. (20″ system pipe size results in a 2″ makeup water connection.)

M. Chemical Feed Systems for Chillers. Chemical feed systems are designed to control the following:

1. System pH, normally between 8 and 9.
2. Corrosion.
3. Scale.

N. Chiller Operating Sequence:

1. Start chilled water and condenser water pumps. Verify chilled water and condenser water flow.
2. Start chiller and cooling tower.
3. Run time.
4. Stop chiller and cooling tower.
5. Stop chilled water and condenser water pumps after 0 to 30 second delay, because some chiller manufacturers use chilled water or condenser water to cool the solid state starter circuitry.

O. Chiller Design, Layout, and Clearance Requirements/Considerations:

1. Design Conditions:
   a. Chiller Load. Tons, Btu/Hr, or MBH.
   b. Chilled Water Temperatures. Entering and Leaving or Entering and ΔT.
   c. Condenser Water Temperatures. Entering and Leaving or Entering and ΔT.
   d. Chilled Water Flows and Fluid Type (correct all data for fluid type).
   e. Condenser Water Flows and Fluid Type (correct all data for fluid type).

f. Evaporator and Condenser Pressure Drops.
g. Fouling Factor.
h. IPLV, Desirable.
i. APLV, Optional.
j. Chilled Water or Condenser Water Reset if Applicable.
k. Ambient Operating Temperature, Dry Bulb and Wet Bulb.
l. Electrical Data:
 1) Compressor or Unit KW.
 2) Full Load, Running Load, and Locked Rotor Amps.
 3) Power Factor.
 4) Energy Efficiency Ratio (EER).
 5) Voltage-Phase-Hertz.

2. Multiple chillers should be used to prevent complete system or building shutdown upon failure of 1 chiller in all chilled water systems over 200 tons (i.e., 2 @ 50%, 2 @ 67%, 2 @ 70%, 3 @ 34%, 3 @ 40%).
3. Water Boxes/Piping Connections:
 a. Marine Type. Marine water boxes enable piping to be connected to the side of the chiller so that piping does not need to be disconnected on order to service machine. Recommend on large chillers, 500 tons and larger.
 b. Non-Marine or Standard Type. Recommend on small chillers, less than 500 tons.
 c. Provide victaulic or flanged connections for first 3 fittings at chiller with non-marine or standard type connections.
 d. Locate piping connections against the wall.
 e. Locate all piping connections opposite the tube clean/pull side of chiller.
 f. Locate oil cooler connections.
4. Show tube clean/pull clearances and location.
5. Minimum recommended clearance around chillers is 36 inches. Maintain minimum clearances for tube pull and cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the chiller. Maintain minimum clearance as required to open access and control doors on chillers for service, maintenance, and inspection.
6. Maintain minimum electrical clearances as required by NEC.
7. Mechanical room locations and placement must take into account how chillers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.
8. If chiller must be disassembled for installation (chiller cannot be shipped disassembled), specify manufacturer's representative for reassembly, do not specify insulation with chiller (field insulate), and specify the chiller to come with remote mounted starter.
9. Show location of chiller starter, disconnect switch, and control panel.
10. Show chiller relief piping.
11. Show sanitary drain locations and chiller drain connections.
12. Locate refrigerant monitoring system, refrigerant sensors, and self-contained breathing apparatus (SCBA). Refrigerant detection devices and SCBA are required by code, *ASHRAE Standard 15.* Detection devices sound an alarm at certain level (low limit) and sound an alarm and activate ventilation system at a higher level (high limit) with levels dependent on refrigerant type.
13. Coordinate height of chiller with overhead clearances and obstructions. Is beam required above chiller for lifting compressor or other components?
14. Low Ambient Operation. Is operation of chiller required below 40°F., 0°F, etc., or will airside economizers provide cooling?

15. Wind Direction and Speed (Air Cooled Machines). Orient short end of chiller to wind.
16. If isolators are required for the chiller, has isolator height been considered in clearance requirements? If isolators are required for the chiller, has piping isolation been addressed?
17. Locate flow switches in both the evaporator and condenser water piping systems serving each chiller and flow meters as required by system design.
18. Locate pumpdown, pumpout, and refrigerant storage devices if they are required.
19. When combining independent chilled water systems into a central plant,
    a. Create a central system concept, control scheme, and flow schematics.
    b. The system shall only have a single expansion tank connection point sized to handle entire system expansion and contraction.
    c. All systems must be altered, if necessary, to be compatible with central system concept (temperatures, pressures, flow concepts—variable or constant control concepts).
    d. For constant flow and variable flow systems, the secondary chillers are tied into the main chiller plant return main. Chilled water is pumped from the return main through the chiller and back to the return main.
    e. District chilled water systems, due to their size, extensiveness, or both, may require that independent plants feed into the supply main at different points. If this is required, design and layout must enable isolating the plant; provide start-up and shutdown bypasses; and provide adequate flow, temperature, pressure, and other control parameter readings and indicators for proper plant operation and other design issues which affect plant operation and optimization.
20. In large systems, it may be beneficial to install a steam-to-water or water-to-water heat exchanger to place an artificial load on the chilled water system to test individual chillers or groups of chillers during plant start-up, after repairs, or for troubleshooting chiller or system problems.
21. Large and campus chilled water systems should be designed for large delta Ts and for variable flow secondary and tertiary systems.
22. Chilled water pump energy must be accounted for in the chiller capacity because they add heat load to the system.
23. It is best to design chilled water and condenser water systems to pump through the chiller.

20.05 Cooling Towers (CTs)

A. Cooling Tower Types:

1. Induced Draft—Cross Flow.
    a. 200–900 Tons Single Cell.
    b. 400–1,800 Tons Double Cell.
2. Forced Draft, Counter Flow:
    a. 200–1,300 Tons Centrifugal Fans.
    b. 250–1,150 Tons Axial Fans.
3. Ejector Parallel Flow:
    a. 5–750 Tons.

B. Definitions:

1. Range: Difference between entering and leaving water, system ΔT.
2. Approach: Difference between leaving water temperature and entering air wet bulb.
3. Evaporation: Method by which cooling towers cool the water.
4. Drift: Entrained water droplets carried off by the cooling tower. Undesirable side effect.

5. Blowdown or Bleed: Water intentionally discharged from the cooling tower to maintain water quality.
6. Plume: Hot moist air discharged from the cooling tower forming a dense fog.

C. Condenser Water:

1. Most Common Entering Water Temperature (EWT): 95°F.
2. Most Common Leaving Water Temperature (LWT): 85°F.
3. Range: 10–40°F. ΔT.
4. 3.0 GPM/Ton @ 10°F. ΔT.

D. Power: 0.035–0.040 KW/Ton

E. $\mathbf{TONS_{COND} = TONS_{EVAP} \times 1.25}$

$$= 12{,}000 \text{ Btu/Hr. Ton} \times 1.25$$

$$= 15{,}000 \text{ Btu/Hr. Ton}$$

F. Condenser Water Makeup to Cooling Tower:

1. Range:	0.0306–0.0432 GPM/Ton
2. Range:	0.0102–0.0144 GPM/Cond. GPM (1.0–1.4% Condenser GPM)
3. Centrifugal:	40 GPM/1,000 Tons
4. Reciprocating:	40 GPM/1,000 Tons
5. Screw:	40 GPM/1,000 Tons
6. Absorption:	80 GPM/1,000 Tons

G. Cooling Tower Drains: Use 2 times the makeup water rate for sizing cooling tower drains.

H. Cycles of Concentration

1. Range:	2–10
2. Recommend:	3–5

I. Evaporation

1. Range:	0.024–0.03 GPM/Ton
2. Range:	0.008–0.01 GPM/Cond. GPM (0.8–1.0% Condenser GPM)
3. Recommend:	0.01 GPM/Cond. GPM

J. Drift

1. Range:	0.0006–0.0012 GPM/Ton
2. Range:	0.0002–0.0004 GPM/Cond. GPM (0.02–0.04% Condenser GPM)
3. Recommend:	0.0002 GPM/Cond. GPM

K. Blowdown or Bleed (Based on 10°F. Range):

1. Range:	0.006–0.012 GPM/Ton
2. Range:	0.002–0.004 GPM/Cond. GPM (0.2–0.4% Condenser GPM)
3. Recommend:	0.002 GPM/Cond. GPM
4. Centrifugal:	10 GPM/1,000 Tons
5. Reciprocating:	10 GPM/1,000 Tons
6. Screw:	10 GPM/1,000 Tons
7. Absorption:	20 GPM/1,000 Tons

Blowdown GPM, % of Cond. GPM

COOLING TOWER RANGE	CYCLES OF CONCENTRATION								
	2	3	4	5	6	7	8	9	10
10	0.80	0.40	0.30	0.20	0.10	0.10	0.10	0.10	0.10
15	1.20	0.60	0.40	0.30	0.20	0.20	0.15	0.15	0.15
20	1.60	0.80	0.50	0.40	0.30	0.30	0.20	0.20	0.20
25	2.00	1.00	0.65	0.50	0.40	0.35	0.25	0.25	0.23
30	2.40	1.20	0.80	0.60	0.50	0.40	0.30	0.30	0.25
35	2.75	1.40	0.95	0.70	0.55	0.45	0.35	0.35	0.30
40	3.10	1.60	1.10	0.80	0.60	0.50	0.40	0.40	0.35

L. Cooling towers should be located at least 100 feet from the building, when located on the ground, to reduce noise and to prevent moisture from condensing on the building during the intermediate seasons (spring and fall). Cooling towers should also be located 100 feet from parking structures or parking lots to prevent staining of automobile finishes due to water treatment.

20.06 Air Cooled Condensers and Condensing Units (ACCs and ACCUs)

A. Size Range: 0.5–500 6 Tons

B. Air Flow: 600–1,200 CFM/Ton

C. Power:

1. Condenser Fans: 0.1–0.2 HP/Ton
2. Compressors: 1.0–1.3 KW/Ton

20.07 Evaporative Condensers and Condensing Units (ECs and ECUs)

A. Type and Sizes:

1. 10–1,600 Tons Centrifugal Fans
2. 10–1,500 Tons Axial Fans

B. Drift: 0.002 GPM/Cond. GPM

C. Evaporation: 1.6–2.0 GPM/Ton

D. Bleed: 0.8–1.0 GPM/Ton

E. Total: 2.4–3.0 GPM/Ton

20.08 Installation of CTs, ACCs, ACCUs, ECs, and ECUs

A. Allow ample space to provide proper airflow to fans and units in accordance with manufacturer's recommendations.

B. Top discharge of unit should be at the same height or higher level than adjoining building or wall to minimize recirculation caused by down drafts between unit and wall. Raise the unit or provide discharge hood to obtain proper discharge height.

C. Elevating units may decrease space required between units and between units and walls. ONLY DECREASE SPACE IN ACCORDANCE WITH MANUFACTURER'S RECOMMENDATIONS.

D. Decking or metal plates over units between walls and other units may decrease space required between units and between units and walls. ONLY DECREASE SPACE IN ACCORDANCE WITH MANUFACTURER'S RECOMMENDATIONS.

E. Providing discharge hoods with units may decrease space required between units and between units and walls. ONLY DECREASE SPACE IN ACCORDANCE WITH MANUFACTURER'S RECOMMENDATIONS.

F. Chemical Feed Systems for CTs, ECs, and ECUs. Chemical feed systems are designed to control the following:

1. System pH, Normally between 8 and 9.
2. Corrosion.
3. Scale.
4. Biological and Microbial Growth.

G. Clearance Requirements:

1. Minimum recommended clearance around CTs, ACCs, ACCUs, ECs, and ECUs is 36 inches. Maintain minimum clearances as recommended by the equipment manufacturer. Maintain minimum clearance as required to open access and control doors on equipment for service, maintenance, and inspection.
2. Mechanical room locations and placement must take into account how CTs, ACCs, ACCUs, ECs, and ECUs can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

20.09 Heat Exchangers

A. Shell and Tube:

1. Used where the approach of the system is greater than 15 ± F.
2. Straight Tube or U-Tube Design.
3. Generally used in heating systems.
4. Water to Water:
   a. Maximum Tube Velocity: 6 Ft./Sec.
   b. Maximum Shell Velocity: 5 Ft./Sec.
5. Steam to Water:
   a. Maximum Water Velocity: 6 Ft./Sec.
   b. If system steam capacity exceeds 2″ control valve size, provide 2 control valves with ⅓ and ⅔ capacity split.

B. Plate and Frame:

1. Used where the approach of the system is less than 15 ± F.
2. Generally used in cooling systems.

C. Definitions:

1. Range: Difference between entering and leaving water, system ΔT.
2. Approach: Difference between hot side entering water temperature and cold side leaving water temperature.

D. Clearance and Design Requirements:

1. Minimum recommended clearance around heat exchangers is 36 inches. Maintain minimum clearances for tube pull and cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the heat exchanger.
2. Mechanical room locations and placement must take into account how heat exchangers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.
3. Multiple heat exchangers should be used to prevent complete system or building shutdown upon failure of 1 heat exchanger in all water systems over 200 tons or 2,400,000 Btu/Hr. (i.e., 2 @ 50%, 2 @ 67%, 2 @ 70%, 3 @ 34%, 3 @ 40%).
4. Heat Transfer Factors:
   a. Change in enthalpy on the primary side (hydronic side).
   b. Change in enthalpy on the secondary side.
   c. Heat transfer through the heat exchanger dependent on film coefficients and heat transfer surface area.
5. Methods of Heat Transfer:
   a. Parallel Flow. Both mediums flow in the same direction. Least effective method of heat transfer.
   b. Counter-Flow. Mediums flow in opposite directions. Most effective method of heat transfer.
   c. Cross-Flow. Mediums flow at right angles to each other. Heat transfer effectiveness between parallel and counter flow methods.
   d. Combination. Cross-Flow/Counter-Flow or Cross-Flow/Parallel Flow. Typical in shell and tube heat exchangers.

20.10 Boilers, General

A. Class I Boilers. *ASME Boiler and Pressure Vessel Code, Section I:*

1. Steam Boilers, Greater than 15 Psig
2. Hot Water Boilers:
   a. Greater than 160 Psig
   b. Greater than 250°F.
3. Common Terminology:
   a. Process Boilers
   b. Power Boilers
   c. High Pressure Boilers

B. Class IV Boilers. *ASME Boiler and Pressure Vessel Code, Section IV:*

1. Steam Boilers, 15 psig and less
2. Hot Water Boilers:
   a. 160 psi and less
   b. 250°F. and less
3. Common Terminology:
   a. Commercial Boilers

   b. Industrial Boilers
   c. Heating Boilers
   d. Low Pressure Boilers

C. Common Boiler Design Pressures:

1. 15 Psig
2. 30 Psig
3. 60 Psig
4. 125 Psig
5. 150 Psig
6. 200 Psig
7. 250 Psig
8. 300 Psig
9. 350 Psig

D. Boiler Sequence of Operation:

1. Prepurge
2. Pilot Ignition and Verification
3. Main Flame Ignition and Verification
4. Run Time
5. Post Purge
6. Boiler Operational Considerations:
   a. Hot Water and Steam Boilers:
      1) Prevent hot or cold shock
      2) Prevent frequent cycling
      3) Provide proper water treatment
   b. Hot Water Boilers Only:
      1) Provide continuous circulation
      2) Balance flow through boilers
      3) Provide proper over pressure
   c. Causes of Increased Stack Temperature:
      1) Soot buildup
      2) Scale buildup
      3) Combustion chamber and pass sealing problems

E. Boiler Types:

1. Fire Tube Boilers (Scotch Marine)
2. Water Tube Boilers
3. Flexible Tube Boilers
4. Cast Iron Boilers
5. Modular Boilers
6. Electric Boilers
7. Fire Tube versus Water Tube Boiler Characteristics are shown in the following table:

Fire Tube Versus Water Tube Boilers

COMPARED ITEM	FIRE TUBE BOILERS	WATER TUBE BOILERS
STEAM QUALITY	98.5%	99.5%
STEAM PURITY	52.5 ppm	17.5 ppm can be modified to obtain 1 ppm
EFFICIENCY	85% Average	80% Average
DESIGN PRESSURE	300 psig	900 psig
DESIGN TEMPERATURE	350 °F.	455 °F.
SUPER HEATERS	None	Available to 750 °F.
LOAD SWINGS	Long Recovery Time	Short Recovery Time
WATER WEIGHT	Factor of 2.5	Factor of 1.0
LENGTH	Longer	Shorter
HEIGHT	Shorter	Higher
OVERFIRE	No	10% to 15% for Short Periods
SPACE	Door Swing and Tube Pull	3'-0" Minimum All Around
ELECTRICAL LOAD	Greater Hp Required	Lower Hp Required
WATER QUALITY	Same	Same
TURN DOWN	10:1 Gas; 8:1 Fuel Oil #2	10:1 Gas; 8:1 Fuel Oil #2
U.L. LABEL	Standard Entire Package	Not Available for Entire Package - Components Only
SOOT BLOWERS	None	Standard Option
ULTIMATE DECISION	Customer Preference	Customer Preference

F. Boiler Efficiency:

1. Combustion Efficiency: Indication of the burner's ability to burn fuel measured by the unburned fuel and excess air in the exhaust.
2. Thermal Efficiency: Indication of the heat exchanger's effectiveness to transfer heat from the combustion process to the water or steam in a boiler, but does not account for radiation and convection losses.
3. Fuel-to-Steam Efficiency: Indication of the overall efficiency of the boiler including effectiveness of the heat exchanger, radiation losses, and convection losses (output divided by input). The test to determine fuel-to-steam efficiency is defined by *ASME Power Test Code, PTC 4.1:*
   a. Input-Output Method.
   b. Heat Loss Method.
4. Boiler Efficiency: Indication of either Thermal Efficiency or Fuel-to-Steam Efficiency depending on context.

G. Boiler Plant Efficiency Factors:

1. Boiler, 80 to 85% Efficient:
   a. Radiation Losses.

   b. Convection Losses.
   c. Stack Losses.
2. Boiler Room, Steam:
   a. Heating of Combustion Air.
   b. Heating of Makeup Water.
   c. Steam Condensate not returned.
   d. Boiler Blowdown.
   e. Radiation Losses:
      1) Condensate Tank.
      2) Condensate Pump.
      3) Feed Water Pump.
      4) Deaerator or Feedwater Tank.
3. Boiler Room, Hot Water:
   a. Heating of Combustion Air.
   b. Radiation Losses:
      1) Expansion Tank.
      2) Air Separator.
      3) Pumps.
4. Plant, System:
   a. Steam Leaks and Bad Steam Traps.
   b. Piping, Valves, and Equipment Radiation Losses.
   c. Control Valve Operational Problems.
   d. Flash Steam Losses.
   e. Water or Condensate Leaks/Losses.

H. Steam System Energy Saving Tips:

1. Insulate all hot surfaces to prevent heat loss.
2. Isolate all steam supply piping not being used.
3. Repair all steam piping leaks.
4. Repair all steam traps not operating properly which are bypassing steam.
5. Stop all internal steam leaks including venting of flash steam and open bypass valves around steam traps and control valves.
6. Produce clean, dry steam with the use of a steam separator and proper water treatment.
7. Properly control steam flow at equipment.
8. Use and properly select steam traps.
9. Use flash steam for preheating and other used whenever possible.

I. Packaged Boiler Fuel Types:

1. Natural Gas.
2. Propane.
3. Light Fuel Oil #1 and #2.
4. Heavy Fuel Oil #4, #5, and #6.
5. Digester or Land Fill Gas.

J. Gas Trains:

1. U.L., Standard.
2. IRI.
3. FM.
4. Kemper.
5. CSD (ASME Control Code).
6. *NFPA 8501.*

K. Boiler Capacity Terminology:

1. Start-up Load. Capacity required to bring the boiler system up to temperature, pressure, or both.
2. Running Load. Design Capacity
3. Maximum Instantaneous Demand (MID). A sudden peak load requirement of unusually short duration:
   a. MID loads are often hidden in process equipment loads.
   b. Cold start-up or pickup loads which far exceed their normal operating demands.
   c. Full understanding of MID loads is required to properly select boiler system capacity.
   d. MID Shortfall Corrective Actions:
      1) Change load reaction time to reduce impact; slow down valve operation, reduce number of items with simultaneous start-up (staged start-up).
      2) Add boiler capacity.
      3) Add back pressure regulator downstream of deaerator or feed water tank steam supply connection.
      4) Add an accumulator.

L. Combustion:

1. Improper Combustion:
   a. Oxygen Rich-Fuel Lean: Wastes Energy.
   b. Oxygen Lean-Fuel Rich: Produces CO, soot, and potentially hazardous conditions.
2. What Affects Combustion?
   a. Changes in Barometric Pressure.
   b. Changes in Ambient Air Temperature:
      1) Oxygen Trim systems compensate for ambient air temperature changes.
   c. Ventilation Air:
      1) Total: 10 CFM/BHP
      2) Combustion Air: 8 CFM/BHP
      3) Ventilation: 2 CFM/BHP
   d. Keep boiler room positive with respect to the stack and breeching (+0.10 inches WG maximum). to prevent the entrance of flue gases into the boiler room.
   e. Never exhaust boiler rooms; use supply air with relief air.

M. Stacks and Breeching. Provide a manual damper (lock damper in the open position) or a motorized damper (2-position damper) at the boiler outlet. A motorized damper interlocked with boiler operation is preferred:

1. Multiple Boilers with Common Stack and Breeching. Damper will prevent products of combustion from entering the boiler room when repairing or inspecting boilers while system is still in operation.
2. Multiple Boilers with Individual or Common Stack and Breeching. Damper will prevent the natural draft through the boiler when not firing, thus reducing the energy lost up the stack.

N. 1990 Clean Air Act–Focused on the reduction of the following pollutants:

1. Ozone (O_3).
2. Carbon Monoxide (CO).
3. Nitrogen Oxides (NO_x – NO / NO_2).
4. Sulfur Oxides (SO_x – SO_2 / SO_3).
5. Particulate Matter, 10 ppm.
6. Lead.

O. Standard Controls:

1. Steam Boiler Control and Safeties:
   a. High Limit Pressure Control. Provides a Margin of Safety.
   b. Operating Limit Pressure Control. Starts/Stops Burner.
   c. Modulation Pressure Control. Varies Burner Firing Rate.
   d. Low Limit Pressure Control.
   e. Low Water Cutoff.
   f. Auxiliary Low Water Cutoff.
   g. High Water Cutoff.
2. Hot Water Boiler Controls and Safeties:
   a. High Limit Pressure Control. Provides a Margin of Safety.
   b. High Limit Temperature Control. Provides a Margin of Safety.
   c. Operating Limit Temperature Control. Starts/Stops Burner.
   d. Modulation Temperature Control. Varies Burner Firing Rate.
   e. Low Limit Pressure Control.
   f. Low Limit Temperature Control.
   g. Low Water Flow.
   h. High Water Flow.
3. Fuel System Controls and Safeties:
   a. Low Gas Pressure Switch.
   b. High Gas Pressure Switch.
   c. Low Oil Pressure Switch.
   d. High Oil Pressure Switch.
   e. Low Oil Temperature.
4. Combustion Controls and Safeties:
   a. Pilot Failure Switch.
   b. Flame Failure Switch.
   c. Combustion Air Proving Switch.
   d. Oil Atomization Proving Switch.
   e. Low Fire Hold Control.
   f. Low Fire Switch.
   g. High Fire Switch.

P. Safety, Relief, and Safety Relief Valve testing is dictated by the Insurance Underwriter.

20.11 Hot Water Boilers

A. Boiler Types:

1. Fire Tube Boilers:
   a. 15–800 BHP.
   b. 500–26,780 MBH.
   c. 30–300 psig.
2. Water Tube Boilers:
   a. 350–2,400 BHP.
   b. 13,000–82,800 MBH.
   c. 30–525 psig.
3. Flexible Water Tube Boilers:

   a. 30–250 BHP.
   b. 1,000–8,370 MBH.
   c. 0–150 psig.
4. Cast Iron Boilers:
   a. 10–400 BHP.
   b. 345–13,800 MBH.
   c. 0–40 psig.
5. Modular Boilers:
   a. 4–115 BHP.
   b. 136–4,000 MBH.
   c. 0–150 psig.
6. Electric Boilers:
   a. 15–5,000 KW.
   b. 51–17,065 MBH.
   c. 0–300 psig.

B. Hot Water Boiler Plant Equipment:

1. Boilers.
2. Pumps.
3. Air Separators.
4. Expansion Tanks.

C. Heating Water:

1. Leaving Water Temperature (LWT): 180–200°F.
2. 20–40°F. Δ T Most Common.
3. Boiler System Design Limits:
   a. Minimum Flow through a Boiler: 0.5–1.0 GPM/BHP.
   b. Maximum Flow through a Boiler: Boiler Capacity divided by the temperature difference divided by 500.
   c. Pressure Drop through a Boiler: 3 to 5 Feet H_2O.
   d. Minimum Supply Water Temperature: 170°F. This temperature may vary with boiler design and with manufacturer; verify the exact temperature with the manufacturer.
   e. Minimum Return Water Temperature: 150°F. This temperature may vary with boiler design and with manufacturer; verify the exact temperature with the manufacturer.
   f. Maximum Supply Water Temperature: Based on ASME Design Rating of the Boiler.
4. Heating Capacities:
   a. 3.45 GPM/BHP @ 20°F. Δ T.
   b. 2.30 GPM/BHP @ 30°F. Δ T.
   c. 1.73 GPM/BHP @ 40°F. Δ T.
   d. 10.0 GPM/Therm @ 20°F. Δ T.
   e. 6.7 GPM/Therm @ 30°F. Δ T.
   f. 5.0 GPM/Therm @ 40°F. Δ T.
   g. 10,000 Btuh/GPM @ 20°F. Δ T.
   h. 15,000 Btuh/GPM @ 30°F. Δ T.
   i. 20,000 Btuh/GPM @ 40°F. Δ T.

D. System Types:

1. Low Temperature Heating Water Systems:
   a. 250°F. and Less.
   b. 160 psig maximum.
2. Medium Temperature Heating Water Systems:

a. 251–350°F.
b. 160 psig maximum.
3. High Temperature Heating Water Systems:
a. 351–450°F.
b. 300 psig maximum.

E. Heating Water Storage Systems:

1. 20°F. Δ T:
   a. 0.80 Cu.Ft./MBtu.
   b. 1246.2 Btu/Cu.Ft.
   c. 166.6 Btu/Gal.
2. 30°F. Δ T:
   a. 0.54 Cu.Ft./MBtu.
   b. 1869.3 Btu/Cu.Ft.
   c. 249.9 Btu/Gal.
3. 40°F. Δ T:
   a. 0.40 Cu.Ft./MBtu.
   b. 2492.3 Btu/Cu.Ft.
   c. 333.2 Btu/Gal.

F. Hot Water System Makeup Connection: Minimum connection size shall be 10% of largest system pipe size or 1″, whichever is greater (20″ system pipe size results in a 2″ makeup water connection).

G. Chemical Feed Systems for Water Boilers. Chemical feed systems are designed to control the following:

1. System pH, normally between 8 and 9.
2. Corrosion.
3. Scale.

H. Design, Layout and Clearance Requirements/Considerations:

1. Design Conditions:
   a. Boiler Load, Btu/Hr, or MBH.
   b. Heating Water Temperatures, Entering and Leaving or Entering and Δ T.
   c. Heating Water Flows and Fluid Type (correct all data for fluid type).
   d. Fuel Input, Gas, Fuel Oil, Electric, etc.
   e. Overall Boiler Efficiency.
   f. Water Pressure Drops.
   g. Fouling Factor.
   h. Heating Water Reset if Applicable. Verify with boiler manufacturer that temperature limits are not exceeded.
   i. Electrical Data:
      1) Unit KW, Blower Hp, Compressor Hp, and Fuel Oil Pump Hp.
      2) Full Load, Running Load, and Locked Rotor Amps.
      3) Voltage-Phase-Hertz.
2. Multiple hot water boilers should be used to prevent complete system or building shutdown upon failure of 1 hot water boiler in all heating water systems over 70 boiler horsepower or 2,400,000 Btu/Hr. (i.e., 2 @ 50%, 2 @ 67%, 2 @ 70%, 3 @ 34%, 3 @ 40%).
3. Show tube clean/pull clearances and location.
4. Minimum recommended clearance around boilers is 36 inches. Maintain minimum clearances for tube pull and cleaning of tubes as recommended by the equipment man-

ufacturer. This is generally equal to the length of the boiler. Maintain minimum clearance as required to open access and control doors on boilers for service, maintenance, and inspection.

5. Mechanical room locations and placement must take into account how boilers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.
6. Maintain minimum electrical clearances as required by NEC.
7. Show location of boiler starter, disconnect switch, and control panel.
8. Show gas train and/or fuel oil train location.
9. Show boiler relief piping.
10. Show sanitary drain locations and boiler drain connections.
11. Design and locate combustion air louvers and motorized dampers or engineered combustion air system. What happens if engineered combustion air system malfunctions? Is standby available? Verify that items that might freeze are not located in front of combustion air intake.
12. Coordinate height of boiler with overhead clearances and obstructions. Is beam required above boiler for lifting components? Is catwalk required to service boiler?
13. Boiler stack and breeching. Coordinate routing in boiler room, through building, and discharge height above building with architect and structural engineer.
14. If isolators are required for the boiler, has isolator height been considered in clearance requirements? If isolators are required for the boiler, has piping isolation been addressed?
15. Provide stop check valves (located closest to the boiler) and isolation valves with a drain between these valves on both the supply and return connections to all heating water boilers.
16. Boiler systems pumps should be located so that the pump draws water out of the boiler, because it decreases the potential for entry of air into the system, and it does not impose the pump pressure on the boiler.
17. Interlock the boiler and the pump so that the burner cannot operate without the pump operating.
18. Boiler warming pumps should be piped to both the system header and to the boiler supply piping, allowing the boiler to be kept warm (in standby mode) from the system water flow or to warm the boiler when is has been out of service for repairs without the risk of shocking the boiler with system water temperature. Boiler warming pumps should be selected for 0.1 gpm/BHP (range 0.05 to 0.1 gpm/BHP). At 0.1 gpm/BHP, it takes 45 to 75 minutes to completely exchange the water in the boiler. This flow rate is sufficient to offset the heat loss by radiation and stack losses on boilers when in standby mode of operation. In addition, this flow rate allows the system to keep the boiler warm without firing the boiler, thus allowing for more efficient system operation. For example, it takes 8 to 16 hours to bring a bring a boiler on-line from a cold start. Therefore, the standby boiler must be kept warm to enable immediate start-up of the boiler upon failure of an operating boiler.
19. Circulating hot water through a boiler which is not operating, to keep it hot for standby purposes, creates a natural draft of heated air through the boiler and up the stack, especially in natural draft boilers. Forced draft or induced draft boilers have combustion dampers which close when not firing and therefore reduce, but not eliminate, this heat loss. Although this heat loss is undesirable, for standby boilers, circulating hot water through the boiler is more energy efficient than firing the boiler. Operating (firing) a standby boiler may be in violation of air permit regulations in many jurisdictions today.
20. To provide fully automatic heating water system controls, the controls must look at and evaluate the boiler metal temperature (water temperature) and the refractory temperature prior to starting the primary pumps or enabling the boiler to fire. First, the boiler

system design must circulate system water through the boilers to keep the boiler water temperature at system temperature when the boiler is in standby mode, as discussed for boiler warming pump arrangements. Second, the design must look at the water temperature prior to starting the primary pumps to verify that the boiler is ready for service. And third, the design must look at refractory temperature to prevent boiler from going to high fire if the refractory is not at the appropriate temperature. However, the refractory temperature is usually handled by the boiler control package.

21. Outside air temperature reset of low temperature heating water systems is recommended for energy savings and controllability of terminal units at low load conditions. However, care must be taken with boiler design to prevent thermal shock by low return water temperatures or to prevent condensation in the boiler due to low supply water temperatures and therefore, lower combustion stack discharge temperature.
22. Combustion air dampers must be extra heavy duty and should be low leakage (10 cfm/sq.ft. @ 4″wc differential) or ultralow leakage (6 cfm/sq.ft. @ 4″wc differential) type.
23. When the system design requires the use of dual fuel boilers (natural gas, fuel oil), provide a building automation control system I/O point to determine whether the boiler is on natural gas or fuel oil. Boiler control panels generally have a fuel type switch (Gas/Off/Fuel Oil Switch) which can be connected to create this I/O point. Switching from natural gas to fuel oil (or vice versa) cannot be a fully automatic operation, because the boiler operator must first turn boiler burner to the "Off" position, then turn fuel type switch to fuel oil, then put combustion air linkage into fuel oil position, then slide fuel oil nozzle into position, then put fuel oil pump into "Hand" or "Auto" position, and then turn the boiler burner to the "On" position. Remember to interlock the fuel oil pumps with operation of the boiler on fuel oil. Do not forget to include diesel generator interlocks with fuel oil pumps when the generators are fed from the same fuel oil system.
24. Heating Water System Warm-Up Procedure:
    a. Heating water system start-up should not exceed 100°F. temperature rise per hour, but boiler or heat exchanger manufacture limitations should be consulted.
    b. It is recommended that no more than a 25°F. temperature rise per hour be used when warming heating water systems. Slow warming of the heating water system allows for system piping, supports, hangers, and anchors to keep up with system expansion.
    c. Low temperature heating water systems (250°F and less) should be warmed slowly at 25°F. temperature rise per hour until system design temperature is reached.
    d. Medium and high temperature heating water systems (above 250°F) should be warmed slowly at 25°F. temperature rise per hour until 250°F system temperature is reached. At this temperature the system should be permitted to settle for at least 8 hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 350°F or system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allowing the system to settle for an hour before increasing the temperature or pressure to the next increment. When the system reaches 350°F and the design temperature is above 350°F., the system should be allowed to settle for at least 8 hours or more (preferably overnight). The temperature and pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 455°F or system design temperature in 25°F temperature increments and 25 psig pressure increments, semi-alternating between temperature and pressure increases, and allow the system to settle for an hour before increasing the temperature or pressure to the next increment.

25. Provide heating water systems with warm-up valves for in service start-up as follows. This will allow operators to warm these systems slowly and to prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when only opened a small amount in an attempt to control system warm-up speed.

Bypass and Warming Valves

MAIN VALVE NOMINAL PIPE SIZE	NOMINAL PIPE SIZE	
	SERIES A WARMING VALVES	SERIES B BYPASS VALVES
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

1. **Series A covers steam service for warming up before the main line is opened and for balancing pressures where lines are of limited volume.**
2. **Series B covers lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

26. Heating Water System Warming Valve Procedure:
    a. First, open warming return valve slowly to pressurize the equipment without flow.
    b. Once the system pressure has stabilized, then slowly open the warming supply valve to establish flow and to warm the system.
    c. Once the system pressure and temperature have stabilized, then proceed with the following items listed below, one at a time:
        1) Slowly open the main return valve.
        2) Close the warming return valve.
        3) Slowly open the main supply valve.
        4) Close the warming supply valve.

20.12 Steam Boilers

A. Boiler Types:

1. Fire Tube Boilers:
   a. 15–800 BHP.
   b. 518–27,600 Lb./Hr.
   c. 15–300 psig.
2. Water Tube Boilers:
   a. 350–2,400 BHP.
   b. 12,075–82,800 Lb./Hr.
   c. 15–525 psig.
3. Flexible Water Tube Boilers:
   a. 30–250 BHP.
   b. 10,000–82,000 Lb./Hr.
   c. 15–525 psig.
4. Cast Iron Boilers:
   a. 10–400 BHP.
   b. 1,035–8,625 Lb./Hr.
   c. 0–150 psig.
5. Electric Boilers:
   a. 15–5,000 KW.
   b. 51–17,065 MBH.
   c. 0–300 psig.

B. Steam Boiler Plant Equipment:

1. Pretreatment Systems:
   a. Filters.
   b. Softeners.
   c. Dealkalizers.
   d. RO Units.
2. Feed Water Systems:
   a. Deaerator:
      1) Spray Type.
      2) Packed Column Type.
   b. Feedwater Tank.
   c. Feedwater Pumps.
3. Chemical Feed Systems:
   a. Chemical Pumps.
   b. Chemical Tanks.
   c. Agitators.
4. Sample Coolers.
5. Blowdown Coolers.
6. Surface Blowdown/Feed Water Preheater.
7. Flue Gas Economizers.
8. Boilers.
9. Condensate Return Units and Pumps.
10. Condensate Receiver Tank.
11. Condensate Pumps.
12. Accululators:

a. Type:
   1) Dry.
   2) Wet.
b. Service:
   1) Total System.
   2) Dedicated Lines to Specific Equipment.

13. Super Heaters:
   a. Internal.
   b. External.

C. Steam Capacities:

1. Approx. 1,000 Btuh/1 Lb. Steam.
2. Lb. Steam/Hr. = Lb. Water/Hr.

Steam Capacity per Boiler Horsepower

FEED WATER TEMP.	POUNDS OF DRY SATURATED STEAM PER BOILER HP @ SYSTEM PRESSURE (PSIG) VERSUS FEEDWATER TEMPERATURE (°F.)																	
	0	2	10	15	20	40	50	60	80	100	120	140	150	160	180	200	220	240
30	29.0	29.0	28.8	28.7	28.6	28.4	28.3	28.2	28.2	28.1	28.0	28.0	27.9	27.9	27.9	27.9	27.9	27.8
40	29.3	29.2	29.1	29.0	28.9	28.7	28.6	28.5	28.4	28.3	28.2	28.2	28.2	28.2	28.2	28.1	28.1	28.1
50	29.6	29.5	29.3	29.2	29.1	28.9	28.8	28.8	28.7	28.6	28.5	28.5	28.4	28.4	28.4	28.3	28.3	28.3
60	29.8	29.8	29.6	29.5	29.4	29.2	29.1	29.0	28.9	28.8	28.8	28.7	28.7	28.7	28.6	28.6	28.6	28.5
70	30.1	30.0	29.9	29.8	29.7	29.5	29.4	29.3	29.2	29.1	29.0	29.0	28.9	28.9	28.9	28.8	28.8	28.8
80	30.4	30.3	30.1	30.0	30.0	29.8	29.6	29.6	29.5	29.3	29.2	29.2	29.2	29.2	29.1	29.1	29.1	29.0
90	30.6	30.6	30.4	30.3	30.2	30.0	29.9	29.8	29.7	29.6	29.5	29.5	29.4	29.4	29.4	29.3	29.3	29.3
100	30.9	30.8	30.6	30.6	30.5	30.3	30.2	30.1	30.0	29.8	29.8	29.8	29.7	29.7	29.7	29.6	29.6	29.6
110	31.2	31.2	30.9	30.8	30.8	30.6	30.4	30.3	30.2	30.0	30.0	30.0	30.0	30.0	29.9	29.9	29.9	29.8
120	31.5	31.4	31.2	31.2	31.1	30.8	30.7	30.6	30.5	30.4	30.3	30.3	30.2	30.2	30.2	30.1	30.1	30.1
130	31.8	31.7	31.5	31.4	31.4	31.1	31.0	30.9	30.8	30.7	30.6	30.6	30.5	30.5	30.4	30.4	30.4	30.4
140	32.1	32.0	31.8	31.7	31.6	31.4	31.3	31.2	31.1	31.0	30.9	30.8	30.8	30.8	30.8	30.7	30.7	30.6
150	32.4	32.4	32.1	32.0	31.9	31.7	31.6	31.5	31.4	31.2	31.2	31.2	31.1	31.1	31.0	31.0	30.9	30.9
160	32.7	32.7	32.4	32.4	32.3	32.0	31.9	31.8	31.7	31.5	31.4	31.4	31.4	31.4	31.3	31.3	31.2	31.2
170	33.0	33.0	32.7	32.6	32.6	32.3	32.2	32.1	32.0	31.8	31.7	31.7	31.7	31.7	31.6	31.6	31.5	31.5
180	33.4	33.3	33.0	33.0	32.9	32.6	32.5	32.4	32.3	32.2	32.1	32.0	32.0	32.0	31.9	31.9	31.8	31.8
190	33.8	33.7	33.4	33.3	33.2	32.9	32.8	32.7	32.6	32.5	32.4	32.4	32.3	32.3	32.2	32.2	32.1	32.1
200	34.1	34.0	33.7	33.6	33.5	33.2	33.1	33.0	32.9	32.8	32.7	32.6	32.6	32.6	32.6	32.5	32.4	32.4
212	34.5	34.4	34.2	34.1	33.9	33.6	33.5	33.4	33.3	33.2	33.1	33.0	33.0	33.0	32.9	32.9	32.8	32.8
220	34.8	34.7	34.4	34.3	34.2	33.9	33.8	33.7	33.5	33.4	33.3	33.3	33.2	33.2	33.1	33.1	33.1	33.0
227	35.0	34.9	34.7	34.5	34.4	34.1	34.0	33.9	33.8	33.7	33.6	33.5	33.5	33.4	33.4	33.3	33.3	33.3
230	35.2	35.0	34.8	34.7	34.5	34.2	34.1	34.0	33.9	33.8	33.7	33.6	33.6	33.5	33.5	33.4	33.4	33.4

D. Steam Boiler Drums:

1. Top Drum: Steam Drum.
2. Bottom Drum: Mud or Blowdown Drum.

E. System Types:

1. Low Pressure Steam: 0–15 psig

2. Medium Pressure Steam: 16–100 psig
3. High Pressure Steam: 101 psig and greater

F. Steam Carryover:

1. Steam carryover is the entrainment of boiler water with the steam.
2. Causes of Carryover:
   a. Mechanical:
      1) Poor Boiler Design.
      2) Burner Misalignment.
      3) High Water Level.
   b. Chemical:
      1) High Total Dissolved Solids (TDS).
      2) High Total Suspended Solids (TSS).
      3) High Alkalinity.
      4) High Amine Levels.
      5) Presence of Oils or Other Organic Materials.
3. Problems Caused by Carryover:
   a. Deposits minerals on valves, piping, heat transfer surfaces and other steam using equipment.
   b. Causes thermal shock to system.
   c. Contaminates process or products which have direct steam contact.
   d. If steam is used for humidification, a white dust is often left on air handling unit components, ductwork surfaces, and furniture and other equipment within the space.
4. Carryover Control:
   a. Install steam separation devices.
   b. Maintain proper steam space in steam drum and boiler.
   c. Maintain proper water chemistry—TDS, TSS, alkalinity, etc.

G. Design, Layout, and Clearance Requirements/Considerations:

1. Design Conditions:
   a. Boiler Load: Btu/Hr, or MBH.
   b. Steam Pressure and Flow Rate.
   c. Fuel Input: Gas, Fuel Oil, Electric, etc.
   d. Overall Boiler Efficiency.
   e. Fouling Factor.
   f. Electrical Data:
      1) Unit KW, Blower Hp, Compressor Hp, and Fuel Oil Pump Hp.
      2) Full Load, Running Load and Locked Rotor Amps.
      3) Voltage-Phase-Hertz.
2. Multiple steam boilers should be used to prevent complete system or building shut down upon failure of 1 steam boiler in all steam systems over 70 boiler horsepower or 2,400,000 Btu/Hr. (i.e., 2 @ 50%, 2 @ 67%, 2 @ 70%, 3 @ 34%, 3 @ 40%).
3. Show tube clean/pull clearances and location.
4. Minimum recommended clearance around boilers is 36 inches. Maintain minimum clearances for tube pull and cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length of the boiler. Maintain minimum clearance as required to open access and control doors on boilers for service, maintenance, and inspection.
5. Mechanical room locations and placement must take into account how boilers can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

6. Maintain minimum electrical clearances as required by NEC.
7. Show location of boiler starter, disconnect switch, and control panel.
8. Show gas train and/or fuel oil train location.
9. Show boiler relief piping.
10. Show sanitary drain locations and boiler drain connections.
11. Design and locate combustion air louvers and motorized dampers or engineered combustion air system. What happens if engineered combustion air system malfunctions? Is standby available? Verify that items that might freeze are not located in front of combustion air intake.
12. Coordinate height of boiler with overhead clearances and obstructions. Is beam required above boiler for lifting components? Is catwalk required to service boiler?
13. Boiler stack and breeching. Coordinate routing in boiler room, through building, and discharge height above building with architect and structural engineer.
14. Provide stop check valve (located closest to the boiler) and isolation valve with a drain between these valves on the steam supply connections to all steam boilers.
15. Combustion air dampers must be extra heavy duty and should be low leakage (10 CFM/sq.ft. @ 4″wc differential) or ultralow leakage (6 CFM/sq.ft. @ 4″wc differential) type.
16. When the system design requires the use of dual fuel boilers (natural gas, fuel oil), provide a building automation control system I/O point to determine whether the boiler is on natural gas or fuel oil. Boiler control panels generally have a fuel type switch (Gas/Off/Fuel Oil Switch) which can be connected to create this I/O point. Switching from natural gas to fuel oil (or vice versa) cannot be a fully automatic operation, because the boiler operator must first turn boiler burner to the "Off" position, then turn fuel type switch to fuel oil, then put combustion air linkage into fuel oil position, then slide fuel oil nozzle into position, then put fuel oil pump into "Hand" or "Auto" position, and then turn the boiler burner to the "On" position. Remember to interlock the fuel oil pumps with operation of the boiler on fuel oil. Do not forget to include diesel generator interlocks with fuel oil pumps when the generators are fed from the same fuel oil system.
17. Steam System Warm-Up Procedure:
    a. Steam system start-up should not exceed 100°F. temperature rise per hour (50 psig per hour); boiler or heat exchanger manufacture limitations should be consulted.
    b. It is recommended that no more than a 25°F. temperature rise per hour (15 psig per hour) be used when warming steam systems. Slow warming of the steam system allows for system piping, supports, hangers, and anchors to keep up with system expansion.
    c. Low pressure steam systems (15 psig and less) should be warmed slowly at 25°F. temperature rise per hour (15 psig per hour) until system design pressure is reached.
    d. Medium and high pressure steam systems (above 15 psig) should be warmed slowly at 25°F. temperature rise per hour (15 psig per hour) until 250°F-15 psig system temperature-pressure is reached. At this temperature-pressure the system should be permitted to settle for at least 8 hours or more (preferably overnight). The temperature-pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 120 psig or system design pressure in 25 psig pressure increments, and allow the system to settle for an hour before increasing the pressure to the next increment. When the system reaches 120 psig and the design pressure is above 120 psig, the system should be allowed to settle for at least 8 hours or more (preferably overnight). The pressure maintenance time gives the system piping, hangers, supports, and anchors a chance to catch up with the system expansion. After allowing the system to settle, the system can be warmed up to 300 psig or system design pressure in 25 psig pressure increments, and allow the system to settle for an hour before increasing the pressure to the next increment.

18. Provide steam systems with warm-up valves for in service start-up as shown in the following table. This will allow operators to warm these systems slowly and to prevent a sudden shock or catastrophic system failure when large system valves are opened. Providing warming valves also reduces wear on large system valves when only opened a small amount in an attempt to control system warm-up speed.

Bypass and Warming Valves

MAIN VALVE NOMINAL PIPE SIZE	NOMINAL PIPE SIZE	
	SERIES A WARMING VALVES	SERIES B BYPASS VALVES
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

1. **Series A covers steam service for warming up before the main line is opened, and for balancing pressures where lines are of limited volume.**
2. **Series B covers lines conveying gases or liquids where bypassing may facilitate the operation of the main valve through balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.**

19. Steam System Warming Valve Procedure:
    a. Slowly open the warming supply valve to establish flow and to warm the system.
    b. Once the system pressure and temperature have stabilized, then proceed with the following items listed below, one at a time:
        1) Slowly open the main supply valve.
        2) Close the warming supply valve.
20. If isolators are required for the boiler, has isolator height been considered in clearance requirements? If isolators are required for the boiler, has piping isolation been addressed?

H. Low Water Cutoffs:

1. Primary: Float Type.
2. Auxiliary: Probe Type.

3. Low Water Cutoffs should be tested by Evaporation Test:
   a. Take boiler to low fire.
   b. Shut off feed water to boiler.
   c. Operate boiler until low water cutoff shuts down boiler or water level in gauge glass falls below low water cutoff activation point, but still remains visible in glass.
   d. Conduct evaporation test at least every 30 days; recommend once a week.
4. Class I Boilers. Low water cutoff is 3″ above top row of tubes in fire tube boilers.
5. Class IV Boilers. Low water cutoff is 0″ to ¼″ above top row of tubes in fire tube boilers.
6. WATER SHOULD ALWAYS BE VISIBLE IN GAUGE GLASS.
   IF WATER IS NOT VISIBLE IN GAUGE GLASS, IMMEDIATELY FOLLOW THE TWO STEPS BELOW ONE AFTER ANOTHER IN ANY ORDER:
   SHUT OFF BOILER BURNER.
   SHUT OFF BOILER FEED WATER.
   THEN ALLOW BOILER TO COOL AND INSPECT FOR DAMAGE.

I. Deaerator or Feedwater Tank:

1. The deaerator or the feedwater tank purpose is to remove oxygen, carbon dioxide, hydrogen sulfide, and other non-condensable gases and to heat boiler feedwater.
2. They also preheat the feed water prior to being pumped to the boiler. Cold feed water temperatures may cause:
   a. Thermal Shock.
   b. Oxygen Rich Feed Water, which causes corrosion.
3. This equipment should remove oxygen in the water to levels measured in parts per billion (ppb).
4. Steam Vent on the Deaerator or Feedwater Tank. Steam should appear 12″ to 18″ above top of vent. If steam appears below 12″, the Deaerator or Feedwater Tank are not removing all the oxygen, carbon dioxide, hydrogen sulfide, and other non-condensable gases.
5. Deaerators should be used when:
   a. System pressure is 75 psig and higher.
   b. Steam systems with little or no standby capacity.
   c. System depends on continuous operation.
   d. System requires 25% or more of makeup water.

J. Sizing Boiler Feed Pumps, Condensate Return Pumps, and Condensate Receivers:

1. If boiler is under 50 psi, size boiler feed pumps or condensate return pumps to discharge at 5 psi above working pressure.
2. If boiler is over 50 psi, size boiler feed pumps or condensate return pumps to discharge at 10 psi above working pressure.
3. Size condensate receivers for 1 minute net capacity based on return rate.
4. Size boiler feedwater system receivers for system capacity (normally estimated at 10 minutes):
   a. Deaerator Systems: 10 minute supply.
   b. Feedwater Tank Systems: 15 minute supply.
5. Size condensate pumps at 3 times the condensate return rate.
6. Size boiler feedwater pumps and transfer pumps at:
   a. Turbine Pumps, Intermittent Operation: 2 times boiler maximum evaporation rate or 0.14 GPM per Boiler Hp.
   b. Centrifugal Pumps, Continuous Operation: 1.5 times boiler maximum evaporation rate or 0.104 GPM per Boiler Hp.
   c. Boiler Feed Water and Transfer Pump Selection Criteria:

    1) Continuous or Intermittent Operation.
    2) Temperature of Feed Water or Condensate.
    3) Flow Capacity (GPM).
    4) Discharge Pressure Required: Boiler Pressure Plus Piping Friction Loss.
    5) NPSH Requirement.
7. Boiler Feedwater Control Types:
   a. On/Off feedwater control is generally used with single boiler systems or in multiple boiler systems when one feedwater pump is dedicated to each boiler and is typically accomplished with a turbine pump.
   b. Level control is generally used with multiple boiler systems where feedwater pumps serve more than one boiler and is typically accomplished with a centrifugal pump.
8. Vacuum Type Steam Condensate Return Units: 0.1 GPM/1,000 Lbs./Hr. of connected load
9. Pumped Steam Condensate Return Units: 2.4 GPM/1,000 Lbs./Hr.

K. Boiler Blowdown Systems:

1. Bottom Blowdown. Bottom blowdown, sometimes referred to as manual blowdown, functions to remove suspended solids and sediment that have settled out of the water and deposited on the bottom of the boiler. Bottom blowdown is most effective with several short discharges in lieu of one long discharge, because the solids settle out between discharges; this results in the greatest removal of suspended solids with least amount of water.
2. Surface Blowdown. Surface blowdown, sometimes referred to as automatic blowdown, continuous blowdown, or periodic blowdown, depending on how the blowdown is controlled, functions to remove dissolved solids, surface water scum, and foam to maintain proper conductivity levels:
   a. Automatic:
      1) Conductivity Probe.
      2) Timer.
   b. Continuous.
   c. Periodic (manual) by Time.

L. Boiler Blowdown Separator Makeup:

1. Non-continuous blowdown (bottom blowdown): 5.0 GPM/1,000 Lbs./Hr.
2. Continuous blowdown (surface blowdown): 0.5 GPM/1,000 Lbs./Hr.

M. Blowdown Separator Drains: 10 GPM/1000 Lbs./Hr Boiler Output.

N. Steam Boiler Water Makeup:

1. Boilers: 4.0 GPM/1,000 Lbs./Hr. Each.
2. Deaerator/Feed Water Unit: 4.0 GPM/1,000 Lbs./Hr. Each.
3. Makeup water for the steam system is only required at one of the boilers or one of the feed water units at any given time, for system sizing.

O. Chemical Feed Systems for Steam Boilers. Chemical feed systems are designed to control the following:

1. System pH, normally between 8 and 9.
2. Oxygen Level, less than 0.007 PPM (7 ppb).
3. Water Conditioning Level.
4. Carbon Dioxide Level.
5. Scale.
6. Corrosion.

20.13 Makeup Water Requirements

A. Hot Water System Makeup Connection: Minimum connection size shall be 10% of largest system pipe size or 1″, whichever is greater (20″ system pipe size results in a 2″ makeup water connection).

B. Chilled Water System Makeup Connection: Minimum connection size shall be 10% of largest system pipe size or 1″, whichever is greater (20″ system pipe size results in a 2″ makeup water connection).

C. Condenser Water Makeup to Cooling Tower:

1. Centrifugal: 40 GPM/1,000 Tons
2. Reciprocating: 40 GPM/1,000 Tons
3. Screw Chillers: 40 GPM/1,000 Tons
4. Absorption Chillers: 80 GPM/1,000 Tons

D. Cooling Tower Blowdown and Drains:

1. Drains: Use 2 times the makeup water rate for sizing cooling tower drains.
2. Blowdown:
    a. Centrifugal: 10 GPM/1,000 Tons
    b. Reciprocating: 10 GPM/1,000 Tons
    c. Screw: 10 GPM/1,000 Tons
    d. Absorption: 20 GPM/1,000 Tons

E. Steam Boiler Water Makeup:

1. Boilers: 4.0 GPM/1,000 Lbs./Hr. Each
2. Deaerator/Feed Water Unit: 4.0 GPM/1,000 Lbs./Hr. Each
3. Makeup water for the steam system is only required at one of the boilers or one of the feed water units at any given time, for system sizing.

F. Boiler Blowdown Separator Makeup:

1. Non-continuous blowdown (bottom blowdown): 5.0 GPM/1,000 Lbs./Hr.
2. Continuous blowdown (surface blowdown): 0.5 GPM/1,000 Lbs./Hr.

G. Blowdown Separator Drains: 10 GPM/1,000 Lbs./Hr Boiler Output.

H. Vacuum Type Steam Condensate Return Units: 0.1 GPM/1,000 Lbs./Hr. of connected load

I. Pumped Steam Condensate Return Units: 2.4 GPM/1,000 Lbs./Hr.

J. Humidifiers:

1. Steam Humidifiers: 5.6 GPM/1,000 KW Input or 5.6 GPM/3413 MBH
2. Electric Humidifiers: 5.6 GPM/1,000 KW Input or 5.6 GPM/3413 MBH
3. Evaporative Humidifiers: 5.0 GPM/1,000 Lbs./Hr.
4. Spray Coil Humidifiers: 5.0 GPM/1,000 Lbs./Hr.

K. Air Conditioning Condensate:

1. Unitary Packaged AC Equipment: 0.006 GPM/Ton
2. Air Handling Units (100% outside Air): 0.100 GPM/1,000 CFM
3. Air Handling Units (50% Outdoor Air): 0.065 GPM/1,000 CFM
4. Air Handling Units (25% Outdoor Air): 0.048 GPM/1,000 CFM

5. Air Handling Units (15% Outdoor Air): 0.041 GPM/1,000 CFM
6. Air Handling Units (0% Outdoor Air): 0.030 GPM/1,000 CFM

20.14 Water Treatment and Chemical Feed Systems

A. General:

1. Water Treatment Objectives:
   a. Prevent hard scale and soft sludge deposits.
   b. Prevent corrosion and pitting.
   c. Protect boiler, piping, and equipment metal chemistry.
   d. Prevent steam carryover.
2. Corrosion and Scale/Deposit Control Factors:
   a. pH Level: As the pH of the system water increases (moves toward the alkaline side of the scale), the corrosiveness of the water decreases. However, as the pH of the system water increases, the formation of scale increases. Normal pH range is 6.5 to 9. A typical pH range is 7.8 to 8.8. (Acid pH = 1; Neutral pH = 7; Alkaline pH = 14.)
   b. Hardness: As the hardness of the system water increases, the corrosiveness of the water decreases. However, as the hardness of the system water increases, the formation of scale increases.
   c. Temperature: As the temperature of the system water increases, the corrosiveness of the water increases. In addition, as the temperature of the system water increases, the formation of scale increases. Corrosion rates double for every 20°F increase in water temperature.
   d. Foulants: The more scale-forming material and foulants in the system water, the greater the chances of scale and deposit formation. Foulants include calcium, magnesium, biological growth (algae, fungi, and bacteria), dirt, silt, clays, organic contaminants (oils), silica, iron, and corrosion by-products.
3. Water Treatment Limits:
   a. Oxygen: Less than 0.007 ppm (7 ppb).
   b. Hardness: Less than 5.0 ppm.
   c. Suspended Matter: Less than 0.15 ppm.
   d. pH: 8 to 9.
   e. Silicas: Less than 150 ppm.
   f. Total Alkalinity: Less than 700 ppm.
   g. Dissolved Solids: Less than 7,000 μmho/cm.
4. Water Source Comparison:
   a. Surface Water:
      1) High in Suspended Solids.
      2) High in Dissolved Gases.
      3) Low in Dissolved Solids.
   b. Well Water:
      1) High in Dissolved Solids.
      2) Low in Suspended Solids.
      3) Low in Dissolved Gases.
5. Suspended Solids:
   a. Dirt.
   b. Silt.
   c. Biological Growth.
   d. Vegetation.
   e. Insoluble Organic Matter.

  f. Undissolved Matter.
  g. Iron.
6. Hardness measures the amount of calcium and magnesium in the water.
7. Alkalinity measures the water's ability to neutralize strong acid.
8. Scale is the result of precipitation of hardness salts on heat exchange surfaces.
9. Corrosion is the dissolving or wearing away of metals:
  a. General Corrosion. General corrosion is caused by acidic conditions.
  b. Under-Deposit Corrosion. Under-deposit corrosion is caused by foreign matter resting on a metal surface.
  c. Erosion. Erosion is caused by turbulent water flow.
  d. Pitting Corrosion. Pitting corrosion is caused by the presence of oxygen.
  e. Galvanic Corrosion. Galvanic corrosion is a electrochemical reaction between dissimilar metals.
10. Problems Caused by Poor Water Quality:
  a. Scale and Deposits.
  b. Decreased Efficiency/Heat Transfer.
  c. Equipment Failure/Unscheduled Shutdowns.
  d. Corrosion.
  e. Tube Burnout or Fouling.
  f. Carryover in Steam Systems.
11. Chemical Types:
  a. Scale Inhibitors. Scale inhibitors prevent scale formation:
    1) Phosphonate.
    2) Polyacrylate.
    3) Polymethacrylate.
    4) Polyphosphate.
    5) Polymaleic Acid.
    6) Sulfuric Acid.
  b. Biocides. Biocides prevent biological growth.
    1) Oxidizing:
      a) Chlorine. Most Common.
      b) Chlorine Dioxide.
      c) Bromine. Most Common.
      d) Ozone.
    2) Non-Oxidizing:
      a) Carbamate. Most Common.
      b) Organo-Bromide.
      c) Methylenebis-Thiocyanate.
      d) Isothiazoline.
      e) Quartarnary Ammonium Salts.
      f) Organo-Tin/Quaternary Ammonium Salts.
      g) Glutaraldehyde.
      h) Dodecylguanidine.
      i) Triazine.
      j) Thiocynates.
      k) Quartarnary Ammonium Metalics.
    3) Biocide treatment program should include alternate use of oxidizing and non-oxidizing biocides for maximum effectiveness; see following table:

BIOCIDE	EFFECTIVENESS AGAINST			COMMENTS
	BACTERIA	FUNGI	ALGAE	
Oxidizing Biocides				
Chlorine (Cl_2)	E	G	G	Usable pH range 5 to 8 Effective at neutral pH (pH = 7) Less effective at high pH Reacts with -NH_2 groups
Chlorine Dioxide (ClO_2)	E	G	G	Insensitive to pH levels Insensitive to presence of -NH_2 groups
Bromine	E	G	P	Usable pH range 5 to 10 Effective over broad pH range Substitute for chlorine
Ozone	E	G	G	pH range 7 to 9
Non-Oxidizing Biocides				
Carbamate	E	E	G	pH range of 5 to 9 Good in high suspended solids systems In-compatible with chromate treatment programs
Organo-Bromide (DBNPA)	E	P	P	pH range 6 to 8.5
Methylenebis-Thiocyanate (MBT)	E	P	P	Decomposes above a pH of 8
Isothiazoline	E	G	G	Insensitive to pH levels Deactivated by HS and -NH_2 groups
Quaternary Ammonium Salts	E	G	G	Tendency to foam Surface active Ineffective in organic-fouled systems
Organo-Tin/ Quaternary Ammonia Salts	E	G	E	Tendency to foam Functions best in alkaline pH
Glutaraldehyde	E	E	G	Effective over broad pH range Deactivated by -NH_2 groups
Dodecylguanidine (DGH)	E	E	G	pH range of 6 to 9
Triazine	N	N	E	pH range of 6 to 9 Specific for algae control Must be used with other biocides

Notes:

1. Table Abbreviations:
   E = Excellent Biocide Control.
   G = Good Biocide Control.
   P = Poor Biocide Control.
   N = No Biocide Control.

c. Corrosion Inhibitors. Corrosion inhibitors prevent corrosion:
   1) Molybdate. Most common and most effective.
   2) Nitrite. Most common.
   3) Aromatic Azoles.
   4) Chromate.
   5) Polyphosphate.
   6) Zinc.
   7) Orthophosphate.
   8) Benzotriazole. Copper Corrosion Inhibitor.
   9) Tolyltriazole. Copper Corrosion Inhibitor.
   10) Silicate. Copper and Steel Corrosion Inhibitor.

   d. Dispersants. Dispersants prevent suspended and dissolved solids from settling out or forming scale in the system, remove existing deposits, and enhance biocide effectiveness:
      1) Polyacrylate.
      2) Polymethacrylate.
      3) Polymaleic Acid.
      4) Surfactants.
12. Corrosion monitoring is recommended with the use of corrosion coupons for closed and open hydronic systems.
13. Side stream filtration is recommended to maintain system cleanliness. Filters should be sized to filter the entire volume of the system 3 to 5 times per day.

B. Closed System Chemical Treatment (Chilled Water Systems, Heating Water Systems):

1. Chemical treatment objective is to prevent and control:
   a. Scale Formation.
   b. Corrosion. Major concern.
   c. System pH. Between 8 and 9.
2. Chemical Types Used in Closed Systems.
   a. Scale Inhibitors.
   b. Corrosion Inhibitors.
   c. Dispersants.
3. Most Common Chemicals Used:
   a. Molybdate.
   b. Nitritite Based Inhibitors.
4. Water analysis should be conducted at least once a year, preferably semiannually or quarterly, depending on system water losses.

C. Open System Chemical Treatment (Condenser Water Systems):

1. Chemical treatment objective is to prevent and control:
   a. Scale Formation.
   b. Fouling:
      1) Particulate Matter.
      2) Biological Growth.
   c. Corrosion.
   d. System pH. Between 8 and 9.
2. Chemical Types Used in Open Systems:
   a. Scale Inhibitors.
   b. Biocides.
   c. Corrosion Inhibitors.
   d. Dispersants.
3. Makeup water analysis should be conducted at least twice a year, preferably quarterly.
4. System water analysis should be conducted at least once a week.

D. Steam Systems:

1. Chemical treatment objective is to prevent and control:
   a. Scale Formation.
   b. Corrosion. Major concern.
   c. System pH. Between 8 and 9.
2. Chemical Types Used in Steam Systems:
   a. Scale Inhibitors.

   b. Corrosion Inhibitors.
   c. Dispersants.
3. Steam Boiler System Water Treatment Equipment:
   a. Pre-Treatment: Most Effective Way to Control Steam Boiler Chemical Treatment Issues:
      1) Softeners.
      2) Filters.
      3) Dealkalizers.
      4) RO Units.
   b. Pre-Boiler: Feed Water System Treatment (Deaerator, Feed Water Tank):
      1) An oxygen scavenger should be injected into the storage tank. Injection into the storage tank is the ideal location. It provides the maximum reaction time and protects feedwater tank, pumps, and piping.
      2) An oxygen scavenger can be injected into the feed water line, but is not recommended.
      3) Oxygen Scavenger Chemicals (see following table):
         a) Sodium Sulfite. Low and Medium Pressure Systems.
         b) Hydrazine. Medium and High Pressure Systems.

OXYGEN SCAVENGER	FEED WATER LEVELS	BOILER LEVELS
Sodium Sulfite	10 to 15 ppm	30 to 60 ppm
Hydrazine	0.05 to 0.1 ppm	0.1 to 0.2 ppm

   c. Boiler: Organic Treatment Program:
      1) Scale control chemicals should be injected directly into the boiler; however, they may be injected into the feedwater tank or feed water line.
      2) Polymers. Most common.
      3) Phosphonate.
   d. After-Boiler: Steam and Condensate Pipe Treatment:
      1) Amines:
         a) Neutralizing Amines. Neutralize carbonic acid; may be injected into the boiler or steam header.
         b) Filming Amines. Injected into the steam header.
      2) Injection Location:
         a) Steam Header. Best Location.
         b) Boiler.
         c) Feed Water. Worst Location; Not Recommended.
         d) These chemical can be injected anywhere along the steam piping for better localized protection, especially in long piping runs.
4. Chemical Feed Methods:
   a. Shot Feed or Batch Process. Not Recommended.
   b. Continuous:
      1) Manual Control:
         a) Continuous.
         b) Clock Timer.
         c) Percent Timer.

2) Automated Control:
   a) Activated with Feed Water Pump.
   b) Activated with Makeup Water Flow Control.
   c) Activated with Burner Control.
5. Makeup water analysis should be conducted at least twice a year, preferably quarterly.
6. System water analysis should be conducted at least once a week.

20.15 Fuel Systems and Types

A. Fuel System Design Guidelines:

1. Natural Gas Pressure Reducing Valves (NGPRV):
   a. Use multiple NGPRVs when system natural gas capacity exceeds 2″ NGPRV size, when normal operation calls for 10% of design load for sustained periods, or when there are two distinct load requirements (i.e., summer/winter) which are substantially different. Provide the number of NGPRVs to suit the project:
      1) If system capacity for a single NGPRV exceeds 2″ NGPRV size but is not larger than 4″ NGPRV size, use 2 NGPRVs with 33% and 67% or 50% and 50% capacity split.
      2) If system capacity for a single NGPRV exceeds 4″ NGPRV size, use 3 NGPRVs with 25%, 25%, and 50% or 15%, 35%, and 50% capacity split to suit project.
   b. Provide natural gas pressure regulating valves with positive shutoff ability to prevent building natural gas system from becoming equal to gas utility system pressure when the building natural gas system is not using gas.
2. Natural gas meters should be provided as follows:
   a. Coordinate equipment, building, or site meter requirements with local utility company. If project budget permits, these meter readings should be logged and recorded at the building facilities management and control system.
   b. Meter for a Campus or Site of Buildings. A site meter is generally provided by the utility company.
   c. Meter for Individual Buildings on a Campus. If fed from site meter, design documents should provide a meter for each building. This meter will assist in tracking energy use at each building and for troubleshooting system problems.
   d. Meter for Individual Buildings. A building meter will generally be provided by the utility company.
   e. Meters for Individual Boilers. A meter should be provided by the design documents for each and every boiler; environmental air permit requirements require natural gas to be monitored at each boiler.
   f. Meters for Other Major Users. A meter should be provided by the design documents for each major user within the building (emergency generators, gas fired AHUs, domestic water heaters, unit heaters, kitchens).
3. Boiler fuel oil pump flow rates and generator day tank pump flow rates are generally 2.5 to 3.0 times the boiler and generator consumption rates. Confirm with the manufacture or the electrical engineer that the information received is the consumption rate of the boiler/generator or fuel oil pumping rate of the boiler/generator. When boilers are located above the fuel oil tanks, a method of preventing back siphoning through the return line must be provided. This may be accomplished by providing the return line with a pressure regulator or with an operated valve interlocked with the fuel oil pump. Also, the fuel oil pumps must be provided with a check valve in the discharge, or if large height differentials are required, a motorized discharge isolation valve interlocked with the pump may be required because check valves will leak.
4. Fuel oil meters should be provided as follows:

a. If the fuel oil system is a circulating system with a fuel oil return line, meters must be provided in both the supply and return to determine fuel oil consumed. Most manufacturers provide fuel oil meters with this capability with controls and software to automatically calculate fuel oil consumed. If project budget permits, these meter readings should be logged and recorded at the building facilities management and control system. All fuel oil meters must be shown on the design documents. Environmental regulations require the fuel oil purchased verses fuel oil consumed be recorded and tracked for determining when leaks may be occurring in the system.
b. Meter for each Group of Site Distribution Pumps located at the pumps.
c. Meter for individual buildings on a Campus located at each building. This meter will assist in tracking energy use at each building and for troubleshooting system problems.
d. Meters for Individual Boilers. A meter should be provided for each and every boiler; environmental air permit requirements require fuel oil to be monitored at each boiler.
e. Meters for Other Major Users. A meter should be provided for each major user within the building (emergency generators, gas fired AHUs, domestic water heaters, unit heaters).

B. Natural Gas:

1. 900–1200 Btu/Cu.Ft.
2. 1,000 Btu/Cu.Ft. Average.

C. Fuel Oil:

1. #2: 138,000 Btu/Gal.
2. #4: 141,000 Btu/Gal.
3. #5: 148,000 Btu/Gal.
4. #6: 152,000 Btu/Gal.

D. LP Gas:

1. Butane:
   a. 21,180 Btu/Lb.
   b. 3,200 Btu/Cu.Ft.
2. Propane:
   a. 21,560 Btu/Lb.
   b. 2,500 Btu/Cu.FT.

E. Electric:

1. 3,413 Btuh/KW.
2. 3.413 Btuh/watt.

F. Coal:

1. Anthracite: 14,600–14,800 Btu/Lb.
2. Bituminous: 13,500–15,300 Btu/Lb.

G. Wood:

1. 8,000–10,000 Btu/Lb.

H. Kerosine:

1. 135,000 Btu/Gal.

20.16 Automatic Controls

A. Control Design Guidelines:

1. 2-way control valves should be installed upstream of equipment so that equipment is not subject to pump pressures.
2. Proportional Band. Throttling range over which the regulating device travels from fully closed to fully open.
3. Drift or Offset. Difference between the set point and the actual control point.
4. Rangeability. Ratio of maximum free area when fully open to the minimum free area.
5. Bypass valves should be plug valves, ball valves, or a butterfly valves.
6. Control valves in HVAC systems should be the equal percentage type for output control, because equal percentage control valve flow characteristics are opposite of coil capacity characteristics.
   a. Do not oversize control valves; most control valves are at least one to two sizes smaller than the pipe size.
   b. The greater the resistance at design flow the better the controllability.
   c. Control Valve Pressure Drop:
      1) Minimum Control Valve Pressure Drop: 5% of total system pressure drop.
      2) Preferred Control Valve Pressure Drop: 10 to 15% of total system pressure drop.
      3) Maximum Control Valve Pressure Drop: 25% of total system pressure drop.
   d. When specifying control valves include:
      1) Maximum design flow.
      2) Minimum design flow.
      3) Internal pressure.
      4) Pressure drop at design flow.
      5) Pressure drop at minimum flow.
7. 2-Way Control Valves:
   a. 2-way control valves should be selected for a resistance of 20 to 25 percent of the total system resistance at the valve location. This results in selecting the control valves for the available head at each location requiring a different pressure drop for each valve in direct return systems. In reverse return systems, control valves may be selected with equal pressure drop requirements. If control valves are selected for the pressure drop at each location, balancing valves are not required for external balancing of systems unless the pressure differential at the control valve location becomes excessive. Variable volume systems will be self-balancing.
8. 3-Way Control Valves:
   a. 3-way control valves exhibit linear control characteristics which are not suited for output control at terminal units.
   b. If 3-way control action is desired to maintain minimum flow requirements, use 2 opposed-acting, equal percentage, 2-way valves. A balancing valve must be installed in the bypass adjusted to equal the coil pressure drop. Operate valves sequentially in lieu of simultaneously, because if both valves are operated simultaneously, significant flow variations may occur.
   c. The 3-way valve pressure drop should be greater than the pressure drop (up to twice the pressure drop) of the coil it serves with a balancing valve in the bypass. The bypass valve pressure drop should be adjusted to equal to the coil pressure drop. A balancing valve or flow control device should be installed in the return downstream of the 3-way valve.
9. Do not use On/Off type control valves, except for small line sizes (1 inch and smaller).
10. Provide a fine mesh strainer ahead of each control valves to protect the control valve.

B. Control Definitions: Control definitions listed below were taken from the *Honeywell Control Manual* listed in Part 2:

1. Algorithm: A calculation method that produces a control output by operating on an error signal or a time series of error signals. Operational logic effected by a control system usually resident in controlled hardware or software.
2. Amplifiers: Amplifiers condition the control signal, including linearization, and raise it to a level adequate for transmission and use by controllers.
3. Analog: Continuously variable (i.e., mercury thermometer, clock, faucet controlling water from closed to open).
4. Authority: The effect of the secondary transmitter versus the effect of the primary transmitter.
5. Automatic Control System: A system that reacts to a change or imbalance in the variable it controls by adjusting other variables to restore the system to the desired balance.
6. Binary: A distinct variable, a noncontinuous variable (i.e., digital clock, digital thermometer, digital radio dial) also related to computer systems and the binary numbering system (base 2).
7. Closed Loop Control System: Sensor is directly affected by the action of the controlled device, system feedback.
8. Contactors: Similar to relays, but are made with much greater current carrying capacity. Used in devices with high power requirements.
9. Controls: As related to HVAC, three elements are necessary to govern the operation of HVAC systems:
   a. Sensor: A device or component that measures the value of the variable (i.e., temperature, pressure, humidity).
   b. Controller: A device that senses changes in the controlled variable, internally or remotely, and derives the proper corrective action and output to be taken (i.e., receiver/controller, DDC panel, thermostat).
   c. Controlled Device: That portion of the HVAC system that effects the controlled variable (i.e., actuator, damper, valve).
10. Control Action: Affect on a control device to create a response.
11. Controlled Agent: The medium in which the manipulated variable exists (i.e., steam, hot water, chilled water).
12. Controlled Medium: The medium in which the controlled variable exists (i.e., the air within the space).
13. Controlled Variable: The quantity or condition that is measured and controlled (i.e., temperature, flow, pressure, humidity, three states of matter).
14. Control Point: Actual value of the controlled variable (set point plus or minus set point).
15. Corrective Action: Control action that results in a change of the manipulated variable.
16. Cycle: One complete execution of a repeatable process.
17. Cycling: A periodic change in the controlled variable from one value to another. Uncontrolled cycling is called "hunting."
18. Cycling Rate: The number of cycles completed per unit time, typically cycles per hour.
19. Dampers: Dampers are mechanical devices used to control airflow:
   a. Quick Opening: Maximum flow is approached as the damper begins to open.
   b. Linear: Opening and flow are related in direct proportion.
   c. Equal Percentage: Each equal increment of opening increases flow by an equal percentage over the previous value.
   d. Opposed Blade: Balancing, mixing, and modulating control applications. Half of the blades rotate in one direction, while the other half rotate in the other direction:
      1) At low pressure drops opposed blade dampers tend to be equal percentage.
      2) At moderate pressure drops opposed blade dampers tend to be linear.

   3) At high pressure drops opposed blade dampers tend to be quick opening.
   e. Parallel Blade: 2-position control applications. All the blades rotate in a parallel or in the same direction:
      1) At low pressure drops parallel blade dampers tend to be linear.
      2) At high pressure drops parallel blade dampers tend to be quick opening.
20. Deadband: A range of the controlled variable in which no corrective action is taken by the controlled system and no energy is used.
21. Discriminator: A device which accepts a large number of inputs (up to twenty) and selects the appropriate output signal (averaging relay, high relay, low relay).
22. Deviation: The difference between the set point and the value of the controlled variable at any moment. Also called offset.
23. DDC: Direct Digital Control.
24. Differential: The difference between the turn-on signal and the turn-off signal.
25. Digital: Series of On and Off pulses arranged to carry messages (i.e., digital radio and TV dials, digital clock, computers).
26. Digital Control: A control loop in which a microprocessor based controller directly controls equipment based on sensor inputs and set point parameters. The programmed control sequence determines the output to the equipment.
27. Direct Acting: Controller is direct acting when an increase in the level of the sensor signal results in an increase in the level of the controller output.
28. Droop: A sustained deviation between the control point and the set point in a 2-position control system caused by a change in the heating or cooling.
29. Dry Bulb Control: Control of the HVAC system based on outside air dry bulb temperature (sensible heat).
30. Electric Control: A control circuit that operates on line or low voltage and uses a mechanical means, such as temperature-sensitive bimetal or bellows, to perform control functions.
31. Electronic Control: A control circuit that operates on low voltage and uses solid state components to amplify input signals and perform control functions.
32. Enthalpy Control: Control of the HVAC system based on outside air enthalpy (total heat).
33. Fail Closed: Position device will assume when system fails (i.e., fire dampers fail closed).
34. Fail Open: Position device will assume when system fails (i.e., present coil valves fail open).
35. Fail Last Position: Position device will assume when system fails (i.e., process coding water valve fails in last position).
36. Final Control Element: A device such as a valve or damper that acts to change the value of the manipulated variable (i.e., controlled device).
37. Floating Action: Dead spot or neutral zone in which the controller sends no signal but allows the device to float in a partly open position.
38. Gain: Proportion of control signal to throttling range.
39. In Control: Control point lies within the throttling range.
40. Interlocks: Devices which connect HVAC equipment so that operation is interrelated and systems function as a whole.
41. Lag: A delay in the effect of a changed condition at one point in the system, or some other condition to which it is related. Also, the delay in response of the sensing element of a control due to the time required for the sensing element to sense a change in the sensed variable.
42. Lead/Lag: A control method in which the selection of the primary and secondary piece of equipment is obtained and alternated to limit and equalize wear on the equipment.
43. Manipulated Variable: The quantity or condition regulated by the automatic control system to cause desired change in the controlled variable.
44. Measured Variable: A variable that is measured and may be controlled.

45. Microprocessor Based Control: A control circuit the operates on low voltage and uses a microprocessor to perform logic and control functions. Electronic devices are primarily used as sensors. The controller often furnishes flexible DDC and energy management control routines.
46. Modulating Action: The output of the controller can vary infinitely over the range of the controller.
47. Modulating Range: Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other.
48. Motor Starters: Electromechanical device which utilizes the principle of electromagnetism to start and stop electric motors, often containing solenoid coil actuators, relays, and overload protective devices.
49. Normally Closed: The position the device will assume when the control signal is removed (position of device in box prior to installation).
50. Normally Open: The position the device will assume when the control signal is removed (position of device in box prior to installation).
51. Offset: The difference between the control point and the set point.
52. On/Off Control: A simple 2-position control system in which the device being controlled is either full On or full Off with no intermediate operating positions available.
53. Open Loop Control System: Sensor is not directly affected by the action of the controlled device; no system feedback.
54. Out of Control: Control point lies outside of the throttling range.
55. Pigtail: A loop put in a sensing device to prevent the element from experiencing temperature or pressure extremes.
56. Pneumatic Control: A control circuit that operates on air pressure and uses a mechanical means, such as temperature sensitive bimetal or bellows, to perform control functions.
57. Proportional Control: A control algorithm or method in which the final control element moves to a position proportional to the deviation of the value of the controlled variable from the set point. Cyclical control (sine/cosine).
58. Proportional-Integral (PI) Control: A control algorithm that combines the proportional (proportional response) and integral (reset response) control algorithms. Cyclical control but automatically narrows the band between upper and lower points. Use most common in commercial building applications.
59. Proportional-Integral-Derivative (PID) Control: A control algorithm than enhances the PI control algorithm by adding a component that is proportional to the rate of change (derivative) of the deviation of the controlled variable. Compensates for system dynamics and allows faster control response. Cyclical control, but automatically narrows the band between upper and lower points and also calculates time between peak high and peak low and adjusts accordingly. Use most common in industrial applications.
60. Relays: An electromagnetic device for remote or automatic control actuated by variation in conditions of an electric circuit and operating in turn other devices (as switches) in the same or different circuit. Carry low-level control voltages and currents.
61. Reverse Acting: Controller is reverse acting when an increase in the level of the sensor signal results in a decrease in the level of the controller output.
62. Sensing Element: A device or component that measures the value of the variable.
63. Sensitivity: Proportion of control signal to throttling range.
64. Set Point: Desired value of the controlled variable (usually in the middle of the throttling range).
65. Snubber: Put on a sensing device to prevent sporadic fluctuations from reaching the sensing device.
66. Step Control: Control method in which a multiple-switch assembly sequentially switches equipment as the controller input varies through the proportional band.

67. Time Delay Relays: Relays which provide a delay between the time the coil is energized and the time the contactors open and/or close.
68. Thermistor: A solid state device in which resistance varies with temperature.
69. Throttling Action: Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other.
70. Throttling Range: Amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other. Also referred to as proportional band.
71. Transducers: Device which changes a pneumatic signal to an electric signal or vice versa. Pneumatic-Electric (PE) or Electric-Pneumatic (EP) switches (2-position transducer or analog to analog).
72. Turndown Ratio: The minimum flow or capacity of a piece of equipment expressed as a ratio of maximum flow/capacity to minimum flow/capacity. The higher the ratio, the better the control.
73. 2-Position Control: Control system in which the device being controlled is either full On or full Off with no intermediate operating positions available (On/Off; open/closed; also called On/Off control).
74. Valves: Valves are mechanical devices used to control flow of steam, water, gas and other fluids:
    a. 2-Way: Temperature Control, Modulate Flow to Controlled Device, Variable Flow System.
    b. 3-Way Mixing: Temperature Control, Modulate Flow to Controlled Device, Constant Flow System; 2 inlets and 1 outlet.
    c. 3-Way Diverting: Used to Divert Flow; generally cannot modulate flow—2 position; 1 inlet and 2 outlets.
    d. Quick Opening Control Valves: Quick opening control valves produce wide free port area with relatively small percentage of total valve stem stroke. Maximum flow is approached as the valve begins to open.
    e. Linear Control Valves: Linear control valves produce free port areas that are directly related to valve stem stroke. Opening and flow are related in direct proportion.
    f. Equal Percentage Control Valves: Equal percentage control valves produce an equal percentage increase in the free port area with each equal increment of valve stem stroke. Each equal increment of opening increases flow by an equal percentage over the previous value (most common HVAC control valve).
    g. Control valves are normally smaller than line size unless used in 2-position applications (open/closed).
    h. Control valves should normally be sized to provide 20 to 60% of the total system pressure drop:
        1) Water system control valves should be selected with a pressure drop equal to 2–3 times the pressure drop of the controlled device.

           OR

           Water system control valves should be selected with a pressure drop equal to 10 Ft. or the pressure drop of the controlled device whichever is greater.

           OR

           Water system control valves for constant flow systems should be sized to provide 25% of the total system pressure drop.

           OR

           Water system control valves for variable flow systems should be sized to provide 10% of the total system pressure drop or 50% of the total available system pressure.
        2) Steam control valves should be selected with a pressure drop equal to 75% of inlet steam pressure.

C. Types of Control Systems:

1. Pneumatic:
   a. Safe.
   b. Reliable.
   c. Proportional.
   d. Inexpensive.
   e. Fully modulating or 2-position in nature.
   f. Seasonal calibration required.
   g. If there are more than a couple dozen control devices in a building, then pneumatic controls would be less expensive than electric or electronic controls.
   h. Widely used in commercial, institutional and industrial facilities.
   i. Pneumatic control system pressure signals:
      1) Typical Heating: 0–7 psi.
      2) Typical Cooling: 8–15 psi.
      3) Max. System Pressure: 30 psi.
   j. Compressor run time should be ⅓ to ½ the operating time.
2. Electric:
   a. Simple control systems.
   b. Used on small HVAC systems.
   c. Mostly used for starting and stopping equipment.
   d. Electric control system signals:
      1) 120 volts and less AC or DC.
      2) Typically 120 volts or 24 volts.
3. Electronic:
   a. Used widely in pre-packaged control systems.
   b. Fully modulating in nature.
   c. Reasonably inexpensive.
   d. Electronic control system signals:
      1) 24 volts or less AC or DC.
      2) Typical voltage signal range of 0 to 10 volts.
      3) Typical amperage signal range of 4 to 20 milliamps.
4. Direct Digital Control (DDC):
   a. Computerized control.
   b. Fully modulating, start/stop and staged control.
   c. Faster and more accurate than all other control systems.
   d. Control systems can be adapted and changed to suit field conditions. Very flexible.
   e. Able to communicate measured, control, input and output data over a network.
   f. Fairly expensive.
   g. Often DDC systems use DDC Controllers and pneumatic actuators to operate valves, dampers and other devices.
   h. DDC system signals:
      1) Typical voltage signal range of 0 to 10 volts DC.
      2) Typical amperage signal range of 4 to 20 milliamps.

D. Control System Objectives:

1. Define Control Functions:
   a. Start/Stop.
   b. Occupied/Unoccupied/Preparatory.
   c. Fan Capacity Control:
      1) Variable Speed Drives.
      2) Inlet Vanes.

      3) Two-Speed Motors.
      4) Discharge Dampers.
      5) Scroll Volume Control.
      6) SA, RA, RFA Fan Tracking.
   d. Pump Capacity Control:
      1) Variable Speed Drives.
      2) Two-Speed Motors.
      3) Variable Flow Pumping Systems (2-Way Control Valves).
   e. Damper Control (OA, RA, RFA, Inlet Vanes).
   f. Valve Control (2-way, 3-way).
   g. Temperature.
   h. Humidity.
   i. Pressure.
   j. Flow.
   k. Temperature Reset (SA, Water).
   l. Terminal Unit Control (room, discharge, sub-master).
   m. Modulate, sequence, cycling.
2. Define Interlock Functions:
   a. Fans/AHUs.
   b. Pumps/Boilers/Chillers.
   c. Smoke Control System Interlocks.
3. Define Safety Functions:
   a. Fire.
   b. Smoke.
   c. Freeze Protection.
   d. Low/High pressure limit.
   e. Low/High temperature limit.
   f. Low/High water.
   g. Low/High flow.
   h. Over/Under electrical current.
   i. Vibration.
4. Alarm Functions (most often safety alarms).
5. Typical Control Algorithms:
   a. Occupied/Unoccupied/Preparatory (Time of Day Scheduling).
   b. Night/Weekend/Holiday (Time of Day/Week/Year Scheduling).
   c. AHU Dry-Bulb Economizer.
   d. AHU Enthalpy Economizer.
   e. Boiler OA Reset.
   f. AHU Discharge Air Control.
   g. AHU Discharge Air Control with Room Reset.
   h. AHU VAV Pressure Independent.
   i. AHU VAV Pressure Dependent.
   j. Chiller Discharge Water Reset.
   k. Daylight Savings Time Adjustments.
   l. Electrical Demand Limiting.
   m. Start/Stop Optimization.
   n. Duty Cycle.
   o. Enthalpy Optimization.
   p. Smoke Control.
   q. Trending.

r. Alarm Instructions.
s. Maintenance Work Order.
t. Run Time Totalizing.

E. Types of Controls:

1. Operating Controls: Operating controls are used to control a device, system, or entire facility in accordance with the needs of the device, system or facility.
2. Safety Controls: Safety controls are used to protect the device, system, or facility from damage should some operating characteristic get out of control; to prevent catastrophic failure of the device or system; and to prevent harm to the occupants of the facility. Most safety controls come in the form of high or low limits:
   a. Automatic reset.
   b. Manual reset.
3. Operator Interaction Controls: Controls in which the building occupant would normally be provided with to activate various HVAC equipment devices or systems.

F. Building Automation and Control Networks (BACnet):

1. BACnet is a communication protocol. A communication protocol is a set of rules governing the exchange of data between two computers. A protocol encompasses both hardware and software specifications including the following:
   a. Physical medium.
   b. Rules for controlling access to the medium.
   c. Mechanics for addressing and routing messages.
   d. Procedures for error recovery.
   e. The specific formats for the data being exchanged.
   f. The contents of the messages.
2. The BACnet goal is to enable building automation and control devices from different manufactures to communicate.
3. BACnet Data Structures:
   a. Analog Input.
   b. Analog Output.
   c. Analog Value.
   d. Binary Input.
   e. Binary Output.
   f. Binary Value.
   g. Calendar: Represents a list of dates that have special meaning when scheduling the operation of mechanical equipment.
   h. Command.
   i. Device: Contains general information about a particular piece of mechanical equipment (i.e., model, location).
   j. Device Table: Shorthand reference to a list of devices.
   k. Directory: Provide information on how to access other objects.
   l. Event Enrollment: Provides a way to define alarms or other types of events.
   m. File.
   n. Group: Shorthand method to access a number of values in one request.
   o. Loop: Represents a feedback control loop (PID).
   p. Mailbox.
   q. Multi-State Input.
   r. Multi-State Output.

s. Program.
t. Schedule.

4. BACnet Object Properties:
   a. Object Identifier.
   b. Object Type.
   c. Present Value.
   d. Description.
   e. Status Flags.
   f. Reliability.
   g. Override.
   h. Out-of-Service.
   i. Polarity.
   j. Inadactive Text.
   k. Active Text.
   l. Change-of-State Time.
   m. Elapsed Active Time.
   n. Change-of-State Count.
   o. Time of Reset.
5. BACnet Applications:
   a. Alarm and Event Services.
   b. File Access Services (Read, Write).
   c. Object Access Services (Add, Create, Delete, Read, Remove, Write).
   d. Remove Device Management Services.
   e. Virtual Terminal Services (Open, Close, Data).
6. BACnet Conformance Classes:
   a. Class 1. Class 1 devices are the lowest level in BACnet system structure and consist of smart sensors.
   b. Class 2. Class 2 devices consist of smart actuators.
   c. Class 3. Class 3 devices consist of unitary controllers.
   d. Class 4. Class 4 devices consist of general purpose local controllers.
   e. Class 5. Class 5 devices consist of operator interface controllers.
   f. Class 6. Class 6 devices are the highest level in BACnet system structure and consist of head-end computers.
7. BACnet Functional Groups:
   a. Clock.
   b. Hand-Held Workstation.
   c. Personal Computer Workstation.
   d. Event Initiation.
   e. Event Response.
   f. Files.
   g. Reinitialize.
   h. Virtual Operator Interface.
   i. Virtual Terminal.
   j. Router.
   k. Device Communications.
   l. Time Master.

PART 21

Auxiliary Equipment

21.01 Fans

A. Fan Types and Size Range are shown in the following table:

FAN TYPE	WHEEL\DRIVE TYPE	SP In.W.G.	WHEEL DIA.In.	CFM	Hp
Utility Sets	FC/B BI/B FC/D	0 - 3 0 - 4 0 - 2.5	8 - 36 10 - 36 6 - 12	200 - 27,500 250 - 27,500 100 - 3,500	1/6 - 30 1/6 - 30 1/6 - 3
Centrifugal	SWSI-BI/B DWDI-BI/B SWSI-AF/B DWDI-AF/B	0 - 12 0 - 12 0 - 14 0 - 14	10 - 73 12 - 73 18 - 120 18 - 120	600 - 123,000 1,300 - 225,000 1,400 - 447,000 2,400 - 804,000	1/3 - 200 1/3 - 400 1/3 - 1500 3/4 - 2500
Tubular Centrifugal	BI/B	0 - 9	10 - 108	450 - 332,000	1/3 - 750
Vane Axial	--/B --/D	0 - 5 0 - 4	18 - 72 18 - 60	1,400 - 115,000 1,200 - 148,000	1/3 - 100 1/3 - 150
TubeAxial	--/B --/D	0 - 1.5 0 - 1	12 - 60 18 - 48	900 - 76,000 2,600 - 48,000	1/3 - 25 1/4 - 15
Propeller	--/B --/D	0 - 1 0 - 1	20 - 72 8 - 48	400 - 80,000 50 - 49,000	1/4 - 15 1/6 - 10
Roof Ventilator	BI/B BI/D	0 - 1.25 0 - 1	7 - 54 6 - 18	100 - 34,000 75 - 3,200	1/4 - 7.5 1/8 - 3/4
RoofUpblast	BI/B BI/D	0 - 1.25 0 - 1.25	9 - 48 9 - 14	200 - 26,000 300 - 3,100	1/4 - 5 1/8 - 1
Sidewall	BI/B BI/D	0 - 1.25 0 - 1	14 - 24 6 - 18	850 - 8,200 80 - 4,000	1/4 - 2 1/8 - 3/4
Inline Centrifugal	BI/B BI/D	0 - 2.25 0 - 1.75	7 - 36 6 - 16	60 - 22,600 60 - 5,100	1/4 - 10 1/8 - 2

Notes:

FC: Forward Curved
BI: Backward Inclined
AF: Backward Inclined Airfoil
B: Belt Drive
D: Direct Drive
DWDI: Double Width, Double Inlet
SWSI: Single Width, Single Inlet

B. Fan Construction Classes are shown in the following table:

FAN CLASS	MAXIMUM TOTAL PRESSURE
I	3-3/4" W.G.
II	6-3/4" W.G.
III	12-3/4" W.G.
IV	Over 12-3/4" W.G.

C. Fan Selection Criteria:

1. Fan to be catalog rated for 15% greater static pressure (SP) than specified SP at specified volume.
2. Select fan so that specified volume is greater than at the apex of the fan curve.
3. Select fan to provide stable operation down to 85% of design volume operating at required speed for the specified conditions.
4. Specified SP at specified air flow.
5. Consider system effects. Fans are tested with open inlets and a length of straight duct on discharge. When field conditions differ from test configuration, performance is reduced. Therefore fan must be selected at slightly higher pressure to obtain desired results.
6. Parallel Fan Operation: At equal static pressure, CFM is additive.
7. Series Fan Operation: At equal CFM, static pressure is additive.
8. Every attempt should be made to have 1.0 to 1.5 diameters of straight duct on the discharge of the fan as a minimum.
9. There should be a minimum of 1.0 diameter of straight duct between fan inlet and an elbow. In plenum installations there should be a minimum of 0.75 of the wheel diameter between the fan inlet and the plenum wall.

D. Fan Terms:

1. Centrifugal: Flow within the fan is substantially radial to the shaft.
2. Axial: Flow within the fan is substantially parallel to the shaft.
3. Static Pressure: Static pressure is the compressive pressure that exists in a confined airstream. Static pressure is a measure of potential energy available to produce flow and to maintain flow against resistance. Static pressure is exerted in all directions and can be positive or negative (vacuum).
4. Velocity Pressure: Velocity pressure is the measure of the kinetic energy resulting from the fluid flow. Velocity pressure is exerted in the direction of fluid flow. Velocity pressure is always positive.
5. Total Pressure: Total pressure is the measure of the total energy of the airstream. Total pressure is equal to static pressure plus velocity pressure. Total pressure can be either positive or negative.
6. Quantity of Airflow: Volume measurement expressed in Cubic Feet per Minute (CFM).
7. Fan Outlet Velocity: Fan airflow divided by the fan outlet area.
8. Fan Velocity Pressure: Fan velocity pressure is derived by converting fan velocity to velocity pressure.
9. Fan Total Pressure: Fan total pressure is equal to the fan's outlet total pressure minus the fan's inlet total pressure.
10. Fan Static Pressure: Fan static pressure is equal to fan's total pressure minus the fan's velocity pressure. Numerically it is equal to the fan's outlet static pressure minus the fan's inlet total pressure.
11. Fan Horsepower: Theoretical calculation of horsepower assuming there are no losses.
12. Break Horsepower (BHP): Break horsepower is the actual power required to drive the fan.
13. System Effect: System effect is the reduced fan performance of manufacturer's fan catalog data due to the difference between field installed conditions and laboratory test conditions (precisely defined inlet and outlet ductwork geometry assuring uniform entrance and exit velocities).
    a. Maintain a minimum of 3 duct diameters of straight duct upstream and downstream of fan inlet and outlet at 2,500 feet per minute (FPM) duct velocity or less. 1 additional duct diameter should be added for each 1,000 FPM above 2,500 fpm.
    b. Recommend maintaining a minimum of 5 duct diameters of straight duct upstream and downstream of fan inlet and outlet at 2,500 feet per minute (FPM) duct velocity

or less. 1 additional duct diameter should be added for each 1,000 FPM above 2,500 FPM.

c. System effect may require a range of 3 to 20 duct diameters of straight duct upstream and downstream of fan inlet and outlet.

E. AMCA Spark Resistant Construction:

1. Type A. All parts of the fan in contact with the airstream must be made of non-ferrous material.
2. Type B. The fan shall have a non-ferrous impeller and non-ferrous ring about the opening through which the shaft passes. Ferrous hubs, shafts, and hardware are allowed if construction is such that a shift of the impeller or shaft will not permit two ferrous parts of the fan to rub or strike.
3. Type C. The fan must be so constructed that a shift of the wheel will not permit two ferrous part of the fan to rub or strike.

F. Centrifugal Fans:

1. Forward Curved Fan (FC):
   a. FC fans have a peak static pressure curve corresponding to the region of maximum efficiency, slightly to the right. Best efficiency at low or medium pressure (0 to 5 in. w.g.)
   b. BHP is minimum at no delivery and increases continuously with increasing flow, with maximum BHP occurring at free delivery.
   c. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly effect CFM.
   d. Fan blades curve toward direction of rotation.
   e. Advantages:
      1) Low cost. Less expensive than BC, BI, or AF fans.
      2) Low speed (400 to 1,200 RPM) minimizes shaft and bearing sizes.
      3) Large operating range: 30–80% wide open CFM.
      4) Highest Efficiency occurs: 40–50% wide open CFM.
   f. Disadvantages:
      1) Possibility of paralleling in multiple fan applications.
      2) Possibility of overloading.
      3) Weak structurally: Not capable of high speeds necessary for developing high static pressures.
   g. Used primarily in low to medium pressure HVAC applications: central station air handling units; rooftop units, packaged units, residential furnaces.
   h. High CFM, Low Static Pressure.
2. Backward Inclined (BI) and Backward Curved (BC) Fans:
   a. BC fans have a peak static pressure curve which occurs to the left of the maximum static efficiency. Best efficiency at medium pressure (3.5 to 5.0 in. w.g.).
   b. BHP increases to a maximum then decreases. They are non-overloading fans.
   c. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly effect CFM.
   d. Fan operates at high speeds—1,200 to 2,400 RPM—about double that of FC fans for similar air quantity.
   e. Blades curve away from or incline from direction of rotation.
   f. BI fans are less expensive than BC fans but do not have as great a range of high efficiency operation.
   g. Advantages:
      1) Higher Efficiencies.

2) Highest Efficiency occurs: 50–60% wide open CFM.
3) Good pressure characteristics.
4) Stronger structural design makes it suitable for higher static pressures.
5) Non-overloading power characteristics.

h. Disadvantages:
1) Higher speeds require larger shaft and bearings.
2) Has larger surge area than forward curved fan.
3) Operating range 40 to 80% of wide open CFM.
4) Can be noisier.
5) More expensive than FC fans.

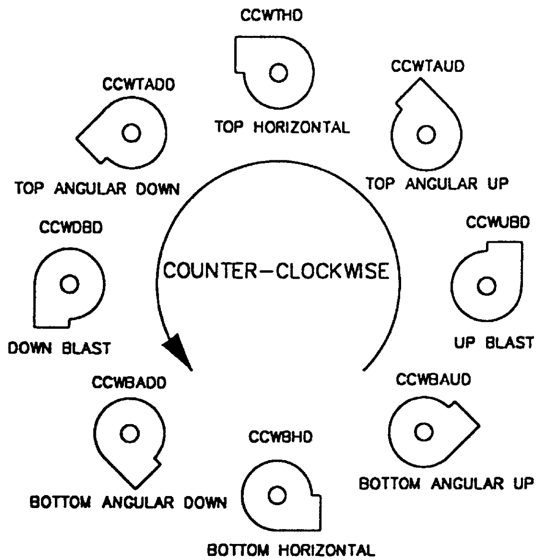
i. Used primarily in large HVAC applications where power savings are significant. Can be used in low, medium, and high pressure systems.

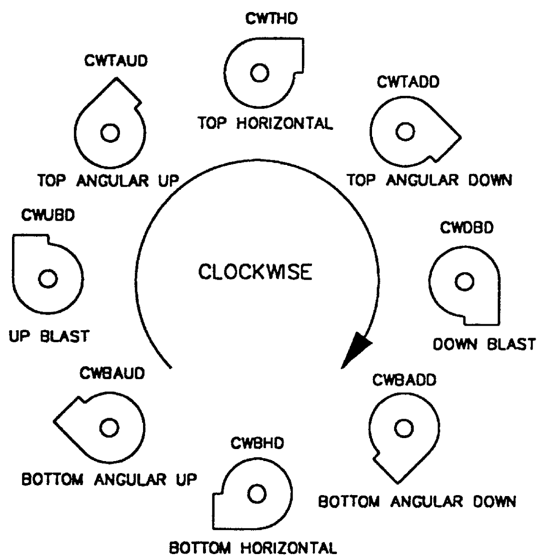
3. Airfoil Fans (AF):
a. AF fans have a peak static pressure curve which occurs to the left of the maximum static efficiency.
b. BHP increases to a maximum then decreases. They are non-overloading fans. Best efficiency at medium pressure (4.0 to 8.0 in. w.g.).
c. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly effect CFM.
d. Fan operates at high speeds—1,200 to 2,800 RPM—about double that of FC fans for similar air quantity.
e. Blades have an aerodynamic shape similar to an airplane wing and are backwardly curved (away from direction of rotation).
f. Advantages:
1) Higher Efficiencies.
2) Highest Efficiency occurs: 50–60% wide open CFM.
3) Good pressure characteristics.
4) Stronger structural design makes it suitable for higher static pressures.
5) Non-overloading power characteristics.

g. Disadvantages:
1) Higher speeds require larger shaft and bearings.
2) Has larger surge area than forward curved fan.
3) Operating range 40 to 80% of wide open CFM.
4) Can be noisier.
5) Most expensive centrifugal fan.

h. Used primarily in large HVAC applications where power savings are significant. Can be used in low, medium, and high pressure systems.
i. Airfoil blade fans have slightly higher efficiency and surge area is slightly larger than backward inclined or backward curved fans.

4. Radial (RA) Fans:
a. Radial fans have self-cleaning blades.
b. Fan horsepower increases with increase in air quantity (overloads) while static pressure decreases.
c. RA fans operate at high speed and pressure—2,000 to 3,000 RPM.
d. Blades radiate from center along radius of fan.
e. Used in industrial applications to transport dust, particles, or materials handling. Not commonly used in HVAC applications.

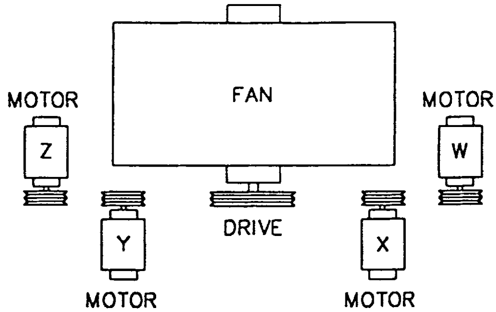




NOTES:

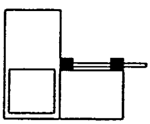
1. DIRECTION OF ROTATION IS DETERMINED FROM DRIVE SIDE OF FAN
2. ON SINGLE INLET FANS, THE DRIVE SIDE OF THE FAN IS ALWAYS CONSIDERED THE SIDE OPPOSITE THE FAN INLET.
3. ON DOUBLE INLET FANS, WHEN THE DRIVES ARE ON BOTH SIDES OF THE FAN, THE DRIVE SIDE OF THE FAN IS THE SIDE HAVING THE HIGHER HORSEPOWER DRIVING UNIT.
4. DIRECTION OF DISCHARGE IS DETERMINED IN ACCORDANCE WITH THE DIAGRAMS. ANGULAR DISCHARGE IS REFERENCED TO THE HORIZONTAL AXIS OF THE FAN AND DESIGNATED IN DEGREES ABOVE OR BELOW THIS REFERENCE.
5. FANS INVERTED FOR CEILING SUSPENSION, OR SIDE WALL MOUNTING, DIRECTION OF ROTATION AND DISCHARGE IS DETERMINED WHEN FAN IS RESTING ON THE FLOOR.

FAN ROTATION AND DISCHARGE POSITIONS

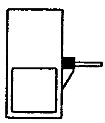


LOCATION OF MOTOR IS DETERMINED BY FACING THE DRIVE SIDE OF THE FAN OR BLOWER AND DESIGNATING THE MOTOR POSITION BY LETTERS W, X, Y, AND Z AS SHOWN ABOVE.

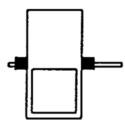
FAN MOTOR POSITIONS



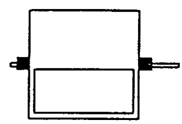
ARRANGEMENT #1 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS ON BASE



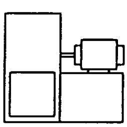
ARRANGEMENT #2 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, BEARINGS IN BRACKET SUPPORTED BY FAN HOUSING



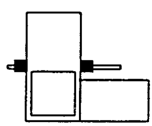
ARRANGEMENT #3 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING



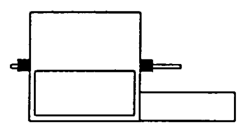
ARRANGEMENT #3 DWDI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING



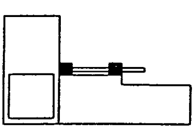
ARRANGEMENT #4 SWSI
FOR DIRECT DRIVE CONNECTION, IMPELLER OVERHUNG ON PRIME MOVER SHAFT, NO BEARINGS ON FAN, PRIME MOVER BASE MOUNTED OR INTEGRALLY CONNECTED



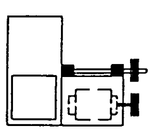
ARRANGEMENT #7 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING, BASE FOR PRIME MOVER



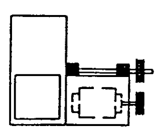
ARRANGEMENT #7 DWDI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING, BASE FOR PRIME MOVER



ARRANGEMENT #8 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS ON BASE, EXTENDED BASE FOR PRIME MOVER



ARRANGEMENT #9 SWSI
FOR BELT DRIVE CONNECTION, IMPELLER OVERHUNG, TWO BEARINGS ON BASE, PRIME MOVER OUTSIDE BASE



ARRANGEMENT #10 SWSI
FOR BELT DRIVE CONNECTION, IMPELLER OVERHUNG, TWO BEARINGS ON BASE, PRIME MOVER INSIDE BASE

FAN DRIVE ARRANGEMENTS

G. Axial Fans:

1. Propeller Fans:
   a. Low pressure, high CFM fans.
   b. Horsepower lowest at maximum flow.
   c. Maximum efficiency is approximately 50% and is reached near free delivery.
   d. No ductwork.
   e. Blade rotation is perpendicular to direction of airflow.
   f. Advantages:
      1) High volumes, low pressures.
      2) BHP lowest at free delivery.
      3) Inexpensive.
      4) Operates at relatively low speeds—900 to 1,800 RPM.
   g. Disadvantages:
      1) Cannot handle static pressure.
      2) BHP increases with static pressure; could overload and shut off.
      3) Air delivery decreases with increase in air resistance.
2. Tubeaxial Fans:
   a. Heavy duty propeller fans arranged for duct connection. Fan blades have aerodynamic configuration.
   b. Slightly higher efficiency than propeller fans.
   c. Discharge air pattern is circular in shape and swirls, producing higher static losses in the discharge duct.
   d. Used primarily in low and medium pressure, high volume, ducted HVAC application where discharge side is not critical. Also used in industrial application: fume hoods, spray booths, drying ovens.
   e. Fans operate at high speeds—2,000 to 3,000 RPM.
   f. Fans are noisy.
   g. Fans may be constructed to be overloading or non-overloading. Non-overloading type fans are more common.
   h. Advantages:
      1) Straight through design.
      2) Space savings.
      3) Capable of higher static pressures than propeller fans.
   i. Disadvantages:
      1) Discharge swirl creates higher pressure drops.
      2) High noise level.
3. Vaneaxial:
   a. Vaneaxial fans are tubeaxial fans with additional vanes to increase efficiency by straightening out airflow.
   b. Vaneaxial fans are more costly than tubeaxial fans.
   c. High pressure characteristics with medium flow rate capabilities.
   d. Fans operate at high speeds—2,000 to 3,000 RPM.
   e. Fans are noisy.
   f. Fans may be constructed to be overloading or non-overloading. Non-overloading type fans are more common.
   g. Typical Selection: 65–95% wide open CFM.
   h. Used in general HVAC applications, low, medium, and high pressure where straight through flow and compact installation are required. Also used in industrial applications: usually more compact than comparable centrifugal type fans for the same duty.

i. Advantages:
   1) Discharge vanes increase efficiency and reduce discharge losses.
   2) Reduced size and straight through design.
   3) Space savings.
   4) Capable of higher static pressures than propeller fans.
j. Disadvantages:
   1) Maximum efficiency only 65%.
   2) Selection Range: 65–90% wide open CFM.
   3) High noise level.

H. Clearance Requirements:

1. Minimum recommended clearance around fans is 24 inches. Maintain minimum clearance as required to open access and control doors on fans for service, maintenance, and inspection.
2. Mechanical room locations and placement must take into account how fans can be move into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

21.02 Pumps

A. Available RPM:

1. 1,150 (1,200).
2. 1,750 (1,800).
3. 3,500 (3,600).

B. Pump Types are shown in the following table:

PUMP TYPE	GPM	HEAD FT. H_2O	HORSEPOWER
Circulators	0 - 150	0 - 60	1/4 - 5
Close Coupled, End Suction	0 - 2,000	0 - 400	1/4 - 150
Frame Mounted, End Suction	0 - 2,000	0 - 500	1/4 - 150
Horizontal Split Case	0 - 12,000	0 - 500	1 - 500
Vertical Inline	0 - 2,000	0 - 400	1/4 - 75

C. Pump Location:

1. Heating Water Systems: Boilers to be on suction side of pumps; pumps to draw through boilers.
2. Chilled Water Systems: Chillers to be on discharge side of pumps; pumps to pump through chillers.

D. Pump Layout and Design Criteria:

1. Pump suction piping should be kept as short and direct as possible with a minimum length of straight pipe upstream of the pump suction as recommended by the pump manufacturer. Manufacturers recommend 5 to 12 pipe diameters.

2. Pump suction pipe size should be at least one pipe size larger than the pump inlet connection.
3. Use flat on top, eccentric reducer to reduce pump suction piping to pump inlet connection size.
4. Pump suction should be kept free from air pockets.
5. Horizontal elbows should not be installed at the pump suction. If a horizontal elbow must be installed at the pump suction, the elbow should be installed at a lower elevation than the pump suction. A vertical elbow at the pump suction with the flow upward toward the pump is desirable.
6. Maintain a minimum of 5 pipe diameters of straight pipe immediately upstream of pump suction unless using suction diffuser.
7. Variable speed pumping cannot be used for pure lift applications, because reduced speeds will fail to provide the required lift.
8. Variable speed pumping is well suited for secondary and tertiary distribution loops of primary/secondary and secondary/tertiary hydronic distribution systems (chilled water and heating water systems).
9. Pump Discharge Check Valves:
   a. Pump discharge check valves should be center guided, spring loaded, disc type check valves.
   b. Pump discharge check valves should be sized so that the check valve is full open at design flow rate. Generally this will require the check valve to be one pipe size smaller than the connecting piping.
   c. Condenser water system and other open piping system check valves should have globe style bodies to prevent flow reversal and slamming.
   d. Install check valves with 4 to 5 pipe diameters upstream of flow disturbances is recommended by most manufacturers.
10. Differential pressure control of the system pumps should never be accomplished at the pump. The pressure bypass should be provided at the end of the system or the end each of the subsystems regardless of whether the system is a bypass flow system or a variable speed pumping system. Bypass flow need not exceed 20 percent of the pump design flow.

E. Pump Selection Criteria:

1. Impeller size for specified duty should not exceed 85% of volute cutwater diameter.
2. Maximum cataloged impeller size should be rated to produce not less than 110% of specified head at specified flow.
3. Specified head at specified flow.
4. 110% of specified flow at specified head.
5. Parallel Pump Operation: At equal head, GPM is additive.
6. Series Pump Operation: At equal GPM, head is additive.
7. Selection Regions:
   a. Preferred Selection—85 to 105% Design Flow.
   b. Satisfactory Selection—66 to 115% Design Flow.
8. Pumps curves:
   a. Flat. 12% rise from design point to shutoff head (0 flow). Flat curves should be used for variable flow systems with single pumps. A flat pump curve is a pump curve where the head at shutoff is approximately 25% higher than the head at the best efficiency point.
   b. Steep. 40% rise from design point to shutoff head (0 flow). Steep curves should be used for variable speed and constant flow systems where two or more pumps are used.

c. Hump. Developed head rises to a maximum as flow decreases and then drops to a lower value at the point of shutoff. Hump curves should be used for constant flow systems with single pumps due to increased efficiency.

9. Select pumps so that the design point is as close as possible or to the left of the maximum efficiency point.
10. Boiler warming pumps should be selected for a flow rate of 0.1 GPM/BHP (range 0.05 to 0.1 GPM/BHP).

F. Pump Seals:

1. Mechanical Seal: Closed Systems.
2. Stuffing Box Seals: Open Systems.

G. Cavitation. Net Positive Suction Head (NPSH):

1. Cavitation: "If the pressure at any point inside the pump falls below the operating vapor pressure of the fluid, the fluid flashes into a vapor and forms bubbles. These bubbles are carried along in the fluid stream until they reach a region of higher pressure. Within this region the bubbles collapse or implode with tremendous shock on the adjacent surfaces. Cavitation is accompanied by a low rumbling and/or a sharp rattling noise and even vibration causing mechanical destruction in the form of pitting and erosion."[1]
2. Causes:
   a. Discharge heads far below the pump's calibrated head at peak efficiency.
   b. Suction lift or suction head lower than the pump rating.
   c. Speeds (RPM) higher than pump rating.
   d. Liquid temperatures higher than that for which system was designed.
3. Remedies:
   a. Increase source fluid level height.
   b. Reduce the distance and/or friction losses (larger pipe) between source and pump.
   c. Reduce temperature of the fluid.
   d. Pressurize source.
   e. Use different pump.
   f. Place balancing valve in pump discharge or trim pump impeller.
4. Systems most susceptible to NPSH problems:
   a. Boiler Feed Water Systems (steam systems).
   b. Cooling Tower and other open systems.
   c. Medium and high temperature water systems.
5. Potential problems increase as:
   a. Elevation above sea level increases.
   b. Height above pump decreases.
   c. Friction losses increase.
   d. Fluid temperature increases.

H. Pump Terms:

1. Friction Head: Friction head is the pressure expressed in psi or in feet of liquid needed to overcome the resistance to the flow in the pipe and fittings.
2. Suction Lift: Suction lift exists when the source of supply is below the centerline of the pump.

[1]Carrier Corporation, *Carrier System Design Manuals, Part 8—Auxiliary Equipment*, (Syracuse: Carrier Corporation, 1971), pp. 8–11.

3. Suction Head: Suction head exists when the source of supply is above the centerline of the pump.
4. Static Suction lift: Static suction lift is the vertical distance from the centerline of the pump down to the free level of the liquid source.
5. Static Suction Head: Static suction head is the vertical distance from the centerline of the pump up to the free level of the liquid source.
6. Static Discharge Head: Static discharge head is the vertical elevation from the centerline of the pump to the point of free discharge.
7. Dynamic Suction Lift: Dynamic suction lift includes the sum of static suction lift, friction head loss, and velocity head.
8. Dynamic Suction Head: Dynamic suction head includes static suction head minus the sum of friction head loss and velocity head.
9. Dynamic Discharge Head: Dynamic discharge head includes the sum of static discharge head, friction head, and velocity head.
10. Total Dynamic Head: Total dynamic head includes the sum of the dynamic discharge head plus the dynamic suction lift or discharge head minus dynamic suction head.
11. Velocity Head: Velocity head is the head needed to accelerate the liquid. See the following table:

VELOCITY FT/SEC.	VELOCITY HEAD FEET	VELOCITY FT/SEC.	VELOCITY HEAD FEET	VELOCITY FT/SEC.	VELOCITY HEAD FEET
0.5	0.004	7.5	0.875	14.5	3.269
1.0	0.016	8.0	0.995	15.0	3.498
1.5	0.035	8.5	1.123	15.5	3.735
2.0	0.062	9.0	1.259	16.0	3.980
2.5	0.097	9.5	1.403	16.5	4.232
3.0	0.140	10.0	1.555	17.0	4.493
3.5	0.190	10.5	1.714	17.5	4.761
4.0	0.248	11.0	1.881	18.0	5.037
4.5	0.314	11.5	2.056	18.5	5.321
5.0	0.389	12.0	2.239	19.0	5.613
5.5	0.470	12.5	2.429	19.5	5.912
6.0	0.560	13.0	2.627	20.0	6.219
6.5	0.657	13.5	2.833	21.0	6.856
7.0	0.762	14.0	3.047	22.0	7.525

12. Specific Gravity: Specific gravity is the direct ratio of any liquid's weight to the weight of water at 62°F. (62.4 Lbs./Cu.Ft. or 8.33 Lbs./Gal.).
13. Viscosity: Viscosity is a property of a liquid that resists any force tending to produce flow. It is the evidence of cohesion between the particles of a fluid which causes a liquid to offer resistance analogous to friction. A change in the temperature may change the viscosity depending upon the liquid. Pipe friction loss increases as viscosity increases.
14. Static Pressure: Static pressure is the water pressure required to fill the system.

15. Static System Pressure: Static system pressure is the water pressure required to fill the system plus 5 psi.
16. Flow Pressure: Flow pressure is the pressure the pump must develop to overcome the resistance created by the flow through the system.

I. Clearance Requirements:

1. Minimum recommended clearance around pumps is 24 inches. Maintain minimum clearance as required to open access and control doors on pumps for service, maintenance, and inspection.
2. Mechanical room locations and placement must take into account how pumps can be move into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

21.03 Motors

A. Motor Types. Items 1, 2, and 3 are the most common HVAC motor types.

1. Open Drip Proof (ODP): Ventilation openings arranged to prevent liquid drops falling within an angle of 15 degrees from the vertical from affecting motor performance—use indoors and in moderately clean environments.
2. Totally Enclosed Fan Cooled (TEFC): A fan on the motor shaft, outside the stator housing and within the protective shroud, blows air over the motor—use in damp, dirty, corrosive, or contaminated environments.
3. Explosion Proof (EXPRF): Totally enclosed with enclosure designed to withstand internal explosion of a specific gas-air or dust-air mixture to prevent escape of ignition products. Motors are approved for a specific Hazard Classification as covered by the NEC. Class I Explosion Proof and Class II Dust Ignition Resistant are the two most common type of hazardous location motors.
4. Open Drip Proof Air Over (ADAO): Ventilation openings arranged to prevent liquid drops falling within an angle of 15 degrees from the vertical from affecting motor performance—use indoors and in moderately clean environments. Rated for motor cooling by airflow from driven device.
5. Totally Enclosed Non-Ventilated (TENV): No ventilation openings in housing. Motor rated for cooling by airflow from driven device. TENV motors are usually under 5 horsepower.
6. Totally Enclosed Air Over (TEAO): No ventilation openings in housing. Motor rated for cooling by airflow from driven device. TEAO motors frequently have dual horsepower ratings depending on speed and cooling air temperature.

B. Motor Horsepowers, Voltage, Phase, and Operating Guidelines:

1. Suggested horsepower and phase:
   a. Motors ½ Horsepower and larger: 3 Phase.
   b. Motors less than ½ Horsepower: Single Phase.
   c. Considering first cost economics only, it is less costly, on average, to have motors smaller than 1 Hp to be single-phase. At ¾ Hp, single-phase and 3-phase motors cost about the same, but branch circuits and control equipment for 3-phase motors are usually more expensive.
   d. When life cycle owning and operating costs are considered, it is often more economical to provide motors as specified in a. and b. above.
2. Do not start and stop motors more than 6 times per hour.
3. Motors of 5 horsepower and larger should not be cycled; they should run continuously.
4. Specify energy efficient motors.

5. Do not use energy efficient motors with variable speed/frequency drives.
6. For best motor life and reliability, do not select motors to run within the service factors.
7. For every 50°F. (10°C.) increase in motor operating temperature, the life of the motor is cut in half. Conversely, for every 50°F. (10°C.) decrease in motor operating temperature, the life of the motor is doubled.
8. Energy efficient motors have a higher starting current than their standard efficiency counterparts.
9. The best sign of motor trouble is smoke and/or paint discoloration.
10. In general, motors can operate with voltages plus or minus 10% of their rated voltage.
11. Motors in storage should be turned by hand every six months to keep the bearings from drying out.
12. Available Voltages are given in the following table:

PHASE	NOMINAL VOLTAGE	NAMEPLATE VOLTAGE
SINGLE PHASE	120	115
	240	230
	277	265
3 PHASE	208	200
	240	230
	480	460
	600	575

C. Standard Motor Sizes are given in the following table:

MOTOR SIZES (Hp)	RECOMMENDED STARTER TYPE	STANDARD SERVICE FACTORS
1/8; 1/10; 1/12; 1/15; 1/20; 1/25; 1/30; 1/60; 1/100	SPC or PSC	1.40
1/6	SPC or PSC	*
1/4; 1/3	CS	*
1/2; 3/4; 1	MS	*
1-1/2; 2	MS	*
3; 5; 7-1/2; 10; 15; 20; 25; 30; 40; 50; 60; 75; 100; 125; 150; 200; 250	MS	*
300; 350; 400; 450; 500; 600; 700; 750; 800; 900; 1000; 1250; 1500; 1750; 2000; 2250; 2500; 3000; 3500; 4000; 4500; 5000; 5500; 6000 **	MS	*

Notes:
SPC: Split Phase Capacitor Start
PSC: Permanent Split Capacitor Start
CS: Capacitor Start
*See item E.
**Motors generally not used in HVAC applications.

MS: Magnetic Start; Polyphase Induction Motors (Squirrel Cage)

½ Hp thru 50 Hp	Across-the-Line Starter
60 Hp and Larger	Reduced-Voltage Starter

D. Standard Motor RPM: 3,600, 1,800, 1,200, 900, 720, 600, 514.

E. NEMA Motor Service Factors are given in the following table:

HP	3600 RPM	1800 RPM	1200 RPM	900 RPM
1/6 - 1/3	1.35	1.35	1.35	1.35
1/2	1.25	1.25	1.25	1.15
3/4	1.25	1.25	1.15	1.15
1	1.25	1.15	1.15	1.15
1-1/2 - 250	1.15	1.15	1.15	1.15
300 - 2500	1.15	1.15	1.15	1.15

F. Locked Rotor Indicating Code Letters are given in the following table:

LOCKED ROTOR INDICATING CODE LETTERS			
CODE LETTER	KVA/HP	CODE LETTER	KVA/HP
A	0 - 3.14	L	9.00 - 9.99
B	3.15 - 3.54	M	10.00 - 11.19
C	3.55 - 3.99	N	11.20 - 12.49
D	4.00 - 4.49	O	NOT USED
E	4.50 - 4.99	P	12.50 - 13.99
F	5.00 - 5.59	Q	NOT USED
G	5.60 - 6.29	R	14.00 - 15.99
H	6.30 - 7.09	S	16.00 - 17.99
I	NOT USED	T	18.00 - 19.99
J	7.10 - 7.99	U	20.00 - 22.39
K	8.00 - 8.99	V	22.40 - AND UP

1. Standard 3 phase motors often have these locked rotor codes:
    a. 1 Horsepower and smaller: Locked Rotor Code L
    b. 1½ to 2 Horsepower: Locked Rotor Code K
    c. 3 Horsepower: Locked Rotor Code J
    d. 5 Horsepower: Locked Rotor Code H
    e. 7½ to 10 Horsepower: Locked Rotor Code G
    f. 15 Horsepower and Larger: Locked Rotor Code F
2. Standard single phase motors often have these locked rotor codes:
    a. ½ Horsepower and smaller: Locked Rotor Code L

b. ¾ to 1 Horsepower: Locked Rotor Code K
c. 1½ to 2 Horsepower: Locked Rotor Code J
d. 3 Horsepower: Locked Rotor Code H
e. 5 Horsepower: Locked Rotor Code G

G. Motor Insulation Classes are given in the following table:

MOTOR TYPE	MOTOR INSULATION CLASS TEMPERATURE RISE							
	A		B		F		H	
	°C	°F	°C	°F	°C	°F	°C	°F
1. Motors with 1.0 Service Factor(except 3 & 4 Below)	60	140	80	176	105	221	125	257
2. All Motors with 1.15 Service Factor or Higher	70	158	90	194	115	239	---	---
3. Totally-Enclosed Non-Ventilated Motor with 1.0 Service Factor	65	149	85	185	110	230	135	275
4. Motors with Encapsulated Windings and with 1.0 Service, All Enclosures	65	149	85	185	110	230	---	---

Notes:

1. **Abnormal deterioration of insulation may be expected if the ambient temperature of 40°C/104°F is exceeded in regular operation.**
2. **Temperature rise based on 40°C/104°F ambient. Temperature rises are based on operation at altitudes of 3,300 feet or less.**
3. **Class A Motors: Fractional Hp motors, Small Appliances; Maximum Operating Temperature 105°C/221°F.**
4. **Class B Motors: Motors for HVAC Applications, High Quality Fractional Hp Motors; Maximum Operating Temperature 130°C/266°F.**
5. **Class F Motors: Industrial Motors; Maximum Operating Temperature 155°C/311°F.**
6. **Class H Motors: High Temperature, High Reliability, High Ambient; Maximum Operating Temperature 180°C/356°F.**

H. NEMA Motor Design Designations:

1. Design A motors are built with high pullout torque and are used on injection molding machines.
2. Design B motors are built with high starting torque with reasonable starting current and are used with fans, pumps, air handling units, and other HVAC equipment. They are the most common HVAC motor.
3. Design C motors are built with high starting torque and used with hard to start loads and are used with conveyors.
4. Design D motors are built with high starting torque, low starting current, and high slip and are used with cranes, hoists, and low speed presses.

I. Clearance Requirements:

1. Minimum recommended clearance around motors is 24 inches.
2. Mechanical room locations and placement must take into account how motors can be move into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

J. Motor Efficiencies: *ASHRAE Standard 90.1-1989:*

1. NEMA Design B; Single Speed; 1,200, 1,800, or 3,600 RPM; Open Drip Proof (ODP) or Totally Enclosed Fan Cooled (TEFC) Motors 1 Hp and Larger that operate more than 500 hours per year must meet the following minimum nominal efficiencies:

Horsepower	Minimum Nominal Efficiency
1 - 4	78.5
5 - 9	84.0
10 - 19	85.5
20 - 49	88.5
50 - 99	90.2
100 - 124	91.7
125 or Greater	92.4

Note: **Above table is based on *ASHRAE Standard 90.1* prior to adoption of Addendum 90.1c by ASHRAE Board of Directors.**

2. NEMA Design A and B; Open Drip Proof (ODP) or Totally Enclosed Fan Cooled (TEFC) Motors 1 Hp and Larger that operate more than 1,000 hours per year must meet the following minimum nominal efficiencies; Minimum Acceptable Nominal Full-Load Motor Efficiency for Single Speed Polyphase Squirrel-Cage Induction Motors having Synchronous Speed of 3,600, 1,800, 1,200, and 900 RPM.:

Full Load Efficiencies–Open Motors

HP	2-POLE		4-POLE		6-POLE		8-POLE	
	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.
1.0	---	---	82.5	81.5	80.0	78.5	74.0	72.0
1.5	82.5	81.5	84.0	82.5	84.0	82.5	75.5	74.0
2.0	84.0	82.5	84.0	82.5	85.5	84.0	85.5	84.0
3.0	84.0	82.5	86.5	85.5	86.5	85.5	86.5	85.5
5.0	85.5	84.0	87.5	86.5	87.5	86.5	87.5	86.0
7.5	87.5	86.5	88.5	87.5	88.5	87.5	88.5	87.5
10.0	88.5	87.5	89.5	88.5	90.2	89.5	89.5	88.5
15.0	89.5	88.5	91.0	90.2	90.2	89.5	89.5	88.5
20.0	90.2	89.5	91.0	90.2	91.0	90.2	90.2	89.5
25.0	91.0	90.2	91.7	91.0	91.7	91.0	90.2	89.5
30.0	91.0	90.2	92.4	91.7	92.4	91.7	91.0	90.2
40.0	91.7	91.0	93.0	92.4	93.0	92.4	91.0	90.2
50.0	92.4	91.7	93.0	92.4	93.0	92.4	91.7	91.0
60.0	93.0	92.4	93.6	93.0	93.6	93.0	92.4	91.7
75.0	93.0	92.4	94.1	93.6	93.6	93.0	93.6	93.0
100.0	93.0	92.4	94.1	93.6	94.1	93.6	93.6	93.0
125.0	93.6	93.0	94.5	94.1	94.1	93.6	93.6	93.0
150.0	93.6	93.0	95.0	94.5	94.5	94.1	93.6	93.0
200.0	94.5	94.1	95.0	94.5	94.5	94.1	93.6	93.0

Note: Above table is based on *ASHRAE Standard 90.1, Addendum 90.1c.*

Full Load Efficiencies—Enclosed Motors

HP	2-POLE		4-POLE		6-POLE		8-POLE	
	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.
1.0	75.5	74.0	82.5	81.5	80.0	78.5	74.0	72.0
1.5	82.5	81.5	84.0	82.5	85.5	84.0	77.0	75.5
2.0	84.0	82.5	84.0	82.5	86.5	85.5	82.5	81.5
3.0	85.5	84.0	87.5	86.5	87.5	86.5	84.0	82.5
5.0	87.5	86.5	87.5	86.5	87.5	86.5	85.5	84.0
7.5	88.5	87.5	89.5	88.5	89.5	88.5	85.5	84.0
10.0	89.5	88.5	89.5	88.5	89.5	88.5	88.5	87.5
15.0	90.2	89.5	91.0	90.2	90.2	89.5	88.5	87.5
20.0	90.2	89.5	91.0	90.2	90.2	89.5	89.5	88.5
25.0	91.0	90.2	92.4	91.7	91.7	91.0	89.5	88.5
30.0	91.0	90.2	92.4	91.7	91.7	91.0	91.0	90.2
40.0	91.7	91.0	93.0	92.4	93.0	92.4	91.0	90.2
50.0	92.4	91.7	93.0	92.4	93.0	92.4	91.7	91.0
60.0	93.0	92.4	93.6	93.0	93.6	93.0	91.7	91.0
75.0	93.0	92.4	94.1	93.6	93.6	93.0	93.0	92.4
100.0	93.6	93.0	94.5	94.1	94.1	93.6	93.0	92.4
125.0	94.5	94.1	94.5	94.1	94.1	93.6	93.6	93.0
150.0	94.5	94.1	95.0	94.5	95.0	94.5	93.6	93.0
200.0	95.0	94.5	95.0	94.5	95.0	94.5	94.1	93.6

Note: Above table is based on *ASHRAE Standard 90.1, Addendum 90.1c.*

K. Single Phase ODP is given in the following table:

Single Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1200	1/6	48	41	48
	1/4	48, 56	41	51
	1/3	48, 56	56	55
	1/2	56	62	60
	3/4	56, 143T	68	68
	1	184	65	62
	1-1/2	215	67	60
	2	215	68	65
	3	215	75	80
1800	1/8	48	49	58
	1/6	48	49	58
	1/4	48, 56	53	52
	1/3	48, 56	56	55
	1/2	48, 56	64	65
	3/4	56	63	64
	1	56, 143T, 182T	68	72
	1-1/2	56, 145T, 184T	70	64
	2	56, 145T, 182T	73	72
	3	184T	78	78
	5	184T, 213T	74	76
	7-1/2	215T	77	85
	10	215T	84	90
3600	1/3	48, 56	55	68
	1/2	48, 56	57	71
	3/4	56	62	75
	1	56	63	69
	1-1/2	56, 143T	68	77
	2	56, 145T	71	75
	3	56, 182T	76	88
	5	184T	76	88
	7-1/2	213T	81	82
	10	215	83	86

L. Single Phase TEFC is given in the following table:

Single Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1200	1/6	48	41	48
	1/4	48, 56	44	50
	1/3	48, 56	57	56
	1/2	56	59	63
	3/4	56, 143T	68	68
	1	184	67	67
	1-1/2	215	71	69
	2	215	82	84
	3	215	80	82
	5	256	80	82
1800	1/12	42	47	55
	1/8	42	47	55
	1/6	42, 48	49	58
	1/4	48, 56	53	52
	1/3	48, 56	56	55
	1/2	48, 56	63	67
	3/4	56	66	68
	1	56, 143T	68	72
	1-1/2	56, 145T	73	77
	2	182T	75	81
	3	184T	78	87
	5	213T	82	87
	7-1/2	215T	84	87
	10	215T	84	87
3600	1/8	42	45	62
	1/6	42	52	57
	1/4	42	52	57
	1/3	48, 56	55	68
	1/2	48, 56	57	71
	3/4	56	66	74
	1	56	66	81
	1-1/2	56, 143T	70	82
	2	145T	74	78
	3	182T	76	87
	5	184T	84	96
	7-1/2	213T	82	89
	10	215T	86	98

M. Single Phase Explosion Proof is given in the following table:

Single Phase Explosion Proof

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1200	1/3	56	54	56
	1/2	56	59	63
	3/4	56	65	67
	1	184	67	67
	1-1/2	215	71	69
1800	1/3	56	56	58
	1/2	56	65	65
	3/4	56	66	68
	1	56, 143T	66	67
	1-1/2	184	70	70
	2	182T	75	81
	3	215	79	77
	5	215	74	81
3600	1/2	56	55	69
	3/4	56	62	75
	1	56	66	81
	1-1/2	143T	70	82
	2	145T	74	82
	3	182T, 184T	76	87

N. Standard Efficiency 3-Phase ODP is given in the following table:

Standard Efficiency 3-Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
900	1/2	56, 143T	71	57
	3/4	145T	74	56
	1	182T	71	66
	1-1/2	184T	74	67
	2	213T	73	63
	3	215T	76	60
	5	254T	80	60
	7-1/2	256T	85	62
1200	1/4	48, 56	71	58
	1/3	48, 56	71	58
	1/2	48, 56	71	58
	3/4	56, 143T	77	67
	1	56, 145T	77	69
	1-1/2	56, 145T, 182T	78	77
	2	184T	78	72
	3	213T	79	72
	5	215T	83	76
	7-1/2	254T	85	78
	10	256T	86	78
	15	284T	87	82
	20	286T	87	81
	25	324T	88	84
	30	326T	88	80
	40	364T	91	85
	50	365T	88	87
	60	404T	90	82
	75	405T	90	83
	100	444T	91	85
	125	445T	91	85
	150	445T	91	84
	200	447T	91	84
	250	449T	91	84
1800	1/4	48	74	63
	1/3	48, 56	74	63
	1/2	48, 56	74	63
	3/4	48, 56	74	60
	1	56, 142T, 143T	75	64
	1-1/2	56, 145T	79	69
	2	56, 145T	80	70
	3	56, 145T, 182T	81	77
	5	184T	84	82

Standard Efficiency 3-Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1800	7-1/2	213T	86	76
	10	215T	87	78
	15	254T	87	77
	20	256T	89	86
	25	284T	89	83
	30	286T	90	86
	40	324T	91	85
	50	326T	91	85
	60	364T	90	83
	75	365T	90	86
	100	404T	91	86
	125	405T	92	86
	150	445T	92	88
	200	445T	92	89
	250	447T	92	90
	300	447T	92	90
	350	449Z	92	90
	400	449Z	92	90
	450	449Z	92	90
3600	1/4	48, 56	74	63
	1/3	48, 56	74	63
	1/2	48, 56	75	73
	3/4	48, 56	67	63
	1	56	75	64
	1-1/2	56, 143T	78	82
	2	56, 145T	80	86
	3	56, 145T	81	84
	5	56, 182T	81	88
	7-1/2	184T	84	85
	10	213T	87	89
	15	215T	87	91
	20	254T	89	86
	25	256T	89	87
	30	284T	87	87
	40	286T	90	87
	50	324T	88	89
	60	326T	90	88
	75	364T	90	84
	100	365T	93	83
	125	404T	89	88
	150	405T	90	89
	200	444T	91	89
	250	445T	92	90

O. Energy Efficient 3-Phase ODP is given in the following table:

Energy Efficient 3-Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
900	1/2	56, 143T	71	70
	3/4	145T	74	70
	1	182T	71	79
	1-1/2	184T	74	79
	2	213T	73	79
	3	215T	76	85
	5	254T	80	85
	7-1/2	256T	85	85
1200	1/4	48, 56	71	70
	1/3	48, 56	71	70
	1/2	48, 56	71	70
	3/4	56, 143T	77	70
	1	145T	81	72
	1-1/2	182T	83	73
	2	184T	85	75
	3	213T	86	60
	5	215T	87	65
	7-1/2	254T	89	73
	10	256T	89	74
	15	284T	90	77
	20	286T	90	78
	25	324T	91	74
	30	326T	91	78
	40	364T	93	77
	50	365T	93	79
	60	404T	93	82
	75	405T	93	80
	100	444T	93	80
	125	444T	93	84
	150	445T	91	84
	200	447T	91	84
	250	449T	91	84
1800	1/4	48	74	63
	1/3	48, 56	74	63
	1/2	48, 56	74	70
	3/4	48, 56	74	70
	1	143T	82	84
	1-1/2	145T	84	85
	2	145T	84	85
	3	182T	86	86
	5	184T	87	87

Energy Efficient 3-Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1800	7-1/2	213T	88	86
	10	215T	89	85
	15	256T	91	85
	20	256T	91	86
	25	284T	91	85
	30	286T	92	88
	40	324T	92	83
	50	326T	93	85
	60	364T	93	88
	75	365T	93	88
	100	404T	93	83
	125	405T	93	86
	150	445T	93	85
	200	445T	94	85
	250	447T	92	85
	300	447T	92	90
	350	449Z	92	90
	400	449Z	92	90
	450	449Z	92	90
3600	1/4	48, 56	74	63
	1/3	48, 56	74	63
	1/2	48, 56	74	70
	3/4	48, 56	75	70
	1	56	75	79
	1-1/2	143T	82	85
	2	145T	82	87
	3	145T	84	85
	5	182T	85	86
	7-1/2	184T	86	88
	10	213T	87	86
	15	215T	89	89
	20	254T	90	89
	25	256T	90	92
	30	284T	91	91
	40	286T	92	92
	50	324T	93	89
	60	326T	93	91
	75	364T	93	88
	100	365T	92	88
	125	404T	89	88
	150	405T	90	88
	200	444T	91	88
	250	445T	92	88

P. Standard Efficiency 3-Phase TEFC is given in the following table:

Standard Efficiency 3-Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
900	1/4	56	68	48
	1/3	56	68	48
	1/2	56, 143T	68	48
	3/4	145T	73	57
	1	182T	68	64
	1-1/2	184T	74	65
	2	213T	75	66
	3	215T	75	60
	5	254T	80	60
	7-1/2	256T	81	63
	10	284T	88	67
	15	286T	89	66
	20	324T	90	68
	25	326T	88	69
1200	1/6	48	71	58
	1/4	48, 56	71	58
	1/3	56	71	58
	1/2	56	71	58
	3/4	56, 143T	76	68
	1	56, 145T	77	67
	1-1/2	56, 145T, 182T	77	71
	2	184T	80	73
	3	213T	79	73
	5	215T	83	73
	7-1/2	254T	85	75
	10	256T	86	82
	15	284T	88	79
	20	286T	88	81
	25	324T	90	80
	30	326T	91	81
	40	364T	90	85
	50	365T	89	88
	60	404T	91	82
	75	405T	92	81
	100	444T	92	85
	125	445T	93	87
	150	445T	92	88
	200	447T	92	88
	250	449T	92	88
1800	1/8	42	74	63
	1/6	42	74	63
	1/4	48	74	63

Standard Efficiency 3-Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1800	1/3	48, 56	74	63
	1/2	48, 56	74	63
	3/4	48, 56	74	60
	1	56, 143T	77	62
	1-1/2	56, 145T	79	66
	2	56, 145T	81	74
	3	182T	82	78
	5	184T	84	82
	7-1/2	213T	86	79
	10	215T	88	81
	15	254T	90	80
	20	256T	90	83
	25	284T	90	84
	30	286T	91	85
	40	324T	91	84
	50	326T	92	84
	60	364T	91	83
	75	365T	92	86
	100	405T	92	89
	125	444T	92	89
	150	445T	93	89
	200	445T	84	89
	250	447T	84	89
3600	1/6	42	67	63
	1/4	42	67	63
	1/3	48	67	63
	1/2	48, 56	67	63
	3/4	48, 56	75	73
	1	56	75	76
	1-1/2	56, 143T	74	80
	2	56, 145T	76	89
	3	56, 145T, 182T	81	87
	5	184T	85	94
	7-1/2	184T, 213T	86	85
	10	215T	87	92
	15	215T, 254T	89	92
	20	254T, 256T	87	89
	25	256T, 284T	88	87
	30	286T	88	90
	40	324T	86	90
	50	326T	89	91
	60	364T	89	91
	75	365T	89	91
	100	405T	89	91

Q. Energy Efficient 3-Phase TEFC is given in the following table:

Energy Efficient 3-Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
900	1/4	56	68	48
	1/3	56	68	48
	1/2	56, 143T	68	70
	3/4	145T	73	70
	1	182T	68	79
	1-1/2	184T	74	79
	2	213T	75	79
	3	215T	75	85
	5	254T	80	85
	7-1/2	256T	81	85
	10	284T	88	85
	15	286T	89	85
	20	324T	90	85
	25	326T	88	85
1200	1/6	48	71	70
	1/4	48, 56	71	70
	1/3	48, 56	71	70
	1/2	56	71	70
	3/4	56, 143T	76	70
	1	145T	81	72
	1-1/2	182T	83	65
	2	184T	85	68
	3	213T	85	63
	5	215T	86	66
	7-1/2	254T	89	68
	10	256T	89	75
	15	284T	90	72
	20	286T	90	76
	25	324T	90	71
	30	326T	91	79
	40	364T	92	78
	50	365T	92	81
	60	404T	92	83
	75	405T	92	80
	100	444T	93	83
	125	445T	93	85
	150	445T	92	85
	200	447T	91	85
	250	449T	91	85
1800	1/8	42	47	55
	1/6	42, 48	49	58
	1/4	48, 56	53	52

Energy Efficient 3-Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1800	1/3	48, 56	56	55
	1/2	48, 56	74	70
	3/4	48, 56	74	70
	1	143T	82	84
	1-1/2	145T	84	85
	2	145T	84	85
	3	182T	87	83
	5	184T	88	83
	7-1/2	213T	89	85
	10	215T	90	84
	15	254T	91	86
	20	256T	91	85
	25	284T	92	84
	30	286T	93	86
	40	324T	93	83
	50	326T	93	85
	60	364T	93	87
	75	365T	93	87
	100	405T	94	86
	125	444T	94	87
	150	445T	94	88
	200	447T	95	87
	250	447T	84	85
3600	1/6	42	67	63
	1/4	42	67	63
	1/3	48	67	63
	1/2	48, 56	67	70
	3/4	48, 56	75	70
	1	56	75	79
	1-1/2	143T	82	85
	2	145T	82	87
	3	182T	82	87
	5	184T	85	88
	7-1/2	213T	86	86
	10	215T	86	86
	15	254T	88	91
	20	256T	89	89
	25	284T	90	92
	30	286T	91	92
	40	324T	91	91
	50	326T	90	92
	60	364T	91	93
	75	365T	91	91
	100	405T	92	92

R. 3-Phase Explosion Proof is given in the following table:

3-Phase Explosion Proof

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1200	1/3	56	71	58
	1/2	56	71	58
	3/4	56, 143T	72	70
	1	56, 145T	77	69
	1-1/2	56, 145T, 182T	78	77
	2	184T	84	68
	3	213T	80	75
	5	215T	80	75
	7-1/2	254T	80	75
	10	256T	80	75
	15	284T	80	75
1800	1/3	56	74	60
	1/2	56	74	60
	3/4	56	76	69
	1	56, 143T	75	74
	1-1/2	56, 145T	78	80
	2	56, 145T	80	80
	3	182T	82	75
	5	184T	85	80
	7-1/2	213T	86	82
	10	215T	89	82
	15	254T	87	82
	20	256T	92	84
	25	284T	92	86
	30	286T	92	87
	40	324T	92	88
	50	326T	93	86
	60	364T	93	86
	75	365T	93	86
	100	405T	93	86
3600	1/2	56	68	77
	3/4	56	72	79
	1	56	74	79
	1-1/2	143T	74	80
	2	145T	76	89
	3	145T, 182T	81	87
	5	184T	84	94
	7-1/2	184T, 213T	84	90
	10	215T	87	92
	15	254T	86	85
	20	256T	86	85
	25	284T	86	85
	30	286T	86	85
	40	324T	86	85
	50	326T	86	85

21.04 Starters, Disconnect Switches, and Motor Control Centers

A. Starter Types:

1. Manual: (Manual Control):
   a. Reversing/Non-reversing.
   b. Push Button/Toggle Switch.
   c. Available for single phase or 3-phase electrical power.
2. Magnetic: (Automatic Control):
   a. Full Voltage/Across the Line.
   b. Reversing/Non-reversing.
   c. Reduced Voltage:
      1) Reactor.
      2) Resistance.
      3) Auto Transformer.
      4) Wye-Delta/Star Delta.
      5) Full Voltage Part Winding.
      6) Reduced Voltage Part Winding.
   d. 2-Speed Starting:
      1) One Winding. Full Speed; Half Speed.
      2) Two Winding. Full Speed; ⅔ Speed.
      3) Constant Torque.
      4) Variable Torque.
      5) Constant Horsepower.
   e. Available for single phase or 3-phase electrical power.
3. Combination Starter Disconnect Switch: See Magnetic Starter:
   a. Fused.
   b. Non-fused.
   c. Disconnect Switches (Locking/Non-Locking—Recommend Locking Switches).
   d. Available for 3-phase electrical power only, but 3-phase starter can be used with single phase motor (although expensive).

B. Starter Accessories:

1. Pilot Lights: Green, Run; Red, Off.
2. Switches (Locking/Non-Locking—Recommend Locking Switches).
   a. Hand-Off-Auto (HOA).
   b. Push Button.
   c. Toggle Switch.
3. Control Transformer.
4. Overload Protection:
   a. Fused.
   b. Non-fused.
   c. Motor Circuit Protector.
   d. Molded Case Circuit Breaker.
   e. Circuit Fuse Protection: Size based on circuit ampacity and wire size.
   f. Overload Heaters: Size based on motor overload capacity.
   g. Two Levels of Overload Protection:
      1) Type 1: Considerable damage occurs to the contactor and overload relay when an overload happens but the enclosure remains externally undamaged. Parts of the starter or the entire starter may need to be replaced after an overload.

2) Type 2: No damage occurs to the contactor or overload relay except light contact burning is permitted when an overload happens.

h. The choice between circuit breakers and fuses is purely a matter of user preference.

5. Auxiliary Contacts (No-Normally Open/NC-Normally Closed).
6. Relays.

C. Disconnect Switch Sizes and Accepted Fuse Sizes are given in the following table:

SAFETY SWITCH SIZE AMPS	ACCEPTABLE FUSE SIZES AMPS	SAFETY SWITCH SIZE AMPS	ACCEPTABLE FUSE SIZES AMPS
30	15, 20, 25, 30	1600	1600
60	35, 40, 45, 50, 60	2000	2000
100	70, 80, 90, 100	2500	2500
200	110, 125, 150, 175, 200	3000	3000
400	225, 250, 300, 350, 400	4000	4000
600	450, 500, 600	5000	5000
800	700, 800	6000	6000
1200	1000, 1200	----	----

D. Standard Fuse and Circuit Breaker Sizes (Amperes): 1, 3, 6, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, 6000.

E. Starter Types by Starting Method are given in the following table:

STARTING METHOD	INRUSH CURRENT % LRA	STARTING TORQUE % LRT
Across-the-Line	100	100
Auto-Transformer		
80% Tap	71	64
65% Tap	48	42
50% Tap	28	25
Primary Resistor or Reactor		
80% Applied Voltage	80	64
65% Applied Voltage	65	42
58% Applied Voltage	58	33
50% Applied Voltage	50	25
Star Delta	33	33
Part Winding	60	48
Part Winding w/Resistors	60-30	48-12
Wound Rotor (Approx.)	25	150
Solid State	3 x RLA	---

Notes:
1. % LRA = Percent full voltage locked rotor current (amps).
2. % LRT = Percent full voltage locked rotor torque.
3. RLA = Rated Load Amps or Running Load Amps.

F. Motor Size, Starter and Disconnect Switch Size, and Fuse and Circuit Breaker Size are given in the following tables. The following notes are applicable to all schedules:

1. Starters and/or Disconnect Switches. Fuses shall be Class RK5 Time Delay, Dual Element Fuses. Circuit breakers shall be Thermal Magnetic Circuit Breakers.
2. Motor data, starters, disconnect switches, and fuses based on *1993 NEC* and Square D Company.

115 VOLT (120 VOLT) SINGLE PHASE MOTOR STARTER SCHEDULE					
MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/8	1	3.0	30	4.5	15
1/6	1	4.4	30	7	15
1/4	1	5.8	30	9	15
1/3	1	7.2	30	12	15
1/2	1	9.8	30	15	20
3/4	1	13.8	30	20	25
1	1	16.0	30	25	30
1.5	1	20.0	30	30	40
2	1	24.0	30	30	50
3	2	34.0	60	50	70
5	3	56.0	100	80	90
7.5	4	80.0	100	100	110
10	-	-	-	-	-

230 VOLT (240 VOLT) SINGLE PHASE MOTOR STARTER SCHEDULE					
MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/8	1	1.7	30	2.5	15
1/6	1	2.2	30	3.5	15
1/4	1	2.9	30	4.5	15
1/3	1	3.6	30	5.6	15
1/2	1	4.9	30	8	15
3/4	1	6.9	30	10	15
1	1	8.0	30	12	15
1.5	1	10.0	30	15	20
2	1	12.0	30	17.5	25
3	1	17.0	30	25	35
5	2	28.0	60	40	60
7.5	2	40.0	60	60	80
10	3	50.0	60	60	90

200 Volt (208 Volt) Three-Phase Motor Starter Schedule

MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/2	1	2.3	30	3.5	15
3/4	1	3.2	30	5	15
1	1	4.1	30	6.25	15
1.5	1	6.0	30	10	15
2	1	7.8	30	12	15
3	1	11.0	30	17.5	20
5	1	17.5	30	25	35
7.5	1	25.3	60	40	50
10	2	32.2	60	50	60
15	3	48.3	60	60	90
20	3	62.1	100	90	100
25	3	78.2	100	100	110
30	4	92.0	200	125	125
40	4	120.0	200	175	175
50	5	150.0	200	200	200
60	5	177.0	400	250	250
75	5	221.0	400	300	300
100	6	285.0	400	400	400
125	6	359.0	600	500	600
150	6	414.0	600	600	600
200	7	552.0	-	-	800

230 Volt (240 Volt) Three-Phase Motor Starter Schedule

MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/2	1	2.0	30	3.2	15
3/4	1	2.8	30	4.5	15
1	1	3.6	30	5.6	15
1.5	1	5.2	30	8	15
2	1	6.8	30	10	15
3	1	9.6	30	15	20
5	1	15.2	30	25	30
7.5	1	22.0	30	30	45
10	2	28.0	60	40	60
15	2	42.0	60	60	80
20	3	54.0	100	80	90
25	3	68.0	100	100	100
30	3	80.0	100	100	110
40	4	104.0	200	150	150
50	4	130.0	200	200	200
60	5	154.0	200	200	225
75	5	192.0	400	300	250
100	5	248.0	400	350	350
125	6	312.0	400	400	450
150	6	360.0	600	500	600
200	6	480.0	600	600	800
250	7	600.0	800	800	800
300	7	720.0	1200	1000	1000
400	-	-	-	-	-

460 Volt (480 Volt) Three-Phase Motor Starter Schedule

MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/2	1	1.0	30	1.6	15
3/4	1	1.4	30	2.25	15
1	1	1.8	30	2.8	15
1.5	1	2.6	30	4	15
2	1	3.4	30	5.6	15
3	1	4.8	30	8	15
5	1	7.6	30	12	15
7.5	1	11.0	30	17.5	20
10	1	14.0	30	20	25
15	1	21.0	30	30	40
20	1	27.0	60	40	60
25	2	34.0	60	50	70
30	2	40.0	60	60	80
40	3	52.0	100	80	90
50	3	65.0	100	100	100
60	3	77.0	100	100	110
75	4	96.0	200	150	125
100	4	124.0	200	175	200
125	5	156.0	200	200	225
150	5	180.0	400	250	250
200	5	240.0	400	350	350
250	6	300.0	600	500	500
300	6	360.0	600	600	600
400	6	480.0	800	700	700
500	7	540.0	1200	800	800

575 Volt (600 Volt) Three-Phase Motor Starter Schedule

MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/2	1	0.8	30	1.25	15
3/4	1	1.1	30	1.6	15
1	1	1.4	30	2.25	15
1.5	1	2.1	30	3.5	15
2	1	2.7	30	4.5	15
3	1	3.9	30	6.25	15
5	1	6.1	30	10	15
7.5	1	9.0	30	15	15
10	1	11.0	30	17.5	20
15	2	17.0	30	25	35
20	2	22.0	30	30	45
25	2	27.0	60	40	60
30	3	32.0	60	50	60
40	3	41.0	60	60	80
50	3	52.0	100	80	90
60	4	62.0	100	90	100
75	4	77.0	100	110	110
100	4	99.0	200	150	150
125	5	125.0	200	175	200
150	5	144.0	200	200	200
200	5	192.0	400	300	250
250	6	240.0	600	350	350
300	6	290.0	600	400	400
400	6	385.0	600	500	500
500	7	480.0	800	800	700

G. Motor Control Centers (MCC's):

1. NEMA Class I, Type A:
   a. No Terminal boards for load or control connections are provided.
   b. Numbered terminals for field wired power and control connections are provided on starter.
   c. Starter unit mounted pilot devices are internally wired to starter.
2. NEMA Class I, Type B:
   a. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field wired power connections are provided on starter.
   b. Unit control terminal boards for each combination motor controller are provided for field wiring.
   c. Both terminal boards are factory wired and mounted on, or adjacent to, unit.
   d. No load terminal boards for feeder tap units are provided.
   e. Starter unit mounted pilot devices internally wired to starter.
   f. NEMA Class I, Type B will be suitable for most HVAC applications.
3. NEMA Class I, Type C:
   a. Factory wired master section terminal board, mounted on the stationary structure, is provided for each section.
   b. Terminal boards for load connections, are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field wired power connections are provided on starter.
   c. Unit control terminal boards for each combination motor controller are provided for field wiring.
   d. Complete wiring between combination controllers or control assemblies and their master terminal boards are factory installed. No wiring between sections or between master terminals is provided. No interconnections between combination controllers and control assemblies.
   e. No load terminal boards for feeder tap units are provided.
4. NEMA Class II, Type B:
   a. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field wired power connections are provided on starter.
   b. Unit control terminal boards for each combination motor controller are provided for field wiring.
   c. Both terminal boards are factory wired and mounted on, or adjacent to, unit.
   d. Complete wiring between combination controllers or control assemblies in the same and other sections are factory wired.
   e. No load terminal boards for feeder tap units are provided.
5. NEMA Class II, Type C:
   a. Factory wired master section terminal board, mounted on the stationary structure, is provided for each section.
   b. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field wired power connections are provided on starter.
   c. Unit control terminal boards for each combination motor controller are provided for field wiring.
   d. Complete wiring between combination controllers or control assemblies and their master terminal boards in the same section and other sections are factory wired.
   e. No load terminal boards for feeder tap units are provided.
6. MCCs are available in NEMA enclosure types 1, 2, 3R, and 12.

21.05 Adjustable (Variable) Frequency Drives (AFDs or VFDs)

A. AFD Components (from power side to load side):

1. Rectifier Section: Silicon controlled rectifiers (SCRs) or diodes change single or 3-phase AC power to DC power.
2. DC Bus Section: Capacitors and an inductor smooth the rippled DC power supplied by the rectifier.
3. Inverter Section: An inverter converts the DC bus power to 3-phase variable frequency power.
4. Controller Section: The controller turns the inverter on and off to control the output frequency and voltage.

B. AFD Types:

1. Variable Voltage Inverters (VVI) use a silicon controlled rectifier (SCR) to convert incoming AC power to a varying DC power and then they use an inverter to convert the DC power to 3 phase variable voltage and variable frequency power. The disadvantages of VVIs are:
   a. Incoming line notching, which requires isolation transformers.
   b. Power factor is proportional to speed, which may require power factor correction capacitors.
   c. Torque pulsations are experienced at low speeds.
   d. Non-sinusoidal current waveform produce additional heating in the motor.
2. Current Source Inverters (CSI) use SCRs in the rectifier and inverter sections and only and inductor in the DC bus section. The disadvantages of CSIs are:
   a. Incoming line notching, which requires isolation transformers.
   b. Power factor is proportional to speed, which may require power factor correction capacitors.
   c. Motor drive matching is critical to proper operation.
   d. Non-sinusoidal current waveform produce additional heating in the motor.
3. Pulse Width Modulated (PWM) Drives use a full wave diode bridge rectifier to convert the incoming AC power to DC power. Most PWM drives use a 6-pulse converter and some offer a 12-pulse converter in the rectifier section. The DC bus section consists of capacitors and in some cases an inductor. The inverter section uses Insulated Gate Bipolar Transistors (IGBTs), Bipolar Junction Transistors (BJTs), or Gate Turn off Thyristors (GTOs) to convert the DC bus power to a 3-phase variable voltage and variable frequency power. PWM drives are the most common AFD in use in the HVAC industry today despite the fact that it can punish motors electrically, especially 460 and 575 volt motors. The advantages of PWM drives are:
   a. Minimal line notching.
   b. Better efficiency.
   c. Higher power factor.
   d. Larger speed ranges.
   e. Lower motor heating.

   The disadvantages of the PWM drives are:
   a. Higher initial cost.
   b. Regenerative braking is caused because power is allowed to flow in both directions and can act as a drive or a brake.

C. AFD Design Guidelines:

1. For best motor life and reliability, do not operate motors run by AFDs into their service factor and do not select motors to run within the service factors.

2. Do not run motors below 25% of their rated speed or capacity.
3. Use inverter duty motors whenever possible. Inverter duty motors are built with winding thermostats that shut down the motor when elevated temperatures are sensed inside the motor. In addition, these motors are built with oversized frames and external blowers to cool the motor through the full range of speeds.
4. Motors which are operated with AFDs should be specified with phase insulation, should operate at a relatively low temperature rise (most high efficiency motors fit this category), and should use a high class of insulation (either insulation class F or H).
5. Generally, AFDs do not include disconnect switches; therefore the engineer must include a disconnect switch in the project design. The disconnect switch should be fused with the fuse rated for the drive input current rating.
6. Multiple motors can be driven with one AFD.
7. All control wiring should be run separate from AFD wiring.
8. Most AFDs include the following features as standard:
   a. Overload protection devices.
   b. Short Circuit Protection.
   c. Ground Fault Protection.
9. Provide AFDs with a manual bypass in the event the drive fails.

D. AFDs produce non-linear loads, which cause the following unwanted effects:

1. AC system circuits containing excessive currents and unexpectedly higher or lower voltages.
2. Conductor, connector, and component heating which is unsafe.
3. Loss of torque on motors.
4. Weaker contactor, relay, and solenoid action.
5. High heat production in transformers and motors which can be destructive.
6. Poor power factor.

21.06 NEMA Enclosures

A. NEMA Type 1: **Indoor General Purpose, Standard**

B. NEMA Type 2: **Indoor Dripproof**

C. NEMA Type 3R: **Outdoor, Rain Tight, Water Tight, Dust Tight**

D. NEMA Type 4, 4X, 5: **Outdoor Rain Tight, Water Tight, Dust Tight, Corrosion Resistant**

E. NEMA Type 7X: **Explosionproof**

F. NEMA Type 12: **Indoor Oil and Dust Tight**

21.07 Humidifiers

A. Number of Humidifier Manifolds required is given in the following table:

DUCT HEIGHT	NUMBER OF MANIFOLDS
Less than 37"	1
37" - 58"	2
59" - 80"	3
81" - 100"	4
101" and Over	5

B. Humidifier Installation Requirements:

1. Humidifiers shall be installed a minimum of 3′-0″ from any duct transformation, elbow, fitting, or outlet.
2. Consideration must be given to length of vapor trail and air handling unit and ductwork design must provide sufficient length to prevent vapor trail from coming in contact with items downstream of humidifier before vapor has had time to completely evaporate.

C. Humidifier Makeup Requirements:

1. Steam or Electric Humidifiers: 5.6 GPM/1000 KW Input or 5.6 GPM/3413 MBH
2. Evaporative and Spray Coil Humidifiers: 5.0 GPM/1000 Lbs./Hr.

21.08 Insulation

A. Materials:

1. Calcium Silicate Temperature Range: 0–+1200°F.
2. Fiberglass Temperature Range: –20–+1000°F.
3. Mineral Wool Temperature Range: +200–+1900°F.
4. Urethane, Styrene, Beadboard Temperature Range: –350–+250°F.
5. Cellular Glass Temperature Range: –450–+850°F.
6. Ceramic Fiber Temperature Range: 0–+3000°F.
7. Flexible Tubing and Sheets Temperature Range: –40–+250°F.

B. General:

1. Insulation, adhesives, mastics, sealants, and coverings shall have a flame spread rating of 25 or less and a smoke developed rating of 50 or less as determined by an independent testing laboratory in accordance with *NFPA 255* and *UL 728* as required by *ASHRAE 90A* and *90B.* Coatings and adhesives applied in the field shall be non-flammable in the wet state.
2. Hangers on chilled water and other cold piping systems should be installed on the outside of the insulation to prevent hangers from sweating.

C. Pipe Insulation:

1. Insulation shall be sectional molded glass fiber, minimum 3.0 lb. per cubic foot density, thermal conductivity not greater than 0.24 Btu-in/sq.ft./°F./hour at a mean temperature

difference of 75°F. and factory applied jacket of white, flame retardant vapor barrier jacket of 0.001″ aluminum foil laminated to kraft paper reinforced with glass fibers, or all service jacket.

2. Insulation shall be flexible foamed plastic, minimum 5.0 lb. per cubic foot density, thermal conductivity not greater than 0.28 Btu-in/sq.ft./°F./Hour at a mean temperature difference of 75°F.
3. Insulation shall be cellular glass, thermal conductivity not greater than 0.40 Btu-in/sq.ft./°F./hour at a mean temperature difference of 75°F.
4. Insulation shall be foamglass, minimum 8.5 lb. per cubic foot density, thermal conductivity not greater than 0.35 Btu-in/sq.ft./°F./hour at a mean temperature difference of 75°F.
5. Insulation Thickness is given in the following table:

PIPING SYSTEM (7)	PIPE SIZES	INSULATION THICKNESS VS TYPE(1,8)			
		A	B	C	D
CHILLED WATER - 40 °F TO 60 °F (3)	6" & SMALLER 8" & LARGER	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5
CHILLED WATER - 32 °F TO 40 °F (3)	1" & SMALLER 1-1/4" - 6" 8" & LARGER	1.0 1.5 2.0	1.5 2.0 2.5	2.0 2.5 3.5	1.5 2.5 3.0
CHILLED WATER - BELOW 32 °F (3)	2" & SMALLER 2-1/2" - 6" 8" & LARGER	1.5 2.0 2.5	2.0 2.5 3.0	2.5 3.5 4.5	2.5 3.0 4.0
CONDENSER WATER	ALL SIZES	(2)	(2)	(2)	(2)
HEATING WATER - LOW TEMPERATURE 100 °F TO 140 °F (4)	4" & SMALLER 5" & LARGER	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5
HEATING WATER - LOW TEMPERATURE 141 °F TO 200 °F (4)	ALL SIZES	1.5	2.0	2.5	2.5
HEATING WATER - LOW TEMPERATURE 201 °F TO 250 °F (4)	2" & SMALLER 2-1/2" - 6" 8" & LARGER	1.5 2.0 3.5	2.0 2.5 4.5	2.5 3.5 6.0	2.5 3.0 5.5
HEATING WATER - MEDIUM TEMPERATURE 251 °F TO 350 °F (4)	1" & SMALLER 1-1/4" - 4" 5" & LARGER	2.0 2.5 3.5	(10)	3.5 4.5 6.0	3.0 4.0 5.5
HEATING WATER - HIGH TEMPERATURE 351 °F TO 450 °F (4)	2" & SMALLER 2-1/2" - 4" 5" & LARGER	2.5 3.0 3.5	(10)	4.5 5.0 6.0	4.0 4.5 5.5
DUAL TEMPERATURE	ALL SIZES	(9)	(9)	(9)	(9)
HEAT PUMP LOOP	ALL SIZES	(2)	(2)	(2)	(2)
STEAM AND STEAM CONDENSATE - LOW PRESSURE (5)	2" & SMALLER 2-1/2" - 6" 8" & LARGER	1.5 2.0 3.5	2.0 2.5 4.5	2.5 3.5 6.0	2.5 3.0 5.5
STEAM AND STEAM CONDENSATE - MEDIUM PRESSURE (5)	1" & SMALLER 1-1/4" - 4" 5" & LARGER	2.0 2.5 3.5	(10)	3.5 4.5 6.0	3.0 4.0 5.5
STEAM AND STEAM CONDENSATE - HIGH PRESSURE (5)	2" & SMALLER 2-1/2" - 4" 5" & LARGER	2.5 3.0 3.5	(10)	4.5 5.0 6.0	4.0 4.5 5.5
REFRIGERANT SUCTION AND LIQUID LINES (6)	1" & SMALLER 1-1/4" - 6" 8" & LARGER	1.0 1.5 2.0	1.5 2.0 2.5	2.0 2.5 3.5	1.5 2.5 3.0
REFRIGERANT HOT GAS (6)	ALL SIZES	0.75	1.0	1.5	1.0
AIR CONDITIONING CONDENSATE	ALL SIZES	0.5	0.5	1.0	0.75

Notes:

1. Type A: Fiberglass Insulation.
   Type B: Flexible Foamed Plastic Insulation.
   Type C: Cellular Glass Insulation.
   Type D: Foamglass Insulation.
2. Insulation not required on systems with temperatures between 55°F and 105°F., unless insulating pipe for freeze protection; then use chilled water (40°F. and above) thicknesses.
3. Chilled water system piping is often insulated with fiberglass insulation; however, cellular glass and flexible foamed plastic may be more appropriate for moisture condensation protection. Other types of insulation may be used.
4. Heating water system piping is generally insulated with fiberglass pipe insulation. Other types of insulation may be used.
5. Steam system piping and steam condensate system piping are generally insulated with fiberglass pipe insulation. Other types of insulation may be used.
6. Refrigerant system piping is generally insulated with flexible foamed plastic. Other types of insulation may be used. Normally only refrigerant suction lines are insulated, but liquid lines should be insulated where condensation will become a problem and hot gas lines should be insulated where personal injury from contact may pose a problem.
7. Table meets or exceeds *ASHRAE Standard 90.1-1989.*
8. For piping exposed to ambient temperatures increase insulation thickness by 1.0 inch.
9. For dual temperature systems use insulation thickness for more stringent system, usually the heating system.
10. System temperature exceeds temperature rating of insulation.

D. Duct Insulation

1. Internal Duct Liner:
   a. 1″ thick, 1½ pounds per cubic foot density amber color glass fiber blanket with smooth coated matte facing to conform to *TIMA Standard AHC-101, NFPA 90A, NFPA 90B, NFPA 255, UL 181,* and *UL 723.* Duct lining shall have a thermal conductance (k) not greater then 0.26 Btu/sq.ft./°F./hour at a mean temperature difference of 75°F. Vinyl spray face shall not be permitted.
   b. Thicknesses: 1″, 1½″, 2″.
2. External Duct Insulation:
   a. Duct Wrap: Insulation shall be flexible glass fiber blanket, 2″ thick, minimum ¾ lb. per cubic foot density, thermal conductivity not greater than 0.31 Btu-in./sq.ft./°F./hour at a mean temperature difference of 75°F and factory applied jacket of minimum 0.001″ aluminum foil reinforced with glass fiber bonded to flame resistant kraft paper vapor barrier. Thicknesses: 1″, 1½″, 2″.
   b. Duct Board: Insulation shall be glass fiber, 2″ thick, minimum 3.0 lb. per cubic foot density, thermal conductivity not greater than 0.24 Btu-in./sq.ft./°F./hour at a mean temperature difference of 75°F and factory applied jacket of white, flame retardant vapor barrier jacket of 0.001″ aluminum foil reinforced with glass fibers bonded to flame resistant kraft paper. Thicknesses: 1″, 1½″, 2″, 3″, 4″.
   c. Duct Board: Insulation shall be rigid glass fiber board, 2″ thick, minimum 6.0 lb. per cubic foot density, thermal conductivity not greater than 0.22 Btu-in./sq.ft./°F./hour at a mean temperature difference of 75°F and factory applied jacket of white, flame retardant vapor barrier jacket of 0.001″ aluminum foil reinforced with glass fibers bonded to flame resistant kraft paper. Thicknesses: 1″, 1½″, 2″.

3. Insulation Thickness is given in the following table:

DUCT LOCATION	COOLING (3)		
	ANNUAL COOLING DEGREE DAYS BASE 65 °F.	INSULATION R-VALUE	INSULTION THICKNESS (2)
EXTERIOR OF BUILDING:	BELOW 500 500 TO 1150 1151 TO 2000 ABOVE 2000	3.3 5.0 6.5 8.0	0.75 1.5 1.5 2.0
INSIDE BUILDING OR IN UNCONDITIONED SPACES (1): Δ T ≤ 15 15 < Δ T ≤ 40 Δ T > 40	--- --- ---	NONE REQ'D 3.3 5.0	--- 0.75 1.5

DUCT LOCATION	HEATING (3)		
	ANNUAL HEATING DEGREE DAYS BASE 65 °F.	INSULATION R-VALUE	INSULTION THICKNESS
EXTERIOR OF BUILDING:	BELOW 1500 1500 TO 4500 4501 TO 7500 ABOVE 7500	3.3 5.0 6.5 8.0	0.75 1.5 1.5 2.0
INSIDE BUILDING OR IN UNCONDITIONED SPACES (1): Δ T ≤ 15 15 < Δ T ≤ 40 Δ T > 40	--- --- ---	NONE REQ'D 3.3 5.0	--- 0.75 1.5

Notes:

1. **Δ T (Temperature difference) is the difference between space design temperature and the design air temperature in the duct.**
2. **Minimum insulation thickness required. Internally insulated (lined) ducts usually use 1″ thickness. Externally insulated ducts usually use 1½″ or 2″ thickness.**
3. **Table based on *ASHRAE Standard 90.1-1989.***

E. Insulation Protection:

1. Aluminum roll jacketing and fitting covers produced from 0.016 inch thickness, H-14 temper with a smooth finish or approved equal. Install in accordance with manufacturer's recommendations.
2. Prefabricated PVC fitting covers and jacketing with the same insulation and thickness as specified. Install in accordance with manufacturer's recommendations.

21.09 Firestopping and Through-Penetration Protection Systems

A. All openings in fire-rated and smoke-rated building construction must be protected from fire and smoke by systems that seal these openings to resist the pas-

sage of fire, heat, smoke, flames, and gases. These openings include passages for mechanical and electrical systems, expansion joints, seismic joints, construction joints, control joints, curtain wall gaps, the space between the edge of floor slab and the exterior curtain wall and columns, and other openings or cracks.

B. Terms:

1. Firestopping. Firestopping is non-combustible building materials or a system of lumber pieces which are installed to prevent the movement of fire, heat, smoke, flames, and gases to other areas of the building through small concealed spaces. The term *firestopping* is used with all types of building construction except with non-combustible and fire-resistive construction.
2. Through-Penetration Protection Systems (TPPS). TPPS are building materials or assemblies of materials specifically designed and manufactured to form a system designed to prevent the movement of fire, heat, smoke, flames, and gases to other areas of the building through openings made in fire-rated floors and walls to accommodate the passage of combustible and non-combustible items. The term *TPPS* is used with non-combustible and fire-resistive building construction.
3. Combustible Penetrating Items. Combustible penetrating items are materials such as plastic pipe and conduit, electrical cables, and combustible pipe insulation.
4. Non-Combustible Penetrating Items. Non-combustible penetrating items are materials such as copper, iron, or steel pipe; steel conduit; EMT; electrical cable with steel jackets; and other non-combustible items.
5. Annular Space Protection. Annular space protection is the building materials or assembly of materials which protect the space between non-combustible penetrating items and the rated assembly. In concrete or masonry assemblies, the materials generally used for annular space protection are concrete, grout, or mortar. In all other assemblies, the materials must be tested and meet *ASTM E119* standard under positive pressure.
6. Single-Membrane Protection. Single-membrane protection is the building materials or assembly of materials which protect the opening through one side, or a single membrane of a fire-resistive wall, roof/ceiling, or floor/ceiling to accommodate passage of combustible or non-combustible items. Materials protecting single membranes are annular space protection systems or TPPS.
7. Shaft Alternatives. A fire-rated shaft or enclosure is not required if a TPPS system with an F-Rating and a T-Rating equal to the rating of the assembly is used to protect openings made in fire-rated floors and walls to accommodate the passage of combustible and non-combustible items.

C. System Ratings:

1. F-Ratings (Flame Ratings) define the period of time for which the firestopping or TPPS system prevents the passage of flames and hot gases to the unexposed side of the assembly, in accordance with *ASTM E814.* To receive an F-Rating, the system must also pass the hose stream test. F-Ratings are needed for all applications. F-Ratings must be equal to the rating of the assembly.
2. T-Ratings (Thermal Ratings) define the period of time for which the firestopping or TPPS system prevents the passage of flames and hot gases to the unexposed side of the assembly (F-Rating), and must also restrict the temperature rise on the unexposed surface to 325°F. in accordance with *ASTM E814.* T-Ratings must be equal to the rating of the assembly and at least 1 hour. T-Ratings are rarely applied because most penetrations in commercial structures tend to be in non-combustible concealed spaces and are generally only applied where codes require open protectives.

D. TPPS Materials:

1. Intumescent materials expand to form an insulating char.
2. Subliming materials pass from solid to vapor when heated without passing through the liquid phase.
3. Ablative materials char, melt, or vaporize when heated.
4. Endothermic materials, such as concrete and gypsum, absorb heat using chemically bounded water of the material.
5. Ceramic fibers are high temperature refractory materials.

E. Material Forms:

1. Caulks.
2. Putties.
3. Mixes.
4. Sheets, strips or collars.
5. Kits.
6. Devices.

PART 22

Equipment Schedules

22.01 General

A. The equipment requirements listed in this section are general in nature and should be edited to the suit the project. The items listed for a particular piece of equipment are generally not all required. For example, a variable volume terminal unit will have either a hot water coil or steam coil, but not both. Also some Clients and Authorities Having Jurisdiction may not permit some of this information to be included on the drawings (i.e., Manufacturer's Name and Model No.).

B. Abbreviations

1. CFM = Air Flow Rate (Cubic Feet per Minute)
2. GPM = Water Flow Rate (Gallons per Minute)
3. MBH = 1,000 Btu/Hr.
4. Hp = Horsepower
5. DB = Dry Bulb Temperature (°F.)
6. WB = Wet Bulb Temperature (°F.)
7. RH = Relative Humidity (%)
8. EAT = Entering Air Temperature (°F.)
9. LAT = Leaving Air Temperature (°F.)
10. EWT = Entering Water Temperature (°F.)
11. LWT = Leaving Water Temperature (°F.)
12. SP = Static Pressure (In. WG)
13. ESP = External Static Pressure (In. WG)
14. Total SP = Total Static Pressure (In. WG)
15. FLA = Full Load Amps
16. LRA = Locked Rotor Amps
17. FPM = Feet per Minute
18. Air PD = Air Pressure Drop (In. WG)
19. Water PD = Water Pressure Drop (Ft. H_2O)
20. PRV = Pressure Reducing Valve (Psig)
21. RV = Relief Valve (Psig)
22. Psig = Pounds per Square Inch
23. SA = Supply Air CFM
24. RA = Return Air CFM
25. OA = Outside Air CFM
26. EXH = Exhaust Air CFM
27. RFA = Relief Air CFM
28. CC = Cooling Coil
29. HC = Heating Coil
30. PHC = Preheat Coil
31. RHC = Reheat Coil

22.02 Air Balance Schedule

Room Number
Room Name
Source
Number of Occupants
Code Requirements:

- OA CFM
- SA CFM

Supply CFM
Return CFM
Relief CFM
Exhaust CFM
Outdoor CFM
Transfer Air:

- CFM
- To Room
- From Room

Remarks

22.03 Air Compressors

Designation
Location
Service
Type (Reciprocating, Rotary Screw, Duplex, Simplex)
CFM
Pressure Psig
Receiver Size:

- Gallons
- Diameter
- Length

Motor:

- Hp
- RPM
- Volts-Phase-Hertz

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.04 Air Cooled Condensers

Designation
Location
Service
Type
Tons or MBH
Refrigerant Type
Saturated Condenser Temperature
Condenser EAT °F.DB/°F.WB
Minimum OA Temperature
Fans:

- Number
- Hp
- Volts-Phase-Hertz

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.05 Air Cooled Condensing Units

Designation
Location
Service
Type
Tons or MBH
Refrigerant Type
Saturated Condenser Temperature
Condenser EAT °F.DB/°F.WB
Minimum OA Temperature
Compressor:
- Number
- KW
- Volts-Phase-Hertz

Fans:
- Number
- Hp
- Volts-Phase-Hertz

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.06 Air Conditioning Units

Designation
Location
Service
Min. OA CFM
Fan:
- CFM
- ESP
- Number of Wheels
- Wheel Diameter In.
- Motor Hp

Filters:
- Type
- Efficiency

Cooling Coil:
- Refrigerant Type
- Sensible MBH
- Total MBH
- EAT °F.DB/°F.WB

- LAT °F.DB/°F.WB

Compressor:
- Number
- KW

Condenser:
- EAT
- Motor Hp

Exhaust Fan Motor Hp

Electric Heat:
- KW
- EAT
- LAT

Gas Heater:
- Output MBH
- Input MBH
- EAT
- LAT

Hot Water Coil:
- MBH
- EAT
- LAT
- EWT
- LWT
- GPM

Steam Coil:
- MBH
- EAT
- LAT
- # Steam/Hr.
- Steam Pressure Psig

Electric, Volts-Phase-Hertz
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.07 Air Filters (Pre-Filters, Filters, Final-Filters)

Designation
Location
Equipment Served
Number
Type
Width
Height
Depth
Efficiency %
Initial Air PD
Final Air PD
Remarks

22.08 Air Handling Units—Custom, Factory Assembled, Factory Packaged, or Field Fabricated

Designation
Location
Service
Min. OA CFM
Fan:
- CFM
- Type (AF, BI, FC, DWDI, SWSI)
- Class (I, II, III, IV)
- Number of Wheels
- Wheel Diameter
- ESP
- Total SP
- Motor Hp
- Volts-Phase-Hertz

Filters (See Air Filters)
Coils (See Coils—DX, Electric, Steam, Water)
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.09 Air Handling Units—Packaged

Designation
Location
Service
Min. OA CFM
Fan:
- CFM
- Type (AF, BI, FC, DWDI, SWSI)
- No. of Wheels
- Wheel Diameter In.
- ESP
- Total SP
- Motor Hp
- Volts-Phase-Hertz

Filters (See Air Filters)
Coils (See Coils—DX, Electric, Steam, Water)
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.10 Boilers, Hot Water

Designation
Location

Service
Output MBH
Water:
- GPM
- EWT
- LWT
- Water PD

Heater:
- Gas Input MBH
- Oil Input GPH
- Electric:
  - KW
  - Volts-Phase-Hertz

RV Setting
Accessories:
- HP
- KW
- Volts-Phase-Hertz

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.11 Boilers, Steam

Designation
Location
Service
Output # Steam/Hr.
Steam Pressure Psig
Feed Water Temperature
Heating Surface Sq. Ft.
Steam Drum Diameter
Lower Drum Diameter
Gas Input MBH
Oil Input GPH
Electric:
- KW
- Volts-Phase-Hertz

RV Setting
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.12 Cabinet Unit Heaters

Designation
Location
Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, Up Discharge, Down Discharge, Hot Water, Steam, Electric, etc.)

Fan:
- CFM
- RPM
- Motor Hp
- Volts-Phase-Hertz

Hot Water Coil:
- Capacity MBH
- EAT
- GPM
- EWT

Steam Coil:
- Capacity MBH
- EAT
- # Steam/Hr.
- Steam Pressure Psig

Electric Coil:
- KW
- Volts-Phase-Hertz

Runouts:
- Supply
- Return

Manufacturers: Name and Model No.
Remarks

22.13 Chemical Feed Systems

Designation
Location
Service
Pump:
- Type (Positive Displacement)
- GPH
- PSI
- HP
- Volts-Phase-Hertz

Tank Gallons
Agitator:
- HP
- RPM
- Volts-Phase-Hertz

Remarks

22.14 Chillers, Absorption

Designation
Location
Service
Type

Refrigerant Type
Capacity
  Tons Cooling
  MBH Heating
Evaporator
  EWT
  LWT
  GPM
  Water PD
Condenser
  EWT
  LWT
  GPM
  Water PD
Absorber
  Steam Pressure Psig
  # Steam/Hr.
  Gas Pressure In. W.G.
  Gas Input MBH
  Oil Input GPH
Heating:
  EWT
  LWT
  GPM
  Water PD
Electrical:
  Hp
  KW
  Volts-Phase-Hertz
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.15 Chillers, Air Cooled

Designation
Location
Service
Type
Refrigerant Type
Capacity Tons
Evaporator:
  EWT
  LWT
  GPM
  Water PD
Condenser Temperature
Condenser:
  EAT

Fans:
- Number
- Hp

Compressor
- Number
- KW
- Volts-Phase-Hertz

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.16 Chillers, Water Cooled

Designation
Location
Service
Type
Refrigerant Type
Capacity Tons
Evaporator:
- EWT
- LWT
- GPM
- Water PD

Condenser:
- EWT
- LWT
- GPM
- Water PD

Heating (Heat Recovery Type):
- EWT
- LWT
- GPM
- Water PD

Compressor:
- Number
- KW
- Volts-Phase-Hertz

Evaporator Temperature
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.17 Coils, Direct Expansion (DX)

Designation
Location
Equipment Served
Service (CC, Heat Recovery)
Refrigerant Type

MBH
CFM
EAT °F.DB/°F.WB
LAT °F.DB/°F.WB
Maximum Face Velocity FPM
Air PD
Remarks

22.18 Coils, Electric

Designation
Location
Equipment Served
Service (PHC, HC, RHC)
MBH
CFM
EAT
LAT
Maximum Face Velocity FPM
Air PD
KW
Volts-Phase-Hertz
Number of Control Steps
Manufacturers: Name and Model No.
Remarks

22.19 Coils, Steam

Designation
Location
Equipment Served
Service (HC, PHC, RHC)
MBH
CFM
EAT
LAT
Maximum Face Velocity FPM
Air PD
Steam/Hr.
Steam Pressure Psig
Runout Sizes
  Supply
  Return
Remarks

22.20 Coils, Water

Designation
Location

Equipment Served
Service (PHC, CC, HC, RHC)
MBH
CFM
EAT °F.DB/°F.WB
LAT °F.DB/°F.WB
Max. Face Velocity FPM
GPM
EWT
LWT
Air PD
Water PD
Runout Size:
  Supply
  Return
Remarks

22.21 Condensate Pump and Receiver Sets

Designation
Location
Service
Type (Simplex, Duplex)
GPM
Heat Ft. H_2O
Motor Hp
Volts-Phase-Hertz
Tank Capacity Gallons
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.22 Convectors

Designation
Location
Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)
Capacity MBH
EAT
GPM
EWT
Steam/Hr.
Steam Pressure Psig
KW
Volts-Phase-Hertz
Runout Size
  Supply
  Return
Manufacturers: Name and Model No.
Remarks

22.23 Cooling Towers

Designation
Location
Service
Type
GPM
EWT
LWT
Ambient Air °F.WB
Fan
- Number
- CFM
- No. of Motors
- Hp
- ESP In. W.G.
- Volts-Phase-Hertz

Nozzle PD
Height Difference
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.24 Deaerators

Designation
Location
Service
Type
Number of Stages
Outlet Capacity Lb./Hr.
Storage Capacity:
- Pounds
- Minutes

Steam:
- Lbs./Hr.
- Psig

Size (Length × Diameter)
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.25 Design Conditions

Room Number
Room Name
Summer:
- Outside °F.DB/°F.WB
- Inside °F.DB/%RH

Winter:
- Outside °F.DB/°F.WB
- Inside °F.DB/%RH

Remarks

22.26 Electric Baseboard Radiation

Designation
Type (See Specification for Type Designation)
Style (Wall Mounted, Floor Mounted, Flat Top, Sloped Top, Etc.)
Number of Elements
Electric:
- KW
- Volts-Phase-Hertz

Manufacturers: Name and Model No.
Remarks

22.27 Electric Radiant Heaters

Designation
Type (See Specification for Type Designation)
Style
Number of Elements
Length of Unit
Electric:
- KW
- Volts-Phase-Hertz

Manufacturers: Name and Model No.
Remarks

22.28 Evaporative Condensers

Designation
Location
Service
Type
Tons or MBH
Refrigerant Type
Saturated Condenser Temperature
Condenser EAT °F.DB/°F.WB
Minimum OA Temperature
Fans:
- Number
- ESP
- Hp
- Volts-Phase-Hertz

Pump:
- Hp
- Head Ft.H_2O

- Number
- Volts-Phase-Hertz

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.29 Expansion Tanks

Designation
Location
Service (Hot Water, Chilled Water, Condenser Water, Etc.)
Type (Closed, Open, Diaphragm)
Capacity Gallons
Size Diameter × Length
PRV Setting Psig
RV Setting Psig
Connection Size:

- Fill
- System

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.30 Fans

Designation
Location
Service (SA, RA, EA)
CFM
RPM
Drive (Belt, Direct)
Type (BI, AF, FC, Roof, Propeller, Etc.)
Class (I, II, III, IV)
Wheel Diameter Inches
SP
Motor Hp
Volts-Phase-Hertz
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.31 Fan Coil Units

Designation
Nominal CFM
Type (2-Pipe, 4-Pipe, 2-Pipe with Electric Heat)
Style (Recessed, Semi-recessed, Exposed, Concealed, Cabinet, Hi-Rise, Ceiling, Floor, etc.)
Cooling:

- Sensible MBH

Total MBH
GPM
EWT
LWT
EAT °F.DB/°F.WB
Water PD
Runout Size:
Supply
Return
Drain Size
Heating:
MBH
GPM
Water PD
EWT
LWT
EAT °F.DB/°F.WB
Runout Size:
Supply
Return
KW
Volts-Phase-Hertz
Number of Control Steps
Fan:
CFM
Motor Hp
ESP
Volts-Phase-Hertz
Manufacturers: Name and Model No.
Remarks

22.32 Finned Tube Radiation

Designation
Type (See Specification for Type Designation)
Style (Wall Mounted, Floor Mounted, Flat Top, Sloped Top, etc.)
Number of Elements
Element Size:
Fins
Tube
Water:
Capacity MBH
EWT
LWT
EAT
GPM
Water PD
Steam:
Capacity MBH
EAT

  # Steam/Hr.
  Steam Pressure
Manufacturers: Name and Model No.
Remarks

22.33 Flash Tanks

Designation
Location
Service
Type
Discharge Steam Pressure Psig
Tanks Size (Diameter × Height)
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.34 Fluid Coolers/Closed Circuit Evaporative Coolers

Designation
Location
Service
Type
Fluid Type
GPM
EWT
LWT
Ambient Air °F.WB
Fan:
  Number
  CFM
  Number of Motors
  Hp
  ESP
  Volts-Phase-Hertz
Pump:
  Hp
  Head Ft.H_2O
  Number
  Volts-Phase-Hertz
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.35 Fuel Oil Tanks

Designation
Location

Fuel Type
Tank Type (Double Wall, Steel, Fiberglass)
Capacity Gallons
Size:
- Length
- Diameter

Approximate Weight
Connection Sizes:
- Supply
- Return
- Fill
- Vent
- Gauge
- Heating Supply and Return
- Sounding Drop (Tank, Storage)

Pad Size (L × W × Th)
Manhole Size
Manufacturers: Name and Model No.
Remarks

22.36 Gas Pressure Regulators

Designation
Location
Capacity Cu.Ft./Hr.
Inlet:
- Psig
- Pipe Size

Outlet:
- Psig
- Pipe Size

Manufacturers: Name and Model No.
Remarks

22.37 Gravity Ventilators

Designation
Location
Service
Type Dome, Louvered, Filters, No Filters)
Throat Size (L × W)
Physical Size (L × W × H)
Manufacturers: Name and Model No.
Remarks

22.38 Heat Exchangers, Plate and Frame

Designation
Location

Service
Capacity MBH
Cold Side:
- GPM
- EWT
- LWT
- Water PD

Hot Side:
- GPM
- EWT
- LWT
- Water PD

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.39 Heat Exchangers, Shell and Tube, Steam to Water (Converter)

Designation
Location
Service
Capacity MBH
Shell:
- # Steam/Hr.
- Steam Pressure Psig

Tubes:
- GPM
- EWT
- LWT
- Water PD
- Minimum Surface Area Sq. Ft.
- Number of Passes

Approximate Length Ft.
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.40 Heat Exchangers, Shell and Tube, Water to Water

Designation
Location
Service
Capacity MBH
Shell:
- GPM
- EWT
- LWT

Water PD
Tubes:
GPM
EWT
LWT
Water PD
Minimum Surface Area Sq. Ft.
Number of Passes
Approximate Length Ft.
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.41 Heat Pumps, Air Source

Designation
Location
Service
Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)
Fan:
Total CFM
OA CFM
ESP
Cooling:
Sensible MBH
Total MBH
EAT °F.DB/°F.WB
LAT °F.DB/°F.WB
Sink Air Temperature
Heating Capacity:
Compressor MBH
Total MBH
Source Air Temperature
Electrical:
Evaporator Fan Hp
Condenser Fan Hp
Compressor KW
Heater KW
Volts-Phase-Hertz
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.42 Heat Pumps, Water Source

Designation
Location
Service

Type (Recessed, Semi-recessed, Exposed, Concealed, Ceiling, Floor, etc.)
Fan:
- Total CFM
- OA CFM
- ESP

Cooling:
- Sensible MBH
- Total MBH
- EAT °F.DB/°F.WB
- LAT °F.DB/°F.WB
- EWT

Heating Capacity:
- Compressor MBH
- Total MBH
- EWT

Source Water:
- GPM
- Water PD

Runout Size:
- Supply
- Return

Electrical:
- Fan Hp
- Compressor KW
- Heater KW
- Volts-Phase-Hertz

Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.43 Humidifiers

Designation
Location
Service
Capacity:
- # Steam/Hr.
- Steam Pressure Psig

Electric:
- KW
- Volts-Phase-Hertz

Duct/Air Handling Unit Size
Number of Manifolds
Runout Size:
- Supply
- Return
- Drain

Manufacturers: Name and Model No.
Remarks

22.44 Motor Control Centers

Item Number
Hp/KW
FLA
Starter Size
Circuit Breaker Size
Auxiliary Equipment (Specifications)
Nameplate Designation
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.45 Packaged Terminal AC Systems

Designation
Location
Service
Minimum OA CFM
Fan:
- CFM
- ESP
- Number Of Wheels
- Motor Hp

Filters:
- Type
- Efficiency %

DX Cooling:
- Sensible MBH
- Total MBH
- EAT °F.DB/°F.WB
- LAT °F.DB/°F.WB

Compressors:
- Number
- KW

Condenser:
- EAT
- Motor Hp

Electric Heat:
- KW
- EAT
- LAT

Electric Volts-Phase-Hertz
Hot Water:
- MBH
- EAT
- LAT
- EWT
- LWT

- GPM
- Water PD

Steam Heat:

- MBH
- EAT
- LAT
- # Steam/Hr.
- Steam Pressure Psig
- Operating Weight Lbs.
- Manufacturers: Name and Model No.
- Remarks

22.46 Pumps

Designation
Location
Service (Chilled, Heating, Condenser Water, etc.)
Type (End Suction, Horizontal Split Case, In-Line, etc.)
GPM
Head Ft.
RPM
Motor Hp
NPSH
Volts-Phase-Hertz
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

22.47 Radiant Heaters

Designation
Output Capacity MBH
Gas Input MBH
Burner:

- FLA
- LRA
- Volts-Phase-Hertz

Vacuum Pump:

- Motor Hp
- Volts-Phase-Hertz

Length of Reflector
Manufacturers: Name and Model No.
Remarks

22.48 Steam Pressure Reducing Valves

Designation
Location
Capacity # Steam/Hr.

Inlet:
- Pressure Psig
- Pipe Size

Outlet:
- Pressure Psig
- Pipe Size

Manufacturers: Name and Model No.
Remarks

22.49 Steam Pressure Relief Valve

Designation
Location
Capacity # Steam/Hr.
Relief Valve Setting Psig
Discharge Pipe Size
Manufacturers: Name and Model No.
Remarks

22.50 Sound Attenuators (Duct Silencers)

Designation
Location
Service
Type
CFM
Noise Reduction:
- 63 HZ
- 125 HZ
- 250 HZ
- 500 HZ
- 1,000 HZ
- 2,000 HZ
- 4,000 HZ
- 8,000 HZ

Face Velocity FPM
Maximum Air PD
Length Ft.
Manufacturers: Name and Model No.
Remarks

22.51 Terminal Units, Constant Volume Reheat

Designation
CFM Range
Inlet Duct Size
Hot Water Coil:

Capacity MBH
EAT
Number of Rows
GPM
EWT
Water PD

Steam Coil:
Capacity MBH
EAT
Number of Rows
#Steam/Hr.
Steam Pressure Psig

Runout Size:
Supply
Return

Electric Coil:
KW
Volts-Phase-Hertz
No. of Control Steps

Manufacturers: Name and Model No.
Remarks

22.52 Terminal Units, Dual Duct Mixing Box

Designation
CFM Range
Minimum/Maximum CFM:
Cold Deck
Hot Deck

Inlet Duct Size:
Cold
Hot

Manufacturers: Name and Model No.
Remarks

22.53 Terminal Units, Fan Powered

Designation
CFM Range
Minimum CFM Setting
Inlet Duct Size
Fan:
Type (Series, Parallel)
CFM
ESP
Motor Hp
Volts-Phase-Hertz

Hot Water Coil:

Capacity MBH
EAT
Number of Rows
GPM
EWT
Water PD

Steam Coil:
Capacity MBH
EAT
Number of Rows
Steam/Hr.
Steam Pressure Psig

Runout Size:
Supply
Return

Electric Coil:
KW
Volts-Phase-Hertz
Number of Control Steps

Manufacturers: Name and Model No.
Remarks

22.54 Terminal Units, Variable Air Volume (VAV)

Designation
CFM Range
Minimum CFM Setting
Inlet Duct Size

Hot Water Coil:
Capacity MBH
EAT
Number of Rows
GPM
EWT
Water PD

Steam Coil:
Capacity MBH
EAT
Number of Rows
Steam/Hr.
Steam Pressure Psig

Runout Size:
Supply
Return

Electric Coil:
KW
Volts-Phase-Hertz
Number of Control Steps

Manufacturers: Name and Model No.
Remarks

22.55 Unit Heaters

Designation
Location
Type (Horizontal Discharge, Vertical Discharge, Hot Water, Steam, Electric, Gas Fired, Oil Fired, etc.)
Fan:
  CFM
  RPM
  Motor Hp
  Volts-Phase-Hertz
Hot Water Coil
  Capacity MBH
  EAT
  GPM
  EWT
Steam Coil
  Capacity MBH
  EAT
  # Steam/Hr.
  Steam Pressure Psig
Gas Heater:
  Output Capacity MBH
  Input MBH
  EAT
Oil Heater:
  Output Capacity MBH
  Input GPH
  EAT
Electric Coil:
  KW
  Volts-Phase-Hertz
Runouts:
  Supply
  Return
Manufacturers: Name and Model No.
Remarks

22.56 Water Softeners

Designation
Location
Service
Number of Tanks
Capacity:
  Minimum Grains
  Maximum Grains
  GPM
Tank Size (Diameter × Height)

Brine Tank (Diameter × Height)
Electrical Volts-Phase-Hertz
Operating Weight Lbs.
Manufacturers: Name and Model No.
Remarks

PART 23

Equipment Manufacturers

23.01 Central Plant Equipment

A. Air Cooled Condensers and Condensing Units: Trane; Carrier; York; McQuay

B. Boilers, Cast Iron: H.B. Smith; Weil McClain; Burnham

C. Boilers, Copper Tube: Triad; Raypak; Hydrotherm

D. Boilers, Electric: Brasch; Indeeco; Cemline

E. Boilers, Fire Tube: Cleaver Brooks; York-Shipley; Kewaunee; Johnston

F. Boilers, Water Tube: Cleaver Brooks; Babcock & Wilcox; Keeler

G. Chillers, Absorption: Trane; Carrier; York

H. Chillers, Centrifugal: Trane; Carrier; York; McQuay

I. Chillers, Reciprocating: Trane; Carrier; York; McQuay; Bohn; Dunham-Bush

J. Chillers, Rotary Screw: Trane; McQuay; Bohn; Dunham-Bush

K. Cooling Towers: Baltimore Air Coil; Marley; Evapco, Tower Tech

L. Evaporative Condensers and Fluid Coolers: Baltimore Air Coil; Marley; Evapco, Tower Tech

M. Fans, Cabinet Centrifugal: Trane; Buffalo; Carrier; York; McQuay

N. Fans, Ceiling Type: Greenheck; Penn; Cook

O. Fans, Centrifugal, Utility Sets: Greenheck; Barry; Buffalo; Trane; York; Peerless; Twin City; Pace; Ilg; New York Blower; Hartzell Fan, Inc.; Cincinnatti Fan and Ventilator Company, Inc.

P. Fans, Power Roof and Wall Ventilators: Greenheck; Penn; Cook; Jenn-Air; Acme; Powerline; Ilg; Hartzell Fan, Inc.; Cincinnatti Fan and Ventilator Company, Inc.

Q. Fans, Power Roof and Wall Ventilators, Upblast: Greenheck; Penn; Cook; Jenn-Air; Acme; Powerline; Ilg; Hartzell Fan, Inc.; Cincinnatti Fan and Ventilator Company, Inc.

R. Fans, Propeller: Greenheck; ACME; Buffalo; Trane; Powerline; Ilg; American Coolaire; Hartzell Fan, Inc.; Cincinnatti Fan and Ventilator Company, Inc.

S. Fans, Tubular Centrifugal: Greenheck; Barry; Peerless; Twin City; Ilg; New York Blower

T. Fans, Vane Axial: Peerless; Greenheck; Joy; Woods Fan Company; Hartzell Fan, Inc.

U. Heat Exchangers, Plate and Frame: Bell and Gossett; Tranter; Baltimore Air Coil; Alfa-Laval Thermal, Inc.; Paul Mueller

V. Heat Exchangers, Shell and Tube: Bell and Gossett; Taco; Amtrol; Patterson-Kelley; Sims; Dominion; Whitlock

W. Heat Pumps: McQuay; American Air Filter; International Environmental; Friedrich; General Electric

X. Ice Storage Systems: Baltimore Air Coil; Calmac; Turbo; Marley

Y. Pumps, Centrifugal, End Suction, Horizontal Split Case, Close Coupled: Bell and Gossett; Taco; Worthington; Weinman; Allis Chalmers; Amtrol; Aurora; Buffalo; Goulds; Ingersall Rand

Z. Pumps, Centrifugal, Inline: Bell and Gossett; Taco; Amtrol; Goulds; Thrush

AA. Steam Generators, Unfired: Cemline; Ketema

23.02 Air System Equipment and Specialties

A. Air Conditioners, Window and Split Systems: Friedrich; Mitsubishi; Comfortmaker; Eubank; National Comfort Products; Trane; Carrier; York; McQuay

B. Air Filters: American Air Filter; Farr; Cambridge; Continental; Mine Safety Appliances

C. Air Filter Gauges: Dwyer

D. Air Flow Monitors: Air Monitor Corporation; Cambridge Air Sentinel

E. Air Handling Units, Custom Built: Miller-Picking; Buffalo; Air Enterprises; Gamewell; Semco; Mammoth; Racan; Pace; Hunt Air; Acousti Flo; M&I; Gaylord Industries; Governair; York; Industrial Sheet Metal & Mechanical Corp (ISM)

F. Air Handling Units, Direct or Indirect Gas Fired: Weatherite; Reznor; Absolut Aire; Rapid; Concept Designs, Inc.; Sterling; Cambridge Engineering

G. Air Handling Units, Packaged: Trane; Carrier; York; McQuay; Buffalo; Bohn; Dunham-Bush; Magic Aire; Mammoth; Governair

H. Air Purification Systems: Bioclimatic, Inc

I. Coils, Heating and Cooling: Trane; Carrier; York; McQuay; Aerofin; Bohn; Dunham-Bush

J. Dampers, Fire, Smoke, Combination, Motor Operated: Ruskin; Air Balance, Inc.; American Warming and Ventilating, Inc.; Arrow Louver and Damper; Penn Ventilator Co.; Phillips-Aire; United Air/Safe Air

K. Diffusers, Register and Grilles: Krueger, Anemostat, Agitair; Barber-Colman; Titus; Carnes

L. Ductwork, FRP: Beverly-Pacific; Corrosion Products; Environmental Corrections; Fiber Dyne; Harrington; Viron

M. Ductwork, FRP Resins: Atlac Type 711-05 AS; Dion Corres 9300FR; Hetron FR992; Derakane 510A; Interplastics VE8440

N. Ductwork, Halar Coated Stainless Steel: Fab Tech Incorporated; GDS Manufacturing Company; Viron; PSI

O. Fans, Cabinet Centrifugal: Trane; Buffalo; Carrier; York; McQuay

P. Fans, Ceiling Type: Greenheck; Penn; Cook

Q. Fans, Centrifugal, Utility Sets: Greenheck; Barry; Buffalo; Trane; York; Peerless; Twin City; Pace; Ilg; New York Blower; Hartzell Fan, Inc.; Cincinnatti Fan and Ventilator Company, Inc.

R. Fans, Power Roof and Wall Ventilators: Greenheck; Penn; Cook; Jenn-Air; Acme; Powerline; Ilg; Hartzell Fan, Inc.; Cincinnatti Fan and Ventilator Company, Inc.

S. Fans, Power Roof and Wall Ventilators, Upblast: Greenheck; Penn; Cook; Jenn-Air; Acme; Powerline; Ilg; Hartzell Fan, Inc.; Cincinnatti Fan and Ventilator Company, Inc.

T. Fans, Propeller: Greenheck; ACME; Buffalo; Trane; Powerline; Ilg; American Coolaire; Hartzell Fan, Inc.; Cincinnatti Fan and Ventilator Company, Inc.

U. Fans, Tubular Centrifugal: Greenheck; Barry; Peerless; Twin City; Ilg; New York Blower

V. Fans, Vane Axial: Peerless; Greenheck; Joy; Woods Fan Company; Hartzell Fan, Inc.

W. Flexible Duct: Thermaflex; Genflex; Wiremold

X. Gravity Ventilators: Greenheck; Penn; Acme; Cook; Jenn; Powerline

Y. Heat Pumps: McQuay; American Air Filter; International Environmental; Friedrich; General Electric

Z. Humidifiers: Armstrong; Herrmidifier; Dryomatic; Industrial Humidifier Co.; Carnes; Nortec; Hygromatik; Dri-Steam Humidifier Co.

AA. Louvers: American Warming and Ventilating, Inc.; Air Balance, Inc.; Ruskin; Airline Products; Airstream Products; Penn Ventilator Co.; Phillips Industries, Inc.; Arrow United Industries; Construction Specialties, Inc.

BB. Prefabricated Panels: United Sheet Metal Co.; Industrial Acoustics Co.; Gale Corp.

CC. Sound Attenuators (Active Noise Control): Digisonix

DD. Sound Attenuators (Duct Silencers): Industrial Acoustics Co. (IAC); Koppers; Gale; Semco; Vibro Acoustics; Commercial Acoustics; Vibration Mountings, Inc.; Aero-Sonics

EE. Thermometers: Ashcroft; Marsh; Weiss; Marshalltown; Moeller; Taylor Tel-Tru; Trerice; Weksler; Weston

23.03 Water System Equipment and Specialties

A. Air Separators and Air Control Devices: Bell and Gossett; Taco; Amtrol; Thrush

B. Air Vents, Automatic: Bell and Gossett; Taco; Amtrol; Armstrong

C. Backflow Preventers and Pressure Reducing Valves: Watts Regulator; Cobraco Industries

D. Expansion Joints: Metraflex; Keflex; Hyspan; Kopperman; Anaconda; Aeroquip

E. Expansion Tanks: Bell and Gossett; Taco; Amtrol; Woods

F. Filters/Separators: Lakos Solids Separators; 3M Filtration Products; Filterite; Ametek; Puro Flux

G. Flow Measuring Systems, Portable and Permanent: Rockwell International Inc.; Taco; Bell and Gossett; Barton; Fisher and Porter; Girand; Barco; Dietrich Standard

H. Coils, Heating and Cooling: Trane; Carrier; York; McQuay; Aerofin; Bohn; Dunham-Bush

I. Pressure Gauges: Ashcroft; Marsh; Weiss; Marshalltown; Moeller; Trerice; Weksler; Weston; U.S. Gauge

J. Pumps, Centrifugal, End Suction, Horizontal Split Case, Close Coupled: Bell and Gossett; Taco; Worthington; Weinman; Allis Chalmers; Amtrol; Aurora; Buffalo; Paco; Dean; Goulds; Ingersall Rand

K. Pumps, Centrifugal, Inline: Bell and Gossett; Taco; Amtrol; Goulds; Thrush; Paco

L. Relief Valves: Crosby; Farris; Lonnergan; Kunkle

M. Strainers: Mueller; Spence; Sarco; Metraflex; McAlear; Tate Tempco; Boylston; Nicholson

N. Thermometers: Ashcroft; Marsh; Weiss; Marshalltown; Moeller; Taylor Tel-Tru; Trerice; Weksler; Weston

O. Valves, Balancing: Bell and Gossett; Taco; Torr & Anderson (TA)

P. Valves, Ball: Nibco; Hammond; Fairbanks; Worchester; Itt Grinnell; Apollo; Crane; Powell; Contromatics; Dynaquip

Q. Valves, Butterfly: Dezurik; Allis-Chalmers; Centerline; Conoflow; Walworth; Trw Mission; Crane-Monark; Demco; Continental; Milliken Valve Co.; Mueller

R. Valves, Check: Jenkins; Crane; Lunkenheimer; Nibco; Hammond; Powell; Stockham; Walworth; Fairbanks; Kennedy; Milwaukee; RP & C Valve

S. Valves, Silent Check: Miller Valve Co.

T. Valves, Gate: Jenkins; Crane; Lunkenheimer; Nibco; Hammond; Powell; Stockham; Walworth; Fairbanks; Kennedy; Milwaukee; RP & C Valve

U. Valves, Globe: Jenkins; Crane; Lunkenheimer; Nibco; Hammond; Powell; Stockham; Walworth; Fairbanks; Kennedy; Milwaukee; RP & C Valve

V. Valves, Plug: Dezurik; Milliken Valve Co.; Mueller

W. Water Treatment Systems: Betz Dearborn, Inc.; Nalco; Diversey Water Technologies, Inc.; Ashland Chemical Company; Chem Treat, Inc.; Coastline; Tricon Chemical Corporation; Cleaver Brooks Water Management Group; Mogul; Olin; ARC; Culligan

X. Water Heaters, Electric: Cemline; A.O. Smith; PVI; State; Bradford White; Lochinvar; Ruud

Y. Water Heaters, Gas: A.O. Smith; PVI; State; Bradford White; Lochinvar

Z. Water Heaters, Instantaneous, Undersink: In Sink Erator; Eemax

AA. Water Heaters, Oil: A.O. Smith; PVI; State

BB. Water Heaters, Steam: Cemline, A.O. Smith; Bell & Gossett; Patterson & Kelley

23.04 Steam System Equipment and Specialties

A. Coils, Heating and Cooling: Trane; Carrier; York; McQuay; Aerofin; Bohn; Dunham-Bush

B. Condensate Pump and Receiver Units: Federal; Chicago; Domestic Pump; Skidmore; Weinman

C. Condensate Storage Units: Cleaver Brooks; Trane; Crane-Cochrane Buffalo Tank; Adamson

D. Deaerator Feedwater Systems: Cleaver Brooks; Permutit; Chicago; Trane; Crane-Cochrane

E. Steam Control Valves and Regulators: Leslie; Spirax Sarco

F. Steam Generators, Unfired: Cemline, Ketema

G. Steam Pressure Reducing Valves: Spence Regulators; Fisher; Masoneilan

H. Steam Relief Valves: Crosby; Farris; Lonnergan; Kunkle

I. Steam Traps: Armstrong; Sarco; Trane; Anderson; Dunham-Bush

J. Strainers: Mueller; Spence; Sarco; Metraflex; McAlear; Tate Tempco; Boylston; Nicholson

K. Thermometers: Ashcroft; Marsh; Weiss; Marshalltown; Moeller; Taylor Tel-Tru; Trerice; Weksler; Weston

L. Valves, Ball: Nibco; Hammond; Fairbanks; Worchester; Itt Grinnell; Apollo; Crane; Powell; Contromatics; Dynaquip

M. Valves, Butterfly: Dezurik; Allis-Chalmers; Centerline; Conoflow; Walworth; Trw Mission; Crane-Monark; Demco; Continental; Milliken Valve Co.; Mueller

N. Valves, Check: Jenkins; Crane; Lunkenheimer; Nibco; Hammond; Powell; Stockham; Walworth; Fairbanks; Kennedy; Milwaukee; RP & C Valve

O. Valves, Silent Check: Miller Valve Co.

P. Valves, Gate: Jenkins; Crane; Lunkenheimer; Nibco; Hammond; Powell; Stockham; Walworth; Fairbanks; Kennedy; Milwaukee; RP & C Valve

Q. Valves, Globe: Jenkins; Crane; Lunkenheimer; Nibco; Hammond; Powell; Stockham; Walworth; Fairbanks; Kennedy; Milwaukee; RP & C Valve

R. Valves, Plug: Dezurik; Milliken Valve Co.; Mueller

S. Water Softeners: Cleaver Brooks; Cochran; Elgin; Culligan

T. Water Treatment Systems: Betz Dearborn, Inc.; Nalco; Diversey Water Technologies, Inc.; Ashland Chemical Company; Chem Treat, Inc.; Coastline; Tricon Chemical Corporation; Cleaver Brooks Water Management Group; Mogul; Olin; ARC; Culligan

23.05 Terminal Equipment

A. Air Terminal Units (VAV, CV, DD, Fan Powered, etc.): Krueger; Titus; Anemostat; Carnes; Barber-Colman; Buensod

B. Cabinet Unit Heaters: Vulcan; Trane; Ted-Reed; McQuay; Modine; Emerson-Chromalox; Brasch; Berko; Dunham-Bush

C. Coils, Heating and Cooling: Trane; Carrier; York; McQuay; Aerofin; Bohn; Dunham-Bush

D. Computer Room Air Conditioning Units: Liebert; Edpac; Airflow

E. Convectors: Trane; Ted-Reed; Sterling; Dunham-Bush

F. Duct Heater, Electric: Indeeco; Chromalox; Brasch

G. Electric Baseboard Radiation: Vulcan; Chromalox; Trane

H. Fan Coil Units: Trane; Carrier; American Air Filter; McQuay; International Environmental; Nesbitt; Sterling; Dunham-Bush

I. Finned Tube Radiation: Vulcan; Trane; Ted-Reed; Sterling; Dunham-Bush

J. Gravity Ventilators: Greenheck; Penn; Acme; Cook; Jenn; Powerline

K. Heat Pumps: McQuay; American Air Filter; International Environmental; Friedrich; General Electric

L. Humidifiers: Armstrong; Herrmidifier; Dryomatic; Industrial Humidifier Co.; Carnes; Nortec; Hygromatik; Dri-Steam Humidifier Co.

M. Unit Heaters: Vulcan; Trane; Ted-Reed; McQuay; Modine; Emerson-Chromalox; Brasch; Berko; Dunham-Bush; King Electrical Manufacturing; Ruffneck; Reznor; Markel

23.06 Miscellaneous Equipment

A. Automatic Control Systems: Johnson Controls; Honeywell; Barber-Colman; Landis-Gyr Powers; Robertshaw

B. Breechings, Chimneys and Stacks, Double Wall Sheet Metal: Metalbestos; Van Packer; Industrial Chimney; Heat Fab, Inc.

C. Expansion Joints & Flexible Metal Hoses: Mason Industries; Mercer Rubber Co.; Twin City Hose; Garlock; Pathway Bellows Inc.; Proco Products; Flexible Metal Hose; Advanced Thermal Systems Inc.; Vibration Mountings, Inc.; Uni-Source; ATCO Rubber Products; General Rubber

D. Breechings, Chimneys and Stacks, Refractory Lined: Van Packer; Power-Pac

E. Identification: Seton Name Plate Corp.; W.H. Brady Co.; Industrial Safety Supply Co., Inc.; Bunting

F. Insulation Adhesives, Mastics, and Coatings: Fosters

G. Insulation, Calcium Silicate: Atlas; Owens Corning; Johns-Manville

H. Insulation, Ductwork External: Owens Corning, Certainteed, Johns-Manville, Knauf

I. Insulation, Ductwork Lining: Owens Corning; Aeroflex; Johns-Manville; CGS Ultraliner

J. Insulation, Flexible Foamed Plasic: Armstrong; Rubatex; Halstead

K. Insulation, Piping Fiberglass: Owens Corning, Certainteed, Johns-Manville, Knauf

L. Motors: General Electric; Lincoln; Reliance; Louis Allis; Toshiba; Marathon

M. Refrigeration System Specialties: Parker Hannifin; Sporlan Valve; Henry Valve; Alco Controls

N. Variable Frequency Drives: Toshiba Corporation Tosvert; Reliance Electric; Cutler Hammer; Louis Allis Magnetek; ABB; Robicon Corporation; Saftronics

O. Vibration Isolation: Mason Industries; Industrial Acoustics Co. (IAC); Amber/Booth; Korfund; Vibration Eliminator; Vibration Mountings Inc.; Peabody Noise Control Inc.; Metroflex

PART 24

Building Construction Business Fundamentals

24.01 Engineering/Construction Contracts

A. Methods of Obtaining Contracts:

1. Competitive Bidding Contracts. Contracts in which Engineers/Contractors are selected on the basis of their competitive bids.
2. Negotiated Contracts. Contracts in which Engineers/Contractors are selected on the basis of ability, reputation, past experience with the owner, or type of project, etc., and fees are then negotiated.

B. Contract Types:

1. Lump Sum Contract. A contract in which the Engineer/Contractor agrees to carry out the stipulated project for a fixed sum of money.
2. Unit Price Contract. A contract based on estimated quantities of adequately specified items of work and the costs for these items of work are expressed in dollars per unit of work. For example, the unit of work may be dollars per foot of caisson drilled, dollars per cubic yard of rock excavated, or dollars per cubic yard of soil removed.

   This contract is generally only applicable to construction contracts.

   Unit price contracts are usually used when quantities of work cannot be accurately defined by the construction documents (driving piles, foundation excavation, rock excavation, contaminated soil removal, etc.). Unit prices may be included in part of a lump sum or other type of contract.
3. Cost Plus Contracts. A contract in which the owner reimburses the Engineer/Contractor for all costs incurred and compensates them for services rendered. Cost plus contracts are always negotiated. Compensation may be based on the following:
   a. Fixed Percentage of the Cost of the Work (Cost Plus Fixed Percentage Contract). Compensation is based on an agreed percentage of the cost.
   b. Sliding-Scale Percentage of the Cost of the Work (Cost Plus Sliding-Scale Percentage Contract). Compensation is based on an agreed sliding-scale percentage of the cost (federal income taxes are paid on an increasing sliding scale).
   c. Fixed Fee (Cost Plus Fixed Fee Contract). Compensation is based on an agreed fixed sum of money.
   d. Fixed Fee with Guaranteed Maximum Price (Cost Plus Fixed Fee with Guaranteed Maximum Price Contract). Compensation is based on an agreed fixed sum of money and the total cost will not exceed an agreed upon total project cost.
   e. Fixed Fee with Bonus (Cost Plus Fixed Fee with Bonus Contract). Compensation is based on an agreed fixed sum of money and an agreed upon bonus is established for completing the project ahead of schedule, under budget, superior performance, etc.
   f. Fixed Fee with Guaranteed Maximum Price and Bonus (Cost Plus Fixed Fee with Guaranteed Maximum Price and Bonus Contract). Compensation is based on an agreed fixed sum of money, a guaranteed maximum price, and an agreed upon bonus is established for completing the project ahead of schedule, under budget, superior performance, etc.
   g. Fixed Fee with Agreement for Sharing Any Cost Savings (Cost Plus Fixed Fee with Agreement for Sharing Any Cost Savings Contract). Compensation is based on an agreed upon fixed sum of money and an agreed upon method of sharing any cost savings.
   h. Other fixed fee contracts can be generated using variations on those listed above or by negotiating certain aspects particular to the project into a cost plus fixed fee contract with the owner.

4. Incentive Contracts. A contract in which the owner awards or penalizes the Engineer/Contractor for performance of work in accordance with an agreed upon target. The target is often project cost or project schedule.
5. Liquidated Damages Contracts. A contract in which the Engineer/Contractor is required to pay the owner an agreed upon sum of money in accordance with an agreed upon target. The target is often for each calendar day of delay in completion of the project.

   Liquidated damages, when included in the contract, must be a reasonable measure of the damages suffered by the owner due to delay in completion of the project to be enforceble in a court of law. The owner must also be able to demonstrate and prove the damages suffered due to delay in completion of the project. Weather, strikes, contract changes, natural disasters, and other events beyond the control of the contractor can void the claim for liquidated damages.
6. Percentage of Construction Fee Contracts. A contract in which the Engineer's fee is based on an agreed upon percentage of the project's construction cost.
7. Scope of Work. The scope of work is part of the Engineer's contract defining the Engineer's responsibilities and work required to produce the Contract Documents required by the owner to get the project built. The Engineer's scope of work can be compared to the Contract Documents defining a construction contract.

24.02 Building Construction Business Players

A. Owner. The individual or individuals who initiates the building design process (May be a business, corporation, developer, hospital, local government, municipality, state government, or federal government).

B. Architect. Design team member responsible for internal and external space planning, space sizes, relative location and interconnection of spaces, emergency egress, internal and external circulation, aesthetics, life safety, etc. Generally the architect is the lead and the driving force behind the project.

C. Civil Engineers. Design team member responsible for site drainage, roadways, parking, site grading, site circulation, retaining walls, site utilities (sometimes done by the mechanical and electrical engineers), etc.

D. Structural Engineers. Design team member responsible for building structure (design of beams, columns, foundations, floors, roof). Responsible for making the building stand.

E. Interior Designers. Design team member responsible for building finishes (wall coverings, floor coverings, ceilings); often assists with or is responsible for space planning. Often this is also done by the architect.

F. Landscape Architect. Design team member responsible for interior as well as external plantings (grass, shrubs, trees, flowers,) etc.

G. Surveyors. Design team member responsible for establishing contours and site boundaries and locating existing benchmarks, trees, roads, water lines, sanitary and storm sewers, electric and telephone utilities, etc.

H. Geologists/Soils Analysts. Design team member responsible for establishing soil characteristics for foundation analysis, potential ground water problems, rock formations, etc.

I. Transportation Engineer. Design team member responsible for elevators, escalators, dumbwaiters, and other modes of vertical and/or horizontal transportation.

J. Electrical Engineer. Design team member responsible for design of electrical distribution systems, lighting, powering mechanical and other equipment, receptacles, communication systems (telephone, intercom, paging), fire alarm and detection systems, site lighting, site electrical (or civil engineer), emergency power systems, uninterruptable power systems, security systems, etc.

K. Mechanical Engineers:

1. Plumbing Engineer. Design team member responsible for water supply and distribution systems; sanitary, vent, and storm water systems; natural gas systems; medical and laboratory gas and drainage systems; underground storage tanks; plumbing fixtures; etc.
2. Fire Protection Engineer. Design team member responsible for sprinkler and other fire protection systems, standpipe and hose systems, fire pumps, site fire mains, fire extinguishers (or architect), etc.
3. HVAC Engineer. Design team member responsible for the design of the heating, ventilating, and air conditioning systems; ductwork and piping systems; automatic temperature control systems; industrial ventilation systems; environmental control; indoor air quality; heat loss and heat gain within the building; human comfort, etc.

L. Contractors:

1. General Contractor. Also referred to as prime contractor in single contract construction projects. The general contractor is the construction team member responsible for construction of the building structure and foundations, building envelope, interior partitions, building finishes, roofing, site work, elevators, project schedule, project coordination, project management, etc. The general contractor may sub some or all of the work to other contractors. In single contract projects, the general contractor is also responsible for mechanical and electrical work as well, but this work is most often done by sub-contractors.
2. Mechanical Contractor. Also referred to as sub-contractor in single contract construction projects. The mechanical contractor is the construction team member responsible for construction of the building HVAC, plumbing, and fire protection systems. The mechanical contractor may be broken into one, two, or three sub-contracts HVAC and Plumbing and/or Fire Protection. The mechanical contractor may sub some or all of the work to other contractors (plumbing, sheet metal, fire protection, automatic controls, etc.).
3. Electrical Contractor. Also referred to as sub-contractor in single contract construction projects. The electrical contractor is the construction team member responsible for construction of the building electrical systems, fire alarm systems, communication systems, security systems, lighting systems, etc. The electrical contractor may sub some or all of the work to other contractors (communication, security fire alarm, etc.).
4. Prime Contractor. The contractor who signs a contract with the owner to perform the work.
5. Multiple Prime Contractors. When more than one contractor signs a contract with the owner to perform the work. Often this is accomplished with four prime contracts as follows, but may be done with any number of contracts:
   a. General Contract
   b. Mechanical (HVAC) Contract

   c. Plumbing/Fire Protection Contract
   d. Electrical Contract
6. Sub-Contractor. The contractor or contractors who sign a contract with the general or prime contractor to perform a particular portion of the prime contractor's work.
7. Sub-Sub-Contractor. The contractor or contractors who sign a contract with the sub-contractor to perform a particular portion of the sub-contractor's work.

PART 25

Architectural, Structural, and Electrical Information

25.01 Building Structural Systems

A. Standard Nominal Structural Steel Depths:

1. W-Shapes (Wide Flange Beams): 4, 5, 6, 8, 10, 12, 14, 16, 18, 21, 24, 27, 30, 33, 36, 40, 44.
2. S-Shapes (I beams): 3, 4, 5, 6, 7, 8, 10, 12, 15, 18, 20, 24.
3. C-Shapes (Channels): 3, 4, 5, 6, 7, 8, 9, 10, 12, 15.

B. Standard Nominal Joist Depths as Manufactured by Vulcraft:

1. K-Series: 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30.
2. LH-Series & DLH-Series: 18, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 84.

C. Building mechanical equipment support points should not deflect more than 0.33 inch for cooling towers and no more than 0.25 inch for all other mechanical equipment.

D. Maximum Duct and Pipe Sizes that may pass through steel joists are given in the following table:

JOIST DEPTH	ROUND DUCT OR PIPE SIZE	SQUARE DUCT SIZE	RECTANGLE DUCT SIZE
8"	5"	4 X 4	3 X 8
10"	6"	5 X 5	3 X 8
12"	7"	6 X 6	4 X 9
14"	8"	6 X 6	5 X 9
16"	9"	7 X 7	6 X 10
18"	11"	8 X 8	7 X 11
20"	11"	9 X 9	7 X 12
22"	12"	9 X 9	8 X 12
24"	13"	10 X 10	8 X 13
26"	15"	12 X 12	9 X 18
28"	16"	13 X 13	9 X 18
30"	17"	14 X 14	10 X 18

Notes:

1. Table based on Vulcraft K Series Joists. For LH or DLH Series Joists consult with Vulcraft.
2. Above values are maximum sizes; designer must consider duct insulation or duct liner thickness.
3. Do not run ductwork through joists or between joists because it generally becomes a problem in the field. If you must run ductwork through joists or between joists, notify structural engineer and verify locations of joist bridging.

E. Floor Span vs. Structural Member Depths is given in the following table:

Floor-Structural Member Depth (1)

STRUCTURAL MEMBER SPAN	STRUCTURAL STEEL SHAPES				STRUCTURAL STEEL JOISTS			
	BEAMS		GIRDERS		JOISTS (9)		JOISTS GIRDERS	
	MIN. (2,4)	MAX. (3,4,8)	MIN. (2,5,7)	MAX. (3,5,8)	MIN. (2,4,6)	MAX. (3,6)	MIN. (2,5)	MAX. (3,5)
20 Ft.	10"	14"	16"	24"	12"	14"	18"	28"
30 Ft.	16"	18"	21"	33"	16"	24"	20"	40"
40 Ft.	21"	24"	24"	36"	20"	24"	24"	52"
50 Ft.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
60 Ft.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Notes:

1. Floor spans generally do not exceed 40 feet.
2. Assumed Floor Dead Load (DL) = 50 psf; Live Load (LL) = 50 psf.
3. Assumed Floor Dead Load (DL) = 50 psf; Live Load (LL) = 150 psf.
4. Assumed Spacing = ±5′-0″.
5. Assumed Spacing = ±30′-0″.
6. Assumed Spacing = ±2′-0″.
7. Assumed Steel Grade 50 ksi.
8. Assumed Steel Grade 36 ksi.
9. K Series Joists for 20′ and 30′ spans; LH Series for 40′ spans.

F. Roof Span vs. Structural Member Depths is given in the following table:

Roof-Structural Member Depth

STRUCTURAL MEMBER SPAN	STRUCTURAL STEEL SHAPES				STRUCTURAL STEEL JOISTS			
	BEAMS		GIRDERS		JOISTS (7)		JOISTS GIRDERS	
	MIN. (1,3)	MAX. (2,3)	MIN. (1,4,5)	MAX. (2,4,6)	MIN. (1,3)	MAX. (2,3)	MIN. (1,4)	MAX. (2,4)
20 Ft.	8"	10"	10"	18"	12"	14"	18"	28"
30 Ft.	14"	16"	16"	24"	16"	20"	20"	40"
40 Ft.	18"	21"	21"	30"	20"	24"	24"	52"
50 Ft.	N/A	N/A	27"	36"	28"	32"	32"	64"
60 Ft.	N/A	N/A	30"	36"	32"	36"	44"	84"

Notes:

1. Assumed Roof Dead Load (DL) = 20 psf; Live Load (LL) = 20 psf.
2. Assumed Roof Dead Load (DL) = 35 psf; Live Load (LL) = 50 psf.
3. Assumed Spacing = ±5′-0″.
4. Assumed Spacing = ±30′-0″.
5. Assumed Steel Grade 50 ksi.
6. Assumed Steel Grade 36 ksi.
7. K Series Joists for 20′ and 30′ spans; LH Series for 40′, 50′, and 60′ spans.

25.02 Architectural and Structural Information

A. Equipment Weights. Provide equipment weights, sizes, and locations to Architect and Structural Engineer. Architect does not normally need the weights of equipment, but information is needed by Structural Engineer. Obtain weights and sizes from

Manufacturer's catalogs or Manufacturer's Representative. Equipment weights should include the following information as a minimum:

1. Item designation.
2. Location.
3. Size—length, width, height—include curb height if required.
4. Weight. Operating weight if substantially different from installed weight.
5. Floor/Roof openings. Wall openings if load bearing or shear walls are used.
6. Special remarks.

B. Ductwork Weight. Coordinate all ductwork with Structural Engineer, especially when ductwork weight is 20 Lbs./Lf. or more. Provide ductwork weight and drawings showing location of ductwork and sizes. See Appendix A for ductwork weight information.

C. Piping Weight. Coordinate all piping with Structural Engineer especially pipe sizes 6 inches and larger. Provide piping weight, location of anchors and forces and drawings showing location of piping and pipe sizes. See Appendix for pipe weight information.

25.03 Electrical Information

A. Provide electrical information for all mechanical equipment requiring electrical power to the Electrical Engineer. Electrical information should include the following information as a minimum:

1. Item designation.
2. Location.
3. Voltage-Phase-Hertz.
4. Horsepower, Full Load Amps, Locked Rotor Amps, KW, Minimum Circuit Amps: Provide 1 or more.
5. Is equipment to be on emergency power?
6. Who provides starter? Who provides disconnect switch?
7. Control Type, HOA, Manual, etc.
8. Special Requirements?

25.04 Mechanical/Electrical Equipment Space Requirements

A. Commercial Buildings:

1. 8 to 20% of Gross Floor Area. Most of the mechanical equipment is located indoors (i.e., no rooftop AHUs).
2. ¼ to ⅓ of Total Building Volume. This includes the ceiling plenum as mechanical/electrical space.

B. Hospital and Laboratory Buildings:

1. 15 to 50% of Gross Floor Area. Most of the mechanical equipment is located indoors (i.e., no rooftop AHUs).
2. ⅓ to ½ of Total Building Volume. This includes the ceiling plenum as mechanical/electrical space.

C. The original building design should allow from 10 to 15 percent additional shaft space for future expansion and modification of the facility. This additional shaft space will also reduce the initial installation cost.

D. Minimum recommended clearance around boiler and chillers is 36 inches. Minimum recommended clearance around all other mechanical equipment is 24 inches. Maintain minimum clearances for coil pull, tube pull, and cleaning of tubes as recommended by the equipment manufacturer. This is generally equal to the length or width of the tubes or piece of equipment. Maintain minimum clearance as required to open access and control doors on equipment for service, maintenance, and inspection.

E. Minimum recommended clearance between top of lights and deepest structural member is 24 inches.

F. Mechanical and electrical rooms should be centrally located to minimize ductwork, pipe, and conduit runs (size and length). Centrally locating mechanical and electrical spaces will minimize construction, maintenance, and operating costs. Additional space is quite often required when mechanical and electrical equipment rooms cannot be centrally located or when space requirements are fragmented throughout the building. In addition, centrally located equipment rooms will simplify distribution systems and will in some cases decrease above ceiling space requirements.

G. Mechanical rooms with fans and air handling equipment should have at least 10 to 15 square feet of floor area for each 1,000 CFM of equipment air flow.

H. Mechanical rooms with refrigeration equipment must have an exit door which opens directly to the outside or through a vestibule type exit equipped with self-closing, tight-fitting doors.

I. Mechanical rooms must be clear of electrical rooms, elevators, and stairs on at least two sides, preferably on three sides.

J. Electrical rooms must be clear of elevators and stairs on at least two sides, preferably on three sides.

K. In general, mechanical equipment rooms require from 12 to 20 feet clear from floor to underside of structure.

L. Mechanical and electrical shafts must be clear of elevators and stairs on at least two sides. Rectangular shafts with aspect ratios of 2:1 to 4:1 are easier to work mechanical and electrical distribution systems in and out of the shafts than square shafts.

M. The main electrical switchgear room should be located as close as possible to the incoming electrical service. If an emergency generator is required, the emergency generator room should be located adjacent to the main switchgear room to minimize electrical costs and interconnection problems. The emergency generator room should be located on an outside wall, preferably a corner location to enable proper ventilation, combustion air, and venting of engine exhaust.

N. A mechanical equipment room should be located on the first floor or basement floor to accommodate the incoming domestic water service main, the fire protection service mains, and the gas service. These service mains may include meter and regulator assemblies if these assemblies are not installed in meter vaults or outside the building. Consult you local utility company for service and meter/regulator assembly requirements.

O. The locations and placement of mechanical and electrical rooms must take into account how large pieces of equipment (chillers, boilers, cooling towers, transformers, and other large pieces of equipment) can be moved into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

25.05 Americans with Disabilities Act (ADA)

A. ADA Titles:

1. Title I—Equal Employment Opportunity.
2. Title II—State and Local Governments.
3. Title III—New and Existing Public Accommodations and new Commercial Facilities.
4. Title IV—Telecommunications.
5. Title V—Miscellaneous Provisions.

B. Drinking Fountains:

1. Where only one drinking fountain is provided on a floor, a drinking fountain with two bowls, one high bowl and one low bowl, is required.
2. Where more than one drinking fountain is provided on a floor, 50% shall be handicapped accessible and shall be on an accessible route.
3. Spouts shall be no higher than 36 inches above finished floor or grade.
4. Spouts shall be located at the front of the unit and shall direct the water flow parallel or nearly parallel to the front of the unit.
5. Controls shall be mounted on the front or side of the unit.
6. Clearances:
   a. Knee space below unit 27 inches high, 30 inches wide, and 17 to 9 inches deep and a minimum front clear floor space of 30 inch × 48 inch.
   b. Units without clear space below: 30 inch × 48 inch clearance suitable for parallel approach.

C. Water Closets:

1. Height of water closet shall be 17 to 19 inches to the top of the toilet seat.
2. Flush controls shall be hand operated or automatic. Controls shall be mounted on the wide side of toilet areas no more than 44 inches above the floor.
3. At least one toilet shall be handicapped accessible.

D. Urinals:

1. Urinals shall be stall-type or wall hung with and elongated rim at a maximum of 17 inches above the floor.
2. Flush controls shall be hand operated or automatic. Controls shall be mounted no more than 44 inches above the floor.
3. If urinals are provided, at least one shall be handicapped accessible.

E. Lavatories:

1. Lavatories shall be mounted with the rim or counter surface no higher than 34 inches above the finished floor with a clearance of at least 29 inches to the bottom of the apron.
2. Hot water and drain pipe under lavatories shall be insulated or otherwise configured to protect against contact.
3. Faucets shall be lever operated, push-type, and electronically controlled. Self-closing valves are acceptable provided they remain open for a minimum of 10 seconds.

F. Bathtubs:

1. Bathtub controls shall be located toward the front half of the bathtub.
2. Shower unit shall be provided with a hose at least 60 inches long that can be used both as a fixed shower head and a hand-held shower head.

G. Shower Stalls:

1. The shower controls shall be opposite the seat in a 36 inch × 36 inch shower stall and adjacent to the seat in a 30 inch × 60 inch shower stall.
2. Shower unit shall be provided with a hose at least 60 inches long that can be used both as a fixed shower head and a hand-held shower head.

H. Forward Reach:

1. Maximum High Forward Reach: 48 inches.
2. Minimum Low Forward Reach: 15 inches.

I. Side Reach:

1. Maximum High Side Reach: 54 inches.
2. Minimum Low Side Reach: 9 inches.

J. Areas of Rescue Assistance:

1. A portion of a stairway landing within a smokeproof enclosure.
2. A portion of an exterior exit balcony located immediately adjacent to an exit stairway.
3. A portion of a one-hour fire-resistive corridor located immediately adjacent to an exit enclosure.
4. A portion of a stairway landing within an exit enclosure which is vented to the exterior and is separated from the interior of the building with not less than one-hour fire-resistive doors.
5. A vestibule located immediately adjacent to an exit enclosure and constructed to the same fire-resistive standards as required for corridors.
6. When approved by the authorities having jurisdiction, an area or room which is separated from other portions of the building by a smoke barrier.
7. An elevator lobby when elevator shafts and adjacent lobbies are pressurized as required for a smokeproof enclosures by local regulations and when complying with the requirements herein for size, communication and signage.
8. Size:
   a. Each Area of Rescue Assistance shall have at least two accessible areas 30″ × 48″ minimum.
   b. Area shall not encroach on the exit width.
   c. The total number of areas per floor shall be one for every 200 persons. If the occupancy per floor is less than 200, the authorities having jurisdiction may reduce the number of areas to one.
9. A method of two-way communication, with both visible and audible signals, is required between the primary fire entry and the areas of rescue assistance.
10. Each area must be identified.

K. Stairway Width, 48 inches between handrails minimum.

L. Protruding Objects:

1. Objects protruding from wall with their leading edges between 27 and 80 inches above the finished floor shall protrude no more than 4 inches into walks, halls, corridors, passageways, or aisles.

2. Objects mounted with their leading edges at or below 27 inches above the finished floor may protrude any amount.
3. Protruding objects shall not reduce the clear width of an accessible route or maneuvering space.
4. Walks, halls, corridors, passageways, aisles, or other circulation spaces shall have 80 inch minimum clear head room.

M. Controls and Operating Mechanisms:

1. The highest operable part of controls, dispensers, receptacles, and other operable equipment shall be placed within at least one of the reach ranges.
2. Electrical and communication system receptacles on walls shall be mounted no less than 15 inches above the floor.
3. Controls and operating mechanisms shall be operable with one hand and shall not require tight grasping, pinching, or twisting of the wrist. The force required to activate shall be no greater than 5 lbf.

PART 26

Conversion Factors

26.01 Length

1 Mile = 1760 Yds = 5,280 Ft. = 63,360 In. = 1.609 Km
1 Ft. = 0.3048 M = 30.48 Cm = 304.8 Mm
1 In. = 2.54 Cm = 25.4 Mm
1 Cm = 0.3937 In.
1 M = 39.37 In. = 3.2808 Ft. = 1.094 Yds.
1 Km = 3281 Ft. = 0.6214 Miles = 1094 Yds.
1 Fathom = 6 Feet = 1.828804 Meters
1 Furlong = 660 Feet

26.02 Weight

1 Gal. H_2O = 8.33 Lbs.H_2O
1 Lb. = 16 oz. = 7000 grains = 0.4536 Kg
1 Ton = 2000 Lbs. = 907 Kg
1 Kg = 2.205 lbs.
1 Lb. Steam = 1 Lb.H_2O

26.03 Area

1 Sq. Ft. = 144 Sq.In.
1 Acre = 43,560 Sq.Ft. = 4840 Sq.Yds. = 0.4047 Hectares
1 Sq. Mile = 640 Acres
1 Sq. Yd. = 9 Sq.Ft. = 1296 Sq.In.
1 Hectare = 2.417 acres
1 Sq. M = 1,550 Sq. In. = 0.0929 Sq.Ft. = 1.1968 Sq.Yds.

26.04 Volume

1 Cu.Yd. = 27 Cu.Ft. = 46,656 Cu.In. = 1616 Pints = 807.9 Quarts = 764.6 Liters
1 Cu.Ft. = 1,728 Cu.In
1 Liter = 0.2642 Gallons = 1.057 Quarts = 2.113 Pints
1 Gallon = 4 Quarts = 8 Pints = 3.785 Liters
1 Cu. Meter = 61,023 Cu.In. = 0.02832 Cu.Ft. = 1.3093 Cu.Yds.

1 Barrel Oil = 42 Gallons Oil
1 Barrel Beer = 31.5 Gallons Beer
1 Barrel Wine = 31.0 Gallons Wine
1 Bushel = 1.2445 Cu.Ft. = 32 Quarts (Dry) = 64 Pints (Dry) = 4 Pecks

1 Hogshead = 63 Gallon = 8.42184 Cu.Ft.

26.05 Velocity

1 MPH = 5280 Ft./Hr. = 88 Ft./Min. = 1.467 Ft./Sec. = 0.8684 Knots
1 Knot = 1.1515 Mph = 1.8532 Km/Hr. = 1.0 Nautical Miles/Hr.
1 League = 3.0 Miles (Approx.)

26.06 Speed of Sound in Air

1128.5 Ft./Sec. = 769.4 MPH

26.07 Pressure

14.7 psi = 33.95 Ft. H_2O = 29.92 In. Hg = 407.2 In. W.G. = 2116.8 Lbs./Sq.Ft.
1 psi = 2.307 Ft. H_2O = 2.036 In. Hg = 16 ounces = 27.7 In. WC
1 Ft. H_2O = 0.4335 psi = 62.43 Lbs./Sq.Ft.
1 Ounce = 1.73 In. WC

26.08 Density

A. Water:

62.43 Lbs./Cu.Ft. = 8.33 Lbs./Gal. = 0.1337 Cu.Ft./Gal.
1 Cu.Ft. = 7.48052 Gallons = 29.92 Quarts = 62.43 Lbs. H_2O

B. Standard Air @ 60°F., 14.7 psi:

13.329 Cu.Ft./Lb. = 0.0750 Lbs./Cu.Ft.

1 Lb./Cu.Ft. = 177.72 Cu.Ft./Lbs.
1 Cu. Ft./Lb. = 0.00563 Lbs./Cu.Ft.

1 Kg/Cu M = 16.017 Lbs./Cu.Ft.
1 Cu M/Kg = 0.0624 Cu.Ft./Lb

26.09 Energy

1 Hp = 0.746 KW = 746 Watts = 2,545 Btuh ≈ 1.0 KVA
1 KW = 1,000 Watts = 3,413 Btuh = 1.341 Hp
1 Watt = 3.413 Btuh

1 Ton Ac = 12,000 Btuh Cooling = 15,000 Btuh Heat Rejection

1 Btuh = 1 Btu/Hr.
1 BHP = 34,500 Btuh (33,472 Btuh) = 34.5 Lb.Stm/Hr. = 34.5 Lb.H_2O/Hr. = 0.069 GPM = 4.14 GPH = 140 EDR (Sq.Ft. of Equivalent Radiation)
1 Therm = 100,000 Btuh
1 MBH = 1,000 Btuh
1 Lb.Stm/Hr. = 0.002 GPM
1 GPM = 500 Lbs.Stm/Hr.
EDR = Equivalent Direct Radiation
1 EDR = 0.000496 GPM = 0.25 Lbs.Stm.Cond./Hr.
1000 EDR = 0.496 GPM
1 EDR Hot Water = 150 Btu/Hr.
1 EDR Steam = 240 Btu/Hr.
1 EDR = 240 Btu/Hr. (Up to 1,000 Ft. Above Sea Level)
1 EDR = 230 Btu/Hr. (1,000 Ft.–3,000 Ft. Above Sea Level)
1 EDR = 223 Btu/Hr. (3,000 Ft.–5,000 Ft. Above Sea Level)

1 EDR = 216 Btu/Hr. (5,000 Ft.–7,000 Ft. Above Sea Level)
1 EDR = 209 Btu/Hr. (7,000 Ft.–10,000 Ft. Above Sea Level)

26.10 Flow

1 mgd (million gal./day) = 1.547 Cu.Ft./Sec. = 694.4 GPM
1 Cu.Ft./Min. = 62.43 Lbs. H_2O/Min. = 448.8 GPH

26.11 HVAC Metric Conversions

KJ/Hr	=	Btu/Hr × 1.055
CMM	=	CFM × 0.02832
LPM	=	GPM × 3.785
KJ/Lb.	=	Btu/Lb. × 2.326
Meters	=	Feet × 0.3048
Sq. Meters	=	Sq. Feet × 0.0929
Cu. Meters	=	Cu. Feet × 0.02832
Kg	=	Pounds × 0.4536
1.0 GPM	=	500 Lb Steam/Hr
1.0 Lb.Stm/Hr	=	0.002 GPM
1.0 Lb.H_2O/Hr	=	1.0 Lbs. Steam/Hr
Kg/Cu. Meter	=	Pounds/Cu.Ft. × 16.017 (Density)
Cu. Meters/Kg	=	Cu.Ft./Pound × 0.0624 (Specific Volume)
Kg H_2O/Kg DA	=	Gr H_2O/Lb. DA/7,000 = Lb.H_2O/Lb DA

PART 27

Properties of Air and Water

27.01 Properties of Air/Water Vapor Mixtures

A. Psychrometric Definitions:

1. Dry Bulb Temperature. The temperature of air read on a standard thermometer. Units: °F.DB. Symbol: T_{DB} or DB.
2. Wet Bulb Temperature. The wet bulb temperature is the temperature indicated by a thermometer whose bulb is covered by a wet wick and exposed to air moving at a velocity of 1,000 feet per minute. Units: °F.WB. Symbol: T_{WB} or WB.
3. Humidity Ratio. The weight of water vapor in each pound of dry air; also known as specific humidity. Units: Lb.H_2O/Lb.DA or Gr.H_2O/Lb.DA. Symbol: W.
4. Enthalpy. A thermodynamic property which serves as a measure of the heat content above some datum temperature (Air 0 °F.DB and Water 32 °F.). Units: Btu/Lb.DA or Btu/Lb.H_2O. Symbol: h.
5. Specific Volume. The cubic feet of air/water mixture per pound of dry air. Units: Cu.Ft./Lb.DA. Symbol: SpV.
6. Dew Point Temperature. The temperature at which moisture will start to condense from the air. Units: °F.DP. Symbol: T_{DP} or DP.
7. Relative Humidity. The ratio of water vapor in the air/water mixture to the water vapor in saturated air/water mixture. Units: %RH. Symbol: RH.
8. Sensible Heat. Heat that causes a rise in temperature. Units: Btu/Hr. Symbol: H_S.
9. Latent Heat. Heat that causes a change in state (i.e., liquid water to gaseous water). Units: Btu/Hr. Symbol: H_L.
10. Total Heat. Sum of sensible heat and latent heat. Units: Btu/Hr. Symbol: H_T.
11. Sensible Heat Ratio. The ratio of the sensible heat to the total heat. Units: None. Symbol: SHR.
12. Vapor Pressure. Pressure exerted by water vapor in the air. Units: In.Hg. Symbol: P_W.
13. Standard Barometric Pressure. Pressure at Sea Level (29.921 InHg. = 14.7 Psi).

B. Thermodynamic Properties of Air/Water Mixtures are given in the following tables:

TEMPERATURE RANGE °F.	SPECIFIC HEAT BTU/LB °F.
-80 TO 129	0.240
130 TO 215	0.241
216 TO 280	0.242
281 TO 330	0.243
331 TO 370	0.244
371 TO 400	0.245
401 TO 440	0.246
441 TO 460	0.247
461 TO 470	0.248
471 TO 500	0.249

Thermodynamic Properties of Moist Air @ 14.696 PSIA

TEMP °F.	HUMIDITY RATIO		SPECIFIC VOLUME FT.^{3}/LB DA			ENTHALPY BTU/LB DA		
	GRAINS/ LB DA	POUNDS/ LB DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
-80	0.0343	0.0000049	9.553	0.000	9.553	-19.221	0.005	-19.215
-79	0.0371	0.0000053	9.579	0.000	9.579	-18.980	0.005	-18.975
-78	0.0399	0.0000057	9.604	0.000	9.604	-18.740	0.006	-18.734
-77	0.0434	0.0000062	9.629	0.000	9.629	-18.500	0.007	-18.493
-76	0.0469	0.0000067	9.655	0.000	9.655	-18.259	0.007	-18.252
-75	0.0504	0.0000072	9.680	0.000	9.680	-18.019	0.007	-18.011
-74	0.0546	0.0000078	9.705	0.000	9.705	-17.778	0.008	-17.770
-73	0.0588	0.0000084	9.731	0.000	9.731	-17.538	0.009	-17.529
-72	0.0630	0.0000090	9.756	0.000	9.756	-17.298	0.010	-17.288
-71	0.0679	0.0000097	9.781	0.000	9.781	-17.057	0.010	-17.047
-70	0.0728	0.0000104	9.807	0.000	9.807	-16.806	0.011	-16.817
-69	0.0784	0.0000112	9.832	0.000	9.832	-16.577	0.012	-16.565
-68	0.0840	0.0000120	9.858	0.000	9.858	-16.336	0.013	-16.324
-67	0.0903	0.0000129	9.883	0.000	9.883	-16.096	0.013	-16.083
-66	0.0973	0.0000139	9.908	0.000	9.908	-15.856	0.015	-15.841
-65	0.1043	0.0000149	9.934	0.000	9.934	-15.616	0.015	-15.600
-64	0.1120	0.0000160	9.959	0.000	9.959	-15.375	0.017	-15.359
-63	0.1204	0.0000172	9.984	0.000	9.984	-15.117	0.018	-15.135
-62	0.1288	0.0000184	10.010	0.000	10.010	-14.895	0.019	-14.876
-61	0.1386	0.0000198	10.035	0.000	10.035	-14.654	0.021	-14.634
-60	0.1484	0.0000212	10.060	0.000	10.060	-14.414	0.022	-14.392
-59	0.1590	0.0000227	10.085	0.000	10.085	-14.174	0.024	-14.150
-58	0.1701	0.0000243	10.111	0.000	10.111	-13.933	0.025	-13.908
-57	0.1820	0.0000260	10.136	0.000	10.136	-13.693	0.027	-13.666
-56	0.1953	0.0000279	10.161	0.000	10.161	-13.453	0.029	-13.424
-55	0.2086	0.0000298	10.187	0.000	10.187	-13.213	0.031	-13.182
-54	0.2233	0.0000319	10.212	0.001	10.213	-12.972	0.033	-12.939
-53	0.2387	0.0000341	10.237	0.001	10.238	-12.732	0.035	-12.697
-52	0.2555	0.0000365	10.263	0.001	10.263	-12.492	0.038	-12.454
-51	0.2730	0.0000390	10.288	0.001	10.289	-12.251	0.041	-12.211
-50	0.2912	0.0000416	10.313	0.001	10.314	-12.011	0.043	-11.968
-49	0.3115	0.0000445	10.339	0.001	10.340	-11.771	0.046	-11.725
-48	0.3325	0.0000475	10.364	0.001	10.365	-11.531	0.050	-11.481
-47	0.3549	0.0000507	10.389	0.001	10.390	-11.290	0.053	-11.237
-46	0.3787	0.0000541	10.415	0.001	10.416	-11.050	0.056	-10.994
-45	0.4039	0.0000577	10.440	0.001	10.441	-10.810	0.060	-10.750
-44	0.4305	0.0000615	10.465	0.001	10.466	-10.570	0.064	-10.505
-43	0.4592	0.0000656	10.491	0.001	10.492	-10.329	0.068	-10.261
-42	0.4893	0.0000699	10.516	0.001	10.517	-10.089	0.073	-10.016
-41	0.5208	0.0000744	10.541	0.001	10.543	-9.849	0.078	-9.771

Thermodynamic Properties of Moist Air @ 14.696 PSIA

TEMP °F.	HUMIDITY RATIO		SPECIFIC VOLUME FT.³/LB DA			ENTHALPY BTU/LB DA		
	GRAINS/ LB DA	POUNDS/ LB DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
-40	0.5551	0.0000793	10.567	0.001	10.568	-9.609	0.083	-9.526
-39	0.5908	0.0000844	10.592	0.001	10.593	-9.368	0.088	-9.280
-38	0.6286	0.0000898	10.617	0.002	10.619	-9.128	0.094	-9.034
-37	0.6692	0.0000956	10.643	0.002	10.644	-8.888	0.100	-8.788
-36	0.7119	0.0001017	10.668	0.002	10.670	-8.648	0.106	-8.541
-35	0.7567	0.0001081	10.693	0.002	10.695	-8.407	0.113	-8.294
-34	0.8050	0.0001150	10.719	0.002	10.721	-8.167	0.120	-8.047
-33	0.8554	0.0001222	10.744	0.002	10.746	-7.927	0.128	-7.799
-32	0.9086	0.0001298	10.769	0.002	10.772	-7.687	0.136	-7.551
-31	0.9653	0.0001379	10.795	0.002	10.797	-7.447	0.145	-7.302
-30	1.0255	0.0001465	10.820	0.003	10.822	-7.206	0.154	-7.053
-29	1.0885	0.0001555	10.845	0.003	10.848	-6.966	0.163	-6.803
-28	1.1550	0.0001650	10.871	0.003	10.873	-6.726	0.173	-6.553
-27	1.2257	0.0001751	10.896	0.003	10.899	-6.486	0.184	-6.302
-26	1.3006	0.0001858	10.921	0.003	10.924	-6.245	0.195	-6.051
-25	1.3790	0.0001970	10.947	0.003	10.950	-6.005	0.207	-5.798
-24	1.4616	0.0002088	10.972	0.004	10.976	-5.765	0.220	-5.545
-23	1.5498	0.0002214	10.997	0.004	11.001	-5.525	0.233	-5.292
-22	1.6422	0.0002346	11.022	0.004	11.027	-5.284	0.247	-5.038
-21	1.7395	0.0002485	11.048	0.004	11.052	-5.044	0.261	-4.783
-20	1.8424	0.0002632	11.073	0.005	11.078	-4.804	0.277	-4.527
-19	1.9502	0.0002786	11.098	0.005	11.103	-4.564	0.293	-4.271
-18	2.0650	0.0002950	11.124	0.005	11.129	-4.324	0.311	-4.013
-17	2.1847	0.0003121	11.149	0.006	11.155	-4.084	0.329	-3.754
-16	2.3121	0.0003303	11.174	0.006	11.180	-3.843	0.348	-3.495
-15	2.4451	0.0003493	11.200	0.006	11.206	-3.603	0.368	-3.235
-14	2.5858	0.0003694	11.225	0.007	11.232	-3.363	0.390	-2.973
-13	2.7335	0.0003905	11.250	0.007	11.257	-3.123	0.412	-2.710
-12	2.8896	0.0004128	11.276	0.007	11.283	-2.882	0.436	-2.447
-11	3.0534	0.0004362	11.301	0.008	11.309	-2.642	0.460	-2.182
-10	3.2256	0.0004608	11.326	0.008	11.335	-2.402	0.487	-1.915
-9	3.4069	0.0004867	11.351	0.009	11.360	-2.162	0.514	-1.647
-8	3.5973	0.0005139	11.377	0.009	11.386	-1.922	0.543	-1.378
-7	3.7975	0.0005425	11.402	0.010	11.412	-1.681	0.574	-1.108
-6	4.0082	0.0005726	11.427	0.010	11.438	-1.441	0.606	-0.835
-5	4.2287	0.0006041	11.453	0.011	11.464	-1.201	0.640	-0.561
-4	4.4611	0.0006373	11.478	0.012	11.490	-0.961	0.675	-0.286
-3	4.7054	0.0006722	11.503	0.012	11.516	-0.721	0.712	-0.008
-2	4.9616	0.0007088	11.529	0.013	11.542	-0.480	0.751	0.271
-1	5.2304	0.0007472	11.554	0.014	11.568	-0.240	0.792	0.552

Thermodynamic Properties of Moist Air @ 14.696 PSIA

TEMP °F.	HUMIDITY RATIO		SPECIFIC VOLUME FT.^{3}/LB DA			ENTHALPY BTU/LB DA		
	GRAINS/ LB DA	POUNDS/ LB DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
0	5.5125	0.0007875	11.579	0.015	11.594	0.000	0.835	0.835
1	5.8086	0.0008298	11.604	0.015	11.620	0.240	0.880	1.121
2	6.1194	0.0008742	11.630	0.016	11.646	0.480	0.928	1.408
3	6.4449	0.0009207	11.655	0.017	11.672	0.721	0.978	1.699
4	6.7865	0.0009695	11.680	0.018	11.699	0.961	1.030	1.991
5	7.1449	0.0010207	11.706	0.019	11.725	1.201	1.085	2.286
6	7.5201	0.0010743	11.731	0.020	11.751	1.441	1.143	2.584
7	7.9142	0.0011306	11.756	0.021	11.778	1.681	1.203	2.884
8	8.3265	0.0011895	11.782	0.022	11.804	1.922	1.266	3.188
9	8.7584	0.0012512	11.807	0.024	11.831	2.162	1.332	3.494
10	9.2106	0.0013158	11.832	0.025	11.857	2.402	1.402	3.804
11	9.6845	0.0013835	11.857	0.026	11.884	2.642	1.474	4.117
12	10.1808	0.0014544	11.883	0.028	11.910	2.882	1.550	4.433
13	10.7002	0.0015286	11.908	0.029	11.937	3.123	1.630	4.753
14	11.2434	0.0016062	11.933	0.031	11.964	3.363	1.714	5.077
15	11.8118	0.0016874	11.959	0.032	11.991	3.603	1.801	5.404
16	12.4068	0.0017724	11.984	0.034	12.018	3.843	1.892	5.736
17	13.0291	0.0018613	12.009	0.036	12.045	4.084	1.988	6.072
18	13.6801	0.0019543	12.035	0.038	12.072	4.324	2.088	6.412
19	14.3605	0.0020515	12.060	0.040	12.099	4.564	2.193	6.757
20	15.0717	0.0021531	12.085	0.042	12.127	4.804	2.303	7.107
21	15.8144	0.0022592	12.110	0.044	12.154	5.044	2.417	7.462
22	16.5921	0.0023703	12.136	0.046	12.182	5.285	2.537	7.822
23	17.4041	0.0024863	12.161	0.048	12.209	5.525	2.662	8.187
24	18.2511	0.0026073	12.186	0.051	12.237	5.765	2.793	8.558
25	19.1373	0.0027339	12.212	0.054	12.265	6.005	2.930	8.935
26	20.0620	0.0028660	12.237	0.056	12.293	6.246	3.073	9.318
27	21.0273	0.0030039	12.262	0.059	12.321	6.486	3.222	9.708
28	22.0360	0.0031480	12.287	0.062	12.349	6.726	3.378	10.104
29	23.0888	0.0032984	12.313	0.065	12.378	6.966	3.541	10.507
30	24.1864	0.0034552	12.338	0.068	12.406	7.206	3.711	10.917
31	25.3330	0.0036190	12.363	0.072	12.435	7.447	3.888	11.335
32	26.5265	0.0037895	12.389	0.075	12.464	7.687	4.073	11.760
33	27.6290	0.0039470	12.414	0.079	12.492	7.927	4.243	12.170
34	28.7630	0.0041090	12.439	0.082	12.521	8.167	4.420	12.587
35	29.939	0.004277	12.464	0.085	12.550	8.408	4.603	13.010
36	31.164	0.004452	12.490	0.089	12.579	8.648	4.793	13.441
37	32.431	0.004633	12.515	0.093	12.608	8.888	4.990	13.878
38	33.740	0.004820	12.540	0.097	12.637	9.128	5.194	14.322
39	35.098	0.005014	12.566	0.101	12.667	9.369	5.405	14.773

Thermodynamic Properties of Moist Air @ 14.696 PSIA

TEMP °F.	HUMIDITY RATIO		SPECIFIC VOLUME FT.^{3}/LB DA			ENTHALPY BTU/LB DA		
	GRAINS/ LB DA	POUNDS/ LB DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
40	36.512	0.005216	12.591	0.105	12.696	9.609	5.624	15.233
41	37.968	0.005424	12.616	0.110	12.726	9.849	5.851	15.700
42	39.480	0.005640	12.641	0.114	12.756	10.089	6.086	16.175
43	41.041	0.005863	12.667	0.119	12.786	10.330	6.330	16.660
44	42.658	0.006094	12.692	0.124	12.816	10.570	6.582	17.152
45	44.338	0.006334	12.717	0.129	12.846	10.810	6.843	17.653
46	46.067	0.006581	12.743	0.134	12.877	11.050	7.114	18.164
47	47.866	0.006838	12.768	0.140	12.908	11.291	7.394	18.685
48	49.721	0.007103	12.793	0.146	12.939	11.531	7.684	19.215
49	51.646	0.007378	12.818	0.152	12.970	11.771	7.984	19.756
50	53.627	0.007661	12.844	0.158	13.001	12.012	8.295	20.306
51	55.685	0.007955	12.869	0.164	13.033	12.252	8.616	20.868
52	57.813	0.008259	12.894	0.171	13.065	12.492	8.949	21.441
53	60.011	0.008573	12.920	0.178	13.097	12.732	9.293	22.025
54	62.279	0.008897	12.945	0.185	13.129	12.973	9.648	22.621
55	64.631	0.009233	12.970	0.192	13.162	13.213	10.016	23.229
56	67.060	0.009580	12.995	0.200	13.195	13.453	10.397	23.850
57	69.566	0.009938	13.021	0.207	13.228	13.694	10.790	24.484
58	72.163	0.010309	13.046	0.216	13.262	13.934	11.197	25.131
59	74.844	0.010692	13.071	0.224	13.295	14.174	11.618	25.792
60	77.609	0.011087	13.096	0.233	13.329	14.415	12.052	26.467
61	80.472	0.011496	13.122	0.242	13.364	14.655	12.502	27.157
62	83.433	0.011919	13.147	0.251	13.398	14.895	12.966	27.862
63	86.485	0.012355	13.172	0.261	13.433	15.135	13.446	28.582
64	89.635	0.012805	13.198	0.271	13.468	15.376	13.942	29.318
65	92.890	0.013270	13.223	0.281	13.504	15.616	14.454	30.071
66	96.250	0.013750	13.248	0.292	13.540	15.856	14.983	30.840
67	99.722	0.014246	13.273	0.303	13.577	16.097	15.530	31.626
68	103.306	0.014758	13.299	0.315	13.613	16.337	16.094	32.431
69	107.002	0.015286	13.324	0.326	13.650	16.577	16.677	33.254
70	110.824	0.015832	13.349	0.339	13.688	16.818	17.279	34.097
71	114.765	0.016395	13.375	0.351	13.726	17.058	17.901	34.959
72	118.832	0.016976	13.400	0.365	13.764	17.299	18.543	35.841
73	123.025	0.017575	13.425	0.378	13.803	17.539	19.204	36.743
74	127.358	0.018194	13.450	0.392	13.843	17.779	19.889	37.668
75	131.831	0.018833	13.476	0.407	13.882	18.020	20.595	38.615
76	136.437	0.019491	13.501	0.422	13.923	18.260	21.323	39.583
77	141.190	0.020170	13.526	0.437	13.963	18.500	22.075	40.576
78	146.097	0.020871	13.551	0.453	14.005	18.741	22.851	41.592
79	151.158	0.021594	13.577	0.470	14.046	18.981	23.652	42.633

Thermodynamic Properties of Moist Air @ 14.696 PSIA

TEMP °F.	HUMIDITY RATIO		SPECIFIC VOLUME FT.^{3}/LB DA			ENTHALPY BTU/LB DA		
	GRAINS/ LB DA	POUNDS/ LB DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
80	156.380	0.022340	13.602	0.487	14.089	19.222	24.479	43.701
81	162.330	0.023109	13.627	0.505	14.132	19.462	25.332	44.794
82	167.314	0.023902	13.653	0.523	14.175	19.702	26.211	45.913
83	173.040	0.024720	13.678	0.542	14.220	19.943	27.120	47.062
84	178.941	0.025563	13.703	0.561	14.264	20.183	28.055	48.238
85	185.031	0.026433	13.728	0.581	14.310	20.424	29.021	49.445
86	191.303	0.027329	13.754	0.602	14.356	20.664	30.017	50.681
87	197.778	0.028254	13.779	0.624	14.403	20.905	31.045	51.949
88	204.456	0.029208	13.804	0.646	14.450	21.145	32.105	53.250
89	211.323	0.030189	13.829	0.669	14.498	21.385	33.197	54.582
90	218.421	0.031203	13.855	0.692	14.547	21.626	34.325	55.951
91	225.729	0.032247	13.880	0.717	14.597	21.866	35.489	57.355
92	233.261	0.033323	13.905	0.742	14.647	22.107	36.687	58.794
93	241.031	0.034433	13.930	0.768	14.699	22.347	37.924	60.271
94	249.039	0.035577	13.956	0.795	14.751	22.588	39.199	61.787
95	257.299	0.036757	13.981	0.823	14.804	22.828	40.515	63.343
96	265.804	0.037972	14.006	0.852	14.858	23.069	41.871	64.940
97	274.575	0.039225	14.032	0.881	14.913	23.309	43.269	66.578
98	283.612	0.040516	14.057	0.912	14.969	23.550	44.711	68.260
99	292.936	0.041848	14.082	0.944	15.026	23.790	46.198	69.988
100	302.533	0.043219	14.107	0.976	15.084	24.031	47.730	71.761
101	312.438	0.044634	14.133	1.010	15.143	24.271	49.312	73.583
102	322.630	0.046090	14.158	1.045	15.203	24.512	50.940	75.452
103	333.144	0.047592	14.183	1.081	15.264	24.752	52.621	77.373
104	343.980	0.049140	14.208	1.118	15.326	24.993	54.354	79.346
105	355.159	0.050737	14.234	1.156	15.390	25.233	56.142	81.375
106	366.681	0.052383	14.259	1.196	15.455	25.474	57.986	83.460
107	378.539	0.054077	14.284	1.236	15.521	25.714	59.884	85.599
108	390.782	0.055826	14.309	1.279	15.588	25.955	61.844	87.799
109	403.396	0.057628	14.335	1.322	15.657	26.195	63.866	90.061
110	416.402	0.059486	14.360	1.367	15.727	26.436	65.950	92.386
111	429.807	0.061401	14.385	1.414	15.799	26.677	68.099	94.776
112	443.646	0.063378	14.411	1.462	15.872	26.917	70.319	97.237
113	457.877	0.065411	14.436	1.511	15.947	27.158	72.603	99.760
114	472.584	0.067512	14.461	1.562	16.023	27.398	74.964	102.362
115	487.732	0.069676	14.486	1.615	16.101	27.639	77.396	105.035
116	503.356	0.071908	14.512	1.670	16.181	27.879	79.906	107.786
117	519.477	0.074211	14.537	1.726	16.263	28.120	82.497	110.617
118	536.102	0.076586	14.562	1.784	16.346	28.361	85.169	113.530
119	553.252	0.079036	14.587	1.844	16.432	28.601	87.927	116.528

Thermodynamic Properties of Moist Air @ 14.696 PSIA

TEMP °F.	HUMIDITY RATIO		SPECIFIC VOLUME FT.³/LB DA			ENTHALPY BTU/LB DA		
	GRAINS/LB DA	POUNDS/ LB DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
120	570.920	0.081560	14.613	1.906	16.519	28.842	90.770	119.612
121	589.183	0.084169	14.638	1.971	16.609	29.083	93.709	122.792
122	608.020	0.086860	14.663	2.037	16.700	29.323	96.742	126.065
123	627.431	0.089633	14.688	2.106	16.794	29.564	99.868	129.432
124	647.500	0.092500	14.714	2.176	16.890	29.805	103.102	132.907
125	668.192	0.095456	14.739	2.250	16.989	30.045	106.437	136.482
126	689.528	0.098504	14.764	2.325	17.090	30.286	109.877	140.163
127	711.599	0.101657	14.789	2.404	17.193	30.527	113.438	143.965
128	734.370	0.104910	14.815	2.485	17.299	30.767	117.111	147.878
129	757.890	0.108270	14.840	2.569	17.409	31.008	120.908	151.916
130	782.166	0.111738	14.865	2.655	17.520	31.249	124.828	156.076
131	807.254	0.115322	14.891	2.745	17.635	31.489	128.880	160.370
132	833.161	0.119023	14.916	2.837	17.753	31.730	133.066	164.796
133	859.985	0.122855	14.941	2.934	17.875	31.971	137.403	169.374
134	887.628	0.126804	14.966	3.033	17.999	32.212	141.873	174.084
135	916.265	0.130895	14.992	3.136	18.127	32.452	146.504	178.957
136	945.868	0.135124	15.017	3.242	18.259	32.693	151.294	183.987
137	976.458	0.139494	15.042	3.352	18.394	32.934	156.245	189.179
138	1008.133	0.144019	15.067	3.467	18.534	33.175	161.374	194.548
139	1040.872	0.148696	15.093	3.585	18.678	33.415	166.677	200.092
140	1074.766	0.153538	15.118	3.708	18.825	33.656	172.168	205.824
141	1110.501	0.158643	15.143	3.835	18.978	33.897	177.857	211.754
142	1146.236	0.163748	15.168	3.967	19.135	34.138	183.754	217.892
143	1173.854	0.169122	15.194	4.103	19.297	34.379	189.855	244.233
144	1222.858	0.174694	15.219	4.245	19.464	34.620	196.183	230.802
145	1263.269	0.180467	15.244	4.392	19.637	34.860	202.740	237.600
146	1305.220	0.186460	15.269	4.545	19.815	35.101	209.550	244.651
147	1348.676	0.192668	15.295	4.704	19.999	35.342	216.607	251.949
148	1393.770	0.199110	15.320	4.869	20.189	35.583	223.932	259.514
149	1440.544	0.205792	15.345	5.040	20.385	35.824	231.533	267.356
150	1489.110	0.212730	15.370	5.218	20.585	36.064	239.426	275.490
151	1539.615	0.219945	15.396	5.404	20.799	36.305	247.638	283.943
152	1592.003	0.227429	15.421	5.596	21.017	36.546	256.158	292.705
153	1646.526	0.235218	15.446	5.797	21.243	36.787	265.028	301.816
154	1703.163	0.243309	15.471	6.005	21.477	37.028	274.245	311.273
155	1762.166	0.251738	15.497	6.223	21.720	37.269	283.849	321.118
156	1823.584	0.260512	15.522	6.450	21.972	37.510	293.849	331.359
157	1887.508	0.269644	15.547	6.686	22.233	37.751	304.261	342.012
158	1954.162	0.279166	15.572	6.933	22.505	37.992	315.120	353.112
159	2023.707	0.289101	15.598	7.190	22.788	38.233	326.452	364.685

Thermodynamic Properties of Moist Air @ 14.696 PSIA

TEMP °F.	HUMIDITY RATIO		SPECIFIC VOLUME FT.^{3}/LB DA			ENTHALPY BTU/LB DA		
	GRAINS/ LB DA	POUNDS/ LB DA	v_a	v_{as}	v_s	h_a	h_{as}	h_s
160	2096.15	0.29945	15.623	7.459	23.082	38.474	338.263	376.737
161	2171.89	0.31027	15.648	7.740	23.388	38.715	350.610	389.325
162	2250.92	0.32156	15.673	8.034	23.707	38.956	363.501	402.457
163	2333.52	0.33336	15.699	8.341	24.040	39.197	376.979	416.175
164	2420.04	0.34572	15.724	8.664	24.388	39.438	391.095	430.533
165	2510.55	0.35865	15.749	9.001	24.750	39.679	405.865	445.544
166	2605.40	0.37220	15.774	9.355	25.129	39.920	421.352	461.271
167	2685.83	0.38639	15.800	9.726	25.526	40.161	437.578	477.739
168	2809.17	0.40131	15.825	10.117	25.942	40.402	454.630	495.032
169	2918.86	0.41698	15.850	10.527	26.377	40.643	472.554	513.197
170	3034.01	0.43343	15.875	10.959	26.834	40.884	491.372	532.256
171	3155.53	0.45079	15.901	11.414	27.315	41.125	511.231	552.356
172	3283.35	0.46905	15.926	11.894	27.820	41.366	532.138	573.504
173	3418.03	0.48829	15.951	12.400	28.352	41.607	554.160	595.767
174	3560.69	0.50867	15.976	12.937	28.913	41.848	577.489	619.337
175	3711.33	0.53019	16.002	13.504	29.505	42.089	602.139	644.229
176	3870.58	0.55294	16.027	14.103	30.130	42.331	628.197	670.528
177	4039.70	0.57710	16.052	14.741	30.793	42.572	655.876	698.448
178	4219.18	0.60274	16.078	15.418	31.496	42.813	685.260	728.073
179	4410.14	0.63002	16.103	16.138	32.242	43.054	716.524	759.579
180	4613.77	0.65911	16.128	16.909	33.037	43.295	749.871	793.166
181	4830.84	0.69012	16.153	17.730	33.883	43.536	785.426	828.962
182	5063.17	0.72331	16.178	18.609	34.787	43.778	823.487	867.265
183	5311.95	0.75885	16.204	19.551	35.755	44.019	864.259	908.278
184	5579.21	0.79703	16.229	20.564	36.793	44.260	908.061	952.321
185	5867.19	0.83817	16.254	21.656	37.910	44.501	955.261	999.763
186	6177.57	0.88251	16.280	22.834	39.113	44.742	1006.149	1050.892
187	6513.99	0.93057	16.305	24.111	40.416	44.984	1061.314	1106.298
188	6879.04	0.98272	16.330	25.498	41.828	45.225	1121.174	1166.399
189	7276.57	1.03951	16.355	27.010	43.365	45.466	1186.382	1231.848
190	7710.78	1.10154	16.381	28.661	45.042	45.707	1257.614	1303.321
191	8187.55	1.16965	16.406	30.476	46.882	45.949	1335.834	1381.783
192	8712.97	1.24471	16.431	32.477	48.908	46.190	1422.047	1468.238
193	9295.16	1.32788	16.456	34.695	51.151	46.431	1517.581	1564.013
194	9942.03	1.42029	16.481	37.161	53.642	46.673	1623.758	1670.430
195	10667.72	1.52396	16.507	39.928	56.435	46.914	1742.879	1789.793
196	11484.90	1.64070	16.532	43.046	59.578	47.155	1877.032	1924.188
197	12410.93	1.77299	16.557	46.580	63.137	47.397	2029.069	2076.466
198	13473.04	1.92472	16.583	50.636	67.218	47.638	2203.464	2251.102
199	14698.25	2.09975	16.608	55.316	71.923	47.879	2404.668	2452.547
200	16131.78	2.30454	16.663	60.793	77.426	48.121	2640.084	2688.205

27.02 Properties of Air

Barometric Pressures at Various Altitudes at 70°F.

ALTITUDE FEET	BAROMETER (ABSOLUTE PRESSURE)				RELATIVE DENSITY
	IN. HG.	PSI	FT. H_2O	IN.WG.	
60,000	2.14	1.05	2.43	29.1	0.07
50,000	3.44	1.69	3.90	46.8	0.11
40,000	5.56	2.73	6.31	75.7	0.18
30,000	8.90	4.37	10.10	121.1	0.30
20,000	13.76	6.76	15.61	187.2	0.46
15,000	16.88	8.29	19.15	229.7	0.56
10,000	20.57	10.11	23.34	280.0	0.69
9,000	21.34	10.49	24.22	290.5	0.71
8,000	22.12	10.87	25.10	301.0	0.74
7,000	23.09	11.34	26.20	314.2	0.77
6,000	23.98	11.78	27.21	326.4	0.80
5,000	24.89	12.23	28.24	338.8	0.83
4,000	25.84	12.70	29.32	351.7	0.86
3,500	26.33	12.94	29.88	358.3	0.88
3,000	26.81	13.17	30.42	364.8	0.90
2,500	27.31	13.42	30.99	371.7	0.91
2,000	27.82	13.67	31.57	378.6	0.93
1,500	28.33	13.92	32.15	385.6	0.95
1,000	28.85	14.17	32.74	392.6	0.96
500	29.38	14.43	33.33	399.9	0.98
SEA LEVEL	**29.92**	**14.70**	**33.95**	**407.2**	**1.00**
-500	30.47	14.97	34.57	414.7	1.02
-1000	31.02	15.24	35.20	422.2	1.04
-2,000	32.15	15.80	36.48	437.5	1.07
-3,000	33.31	32.16	37.80	453.3	1.11
-4,000	34.51	16.96	39.16	469.7	1.15
-5,000	35.74	17.56	40.55	486.4	1.19

Air Equation Constants for Altitude

ALTITUDE FEET	SENSIBLE HEAT (1)	LATENT HEAT		TOTAL HEAT (4)
		Gr.H_2O (2)	Lb.H_2O (3)	
60,000	0.08	0.048	339	0.315
50,000	0.12	0.075	532	0.495
40,000	0.19	0.123	871	0.810
30,000	0.32	0.204	1452	1.350
20,000	0.49	0.306	2178	2.025
15,000	0.56	0.382	2710	2.520
10,000	0.69	0.470	3340	3.105
9,000	0.77	0.483	3436	3.195
8,000	0.74	0.504	3582	3.330
7,000	0.77	0.525	3727	3.465
6,000	0.80	0.545	3872	3.600
5,000	0.83	0.566	4017	3.735
4,000	0.86	0.586	4162	3.870
3,500	0.88	0.600	4259	3.960
3,000	0.90	0.613	4356	4.050
2,500	0.91	0.620	4404	4.095
2,000	0.93	0.634	4501	4.185
1,500	0.95	0.647	4598	4.275
1,000	0.96	0.654	4646	4.320
500	0.98	0.668	4743	4.410
SEA LEVEL	**1.08**	**0.681**	**4840**	**4.500**
-500	1.19	0.695	4937	4.590
-1,000	1.12	0.708	5034	4.680
-2,000	1.16	0.729	5179	4.815
-3,000	1.20	0.756	5372	4.995
-4,000	1.24	0.783	5566	5.175
-5,000	1.29	0.810	5760	5.335

Notes:
1. Equation Constants Units: BTU/Hr. CFM °F.
2. Equation Constants Units: BTU LbDA/Hr. Gr.H_2O CFM.
3. Equation Constants Units: BTU LbDA/Hr. Lb.H_2O CFM.
4. Equation Constants Units: Lb.DA/Hr. CFM.
5. Use table values in lieu of constants in equations in Part 5, Equations.

Air Equation Constants for Temperature

TEMPERATURE °F.	SENSIBLE HEAT (1)	LATENT HEAT		TOTAL HEAT (4)
		$Gr.H_2O$ (2)	$Lb.H_2O$ (3)	
0	1.204	0.759	5397	5.018
50	1.102	0.695	4937	4.590
60	**1.080**	**0.681**	**4840**	**4.500**
100	1.015	0.640	4550	4.230
150	0.950	0.599	4259	3.960
200	0.896	0.565	4017	3.735
250	0.842	0.531	3775	3.510
300	0.799	0.504	3582	3.330
350	0.756	0.477	3388	3.150
400	0.724	0.456	3243	3.015
450	0.691	0.436	3098	2.880
500	0.659	0.415	2952	2.745
550	0.626	0.395	2807	2.610
600	0.610	0.385	2735	2.543
650	0.583	0.368	2614	2.430
700	0.567	0.358	2541	2.363
750	0.551	0.347	2468	2.295
800	0.529	0.334	2372	2.205
850	0.513	0.323	2299	2.138
900	0.497	0.313	2226	2.070
950	0.486	0.306	2178	2.025
1000	0.470	0.296	2105	1.958

Notes:

1. Equation Constants Units: BTU/Hr. CFM °F.
2. Equation Constants Units: BTU LbDA/Hr. $Gr.H_2O$ CFM.
3. Equation Constants Units: BTU LbDA/Hr. $Lb.H_2O$ CFM.
4. Equation Constants Units: Lb.DA/Hr. CFM.
5. Use table values in lieu of constants in equations in Part 5, Equations.

Air Equation Factors for Density

ALTITUDE FEET	TEMPERATURE °F						
	-40	0	40	70	100	150	200
60,000	0.90	0.08	0.08	0.07	0.07	0.06	0.06
50,000	0.14	0.13	0.12	0.11	0.11	0.10	0.09
40,000	0.23	0.21	0.20	0.19	0.18	0.16	0.15
30,000	0.37	0.34	0.32	0.30	0.28	0.26	0.24
20,000	0.58	0.53	0.49	0.46	0.44	0.40	0.37
15,000	0.71	0.65	0.60	0.56	0.54	0.49	0.45
10,000	0.87	0.79	0.73	0.69	0.65	0.60	0.55
9,000	0.90	0.82	0.76	0.71	0.68	0.62	0.57
8,000	0.93	0.85	0.79	0.74	0.70	0.65	0.60
7,000	0.97	0.89	0.82	0.77	0.73	0.67	0.62
6,000	1.01	0.91	0.85	0.80	0.75	0.69	0.64
5,000	1.05	0.95	0.88	0.83	0.78	0.72	0.66
4,000	1.09	0.99	0.92	0.86	0.81	0.75	0.69
3,500	1.11	1.01	0.94	0.87	0.83	0.77	0.70
3,000	1.13	1.03	0.95	0.89	0.85	0.78	0.71
2,500	1.15	1.05	0.97	0.91	0.87	0.80	0.73
2,000	1.17	1.07	0.99	0.93	0.88	0.81	0.74
1,500	1.20	1.09	1.01	0.95	0.90	0.83	0.76
1,000	1.22	1.11	1.02	0.96	0.92	0.84	0.77
500	1.24	1.13	1.04	0.98	0.94	0.86	0.79
SEA LEVEL	**1.26**	**1.15**	**1.06**	**1.00**	**0.95**	**0.87**	**0.80**
-500	1.28	1.17	1.08	1.02	0.97	0.89	0.81
-1,000	1.31	1.19	1.10	1.04	0.98	0.90	0.83
-2,000	1.35	1.24	1.14	1.07	1.02	0.93	0.86
-3,000	1.40	1.28	1.18	1.11	1.06	0.97	0.89
-4,000	1.45	1.33	1.22	1.15	1.10	1.00	0.92
-5,000	1.51	1.37	1.27	1.19	1.13	1.04	0.96

Notes:

1. Multiply constants in equations in Part 5, Equations, by values in the table.

Air Equation Factors for Density

ALTITUDE FEET	TEMPERATURE °F						
	250	300	350	400	450	500	550
60,000	0.05	0.05	0.05	0.04	0.04	0.04	0.04
50,000	0.09	0.08	0.07	0.07	0.07	0.06	0.06
40,000	0.14	0.13	0.12	0.12	0.11	0.10	0.10
30,000	0.22	0.21	0.19	0.18	0.17	0.16	0.16
20,000	0.34	0.32	0.30	0.29	0.27	0.26	0.24
15,000	0.42	0.39	0.37	0.35	0.33	0.31	0.30
10,000	0.51	0.48	0.45	0.42	0.40	0.38	0.36
9,000	0.53	0.50	0.47	0.44	0.42	0.39	0.38
8,000	0.56	0.52	0.49	0.46	0.43	0.41	0.39
7,000	0.58	0.54	0.51	0.48	0.45	0.43	0.41
6,000	0.60	0.56	0.52	0.49	0.46	0.44	0.42
5,000	0.62	0.58	0.54	0.51	0.48	0.45	0.44
4,000	0.64	0.60	0.56	0.53	0.50	0.47	0.45
3,500	0.66	0.61	0.57	0.54	0.51	0.48	0.46
3,000	0.67	0.62	0.58	0.55	0.52	0.49	0.47
2,500	0.69	0.64	0.59	0.56	0.53	0.50	0.48
2,000	0.70	0.65	0.60	0.57	0.54	0.51	0.49
1,500	0.71	0.66	0.61	0.59	0.55	0.52	0.50
1,000	0.72	0.67	0.62	0.60	0.56	0.53	0.51
500	0.74	0.69	0.64	0.61	0.57	0.54	0.52
SEA LEVEL	**0.75**	**0.70**	**0.65**	**0.62**	**0.58**	**0.55**	**0.53**
-500	0.76	0.71	0.66	0.63	0.59	0.56	0.54
-1,000	0.78	0.73	0.67	0.64	0.60	0.57	0.55
-2,000	0.81	0.75	0.70	0.67	0.62	0.59	0.57
-3,000	0.83	0.78	0.72	0.69	0.65	0.61	0.59
-4,000	0.87	0.81	0.75	0.72	0.67	0.63	0.61
-5,000	0.90	0.84	0.78	0.74	0.69	0.66	0.63

Notes:

1. **Multiply constants in equations in Part 5, Equations, by values in the table.**

Air Equation Factors for Density

ALTITUDE FEET	TEMPERATURE °F						
	600	650	700	750	800	900	1000
60,000	0.04	0.03	0.03	0.03	0.03	0.03	0.03
50,000	0.06	0.06	0.05	0.05	0.05	0.04	0.04
40,000	0.09	0.09	0.09	0.08	0.08	0.07	0.07
30,000	0.15	0.14	0.14	0.13	0.12	0.12	0.11
20,000	0.23	0.22	0.21	0.20	0.19	0.18	0.17
15,000	0.28	0.27	0.26	0.25	0.24	0.22	0.20
10,000	0.34	0.33	0.32	0.31	0.29	0.27	0.25
9,000	0.35	0.34	0.33	0.32	0.30	0.28	0.26
8,000	0.37	0.36	0.34	0.33	0.31	0.29	0.27
7,000	0.39	0.37	0.35	0.33	0.32	0.30	0.28
6,000	0.40	0.38	0.37	0.35	0.33	0.31	0.29
5,000	0.41	0.40	0.38	0.37	0.35	0.32	0.30
4,000	0.43	0.41	0.39	0.38	0.36	0.33	0.31
3,500	0.44	0.42	0.40	0.39	0.37	0.34	0.32
3,000	0.45	0.43	0.41	0.39	0.37	0.35	0.32
2,500	0.46	0.44	0.42	0.40	0.38	0.36	0.33
2,000	0.46	0.45	0.43	0.41	0.39	0.36	0.33
1,500	0.47	0.46	0.44	0.42	0.40	0.37	0.34
1,000	0.48	0.46	0.44	0.42	0.40	0.37	0.35
500	0.49	0.47	0.45	0.43	0.41	0.38	0.36
SEA LEVEL	**0.50**	**0.48**	**0.46**	**0.44**	**0.42**	**0.39**	**0.36**
-500	0.51	0.49	0.47	0.45	0.43	0.40	0.37
-1,000	0.52	0.50	0.48	0.46	0.44	0.41	0.38
-2,000	0.54	0.52	0.49	0.47	0.45	0.42	0.39
-3,000	0.56	0.53	0.51	0.49	0.47	0.43	0.40
-4,000	0.58	0.55	0.53	0.51	0.48	0.45	0.42
-5,000	0.60	0.57	0.55	0.55	0.50	0.47	0.43

Notes:

1. **Multiply constants in equations in Part 5, Equations, by values in the table.**

Physical Properties of Gases

SUBSTANCE	FORMULA	MOLECULAR WEIGHT	PHASE	SPECIFIC VOLUME Cu.Ft./Lbm	DENSITY Lbm/Cu.Ft.	SPECIFIC GRAVITY
GASES						
AIR	---	28.996	GAS	13.333	0.075	1.000
CARBON	C	12.01	SOLID	---	---	---
HYDROGEN	H_2	2.016	GAS	187.723	0.005	0.067
AMMONIA	NH_3	17.031	GAS	21.914	0.046	0.613
SULFUR	S	32.06	GAS	7.407	0.135	1.800
HYDROGEN SULFIDE	H_2S	34.076	GAS	10.979	0.091	1.213
NITROUS OXIDE	N_2O	44.013	GAS	8.772	0.114	1.520
OZONE	O_3	48.0	GAS	8.032	0.125	1.660
ARGON	Ar	39.948	GAS	9.662	0.104	1.380
CHLORINE	Cl_2	70.906	GAS	5.442	0.184	2.450
HELIUM	He	4.002	GAS	96.618	0.010	0.138
NEON	Ne	20.179	GAS	19.130	0.052	0.697
PRODUCTS OF COMBUSTION - COMPLETE						
CARBON DIOXIDE	CO_2	44.01	GAS	8.548	0.117	1.560
WATER VAPOR	H_2O	18.016	GAS	21.017	0.048	0.640
OXYGEN	O_2	32.000	GAS	11.819	0.085	1.133
NITROGEN	N_2	28.016	GAS	13.443	0.074	0.987
PRODUCTS OF COMBUSTION - INCOMPLETE						
CARBON MONOXIDE	CO	28.01	GAS	13.699	0.073	0.967
NITRIC OXIDE	NO	30.006	GAS	12.821	0.078	1.040
NITROGEN DIOXIDE	NO_2	46.006	GAS	---	---	---
NITROUS TRIOXIDE	NO_3	62.005	GAS	---	---	---
NOX	NO_X	---	GAS	---	---	---
SULFURIC OXIDE	SO	48.063	GAS	---	---	---
SULFUR DIOXIDE	SO_2	64.06	GAS	5.770	0.173	2.307
SULFUR TRIOXIDE	SO_3	80.062	GAS	---	---	---
SOX	SO_X	---	GAS	---	---	---

27.03 Properties of Water

Boiling Points of Water

PSIA	BOILING POINT °F.	PSIA	BOILING POINT °F.	PSIA	BOILING POINT °F.
0.5	79.6	44	273.1	150	358.5
1	101.7	46	275.8	175	371.8
2	126.0	48	278.5	200	381.9
3	141.4	50	281.0	225	391.9
4	152.9	52	283.5	250	401.0
5	162.2	54	285.9	275	409.5
6	170.0	56	288.3	300	417.4
7	176.8	58	290.5	325	424.8
8	182.8	60	292.7	350	431.8
9	188.3	62	294.9	375	438.4
10	193.2	64	297.0	400	444.7
11	197.7	66	299.0	425	450.7
12	201.9	68	301.0	450	456.4
13	205.9	70	303.0	475	461.9
14	209.6	72	304.9	500	467.1
14.69	**212.0**	74	306.7	525	472.2
15	213.0	76	308.5	550	477.1
16	216.3	78	310.3	575	481.8
17	219.4	80	312.1	600	486.3
18	222.4	82	313.8	625	490.7
19	225.2	84	315.5	650	495.0
20	228.0	86	317.1	675	499.2
22	233.0	88	318.7	700	503.2
24	237.8	90	320.3	725	507.2
26	242.3	92	321.9	750	511.0
28	246.4	94	323.4	775	514.7
30	250.3	96	324.9	800	518.4
32	254.1	98	326.4	825	521.9
34	257.6	100	327.9	850	525.4
36	261.0	105	331.4	875	528.8
38	264.2	110	334.8	900	532.1
40	267.3	115	338.1	950	538.6
42	270.2	120	341.3	1000	544.8

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
-80	0.000116	0.01732	1953234	1953234	-193.50	1219.19	1025.69
-79	0.000125	0.01732	1814052	1814052	-193.11	1219.24	1026.13
-78	0.000135	0.01732	1685445	1685445	-192.71	1219.28	1026.57
-77	0.000145	0.01732	1566663	1566663	-192.31	1219.33	1027.02
-76	0.000157	0.01732	1456752	1456752	-191.92	1219.38	1027.46
-75	0.000169	0.01733	1355059	1355059	-191.52	1219.42	1027.90
-74	0.000182	0.01733	1260977	1260977	-191.12	1219.47	1028.34
-73	0.000196	0.01733	1173848	1173848	-190.72	1219.51	1028.79
-72	0.000211	0.01733	1093149	1093149	-190.32	1219.55	1029.23
-71	0.000227	0.01733	1018381	1018381	-189.92	1219.59	1029.67
-70	0.000245	0.01733	949067	949067	-189.52	1219.63	1030.11
-69	0.000263	0.01733	884803	884803	-189.11	1219.67	1030.55
-68	0.000283	0.01733	825187	825187	-188.71	1219.71	1031.00
-67	0.000304	0.01734	769864	769864	-188.30	1219.74	1031.44
-66	0.000326	0.01734	718508	718508	-187.90	1219.78	1031.88
-65	0.000350	0.01734	670800	670800	-187.49	1219.82	1032.32
-64	0.000376	0.01734	626503	626503	-187.08	1219.85	1032.77
-63	0.000404	0.01734	585316	585316	-186.67	1219.88	1033.21
-62	0.000433	0.01734	548041	548041	-186.26	1219.91	1033.65
-61	0.000464	0.01734	511446	511446	-185.85	1219.95	1034.09
-60	0.000498	0.01734	478317	478317	-185.44	1219.98	1034.54
-59	0.000533	0.01735	447495	447495	-185.03	1220.01	1034.98
-58	0.000571	0.01735	418803	418803	-184.61	1220.03	1035.42
-57	0.000612	0.01735	392068	392068	-184.20	1220.06	1035.86
-56	0.000655	0.01735	367172	367172	-183.78	1220.09	1036.30
-55	0.000701	0.01735	343970	343970	-183.37	1220.11	1036.75
-54	0.000750	0.01735	322336	322336	-182.95	1220.14	1037.19
-53	0.000802	0.01735	302157	302157	-182.53	1220.16	1037.63
-52	0.000857	0.01735	283335	283335	-182.11	1220.18	1038.07
-51	0.000916	0.01736	265773	265773	-181.69	1220.21	1038.52
-50	0.000979	0.01736	249381	249381	-181.27	1220.23	1038.96
-49	0.001045	0.01736	234067	234067	-180.85	1220.25	1039.40
-48	0.001116	0.01736	219766	219766	-180.42	1220.26	1039.84
-47	0.001191	0.01736	206398	206398	-181.00	1220.28	1040.28
-46	0.001271	0.01736	193909	193909	-179.57	1220.30	1040.73
-45	0.001355	0.01736	182231	182231	-179.14	1220.31	1041.17
-44	0.001445	0.01736	171304	171304	-178.72	1220.33	1041.61
-43	0.001541	0.01737	161084	161084	-178.29	1220.34	1042.05
-42	0.001642	0.01737	151518	151518	-177.86	1220.36	1042.50
-41	0.001749	0.01737	142566	142566	-177.43	1220.37	1042.94

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
-40	0.001863	0.01737	134176	134176	-177.00	1220.38	1043.38
-39	0.001984	0.01737	126322	126322	-176.57	1220.39	1043.82
-38	0.002111	0.01737	118959	118959	-176.13	1220.40	1044.27
-37	0.002247	0.01737	112058	112058	-175.70	1220.40	1044.71
-36	0.002390	0.01738	105592	105592	-175.26	1220.41	1045.15
-35	0.002542	0.01738	99522	99522	-174.83	1220.42	1045.59
-34	0.002702	0.01738	93828	93828	-174.39	1220.42	1046.03
-33	0.002872	0.01738	88489	88489	-173.95	1220.43	1046.48
-32	0.003052	0.01738	83474	83474	-173.51	1220.43	1046.92
-31	0.003242	0.01738	78763	78763	-173.07	1220.43	1047.36
-30	0.003443	0.01738	74341	74341	-172.63	1220.43	1047.80
-29	0.003655	0.01738	70187	70187	-172.19	1220.43	1048.25
-28	0.003879	0.01739	66282	66282	-171.74	1220.43	1048.69
-27	0.004116	0.01739	62613	62613	-171.30	1220.43	1049.13
-26	0.004366	0.01739	59161	59161	-170.86	1220.43	1049.57
-25	0.004630	0.01739	55915	55915	-170.41	1220.42	1050.01
-24	0.004909	0.01739	52861	52861	-169.96	1220.42	1050.46
-23	0.005203	0.01739	49986	49986	-169.51	1220.41	1050.90
-22	0.005514	0.01739	47281	47281	-169.07	1220.41	1051.34
-21	0.005841	0.01740	44733	44733	-168.62	1220.40	1051.78
-20	0.006186	0.01740	42333	42333	-168.16	1220.39	1052.22
-19	0.006550	0.01740	40073	40073	-167.71	1220.38	1052.67
-18	0.006933	0.01740	37943	37943	-167.26	1220.37	1053.11
-17	0.007337	0.01740	35934	35934	-166.81	1220.36	1053.55
-16	0.007763	0.01740	34041	34041	-166.35	1220.34	1053.99
-15	0.008211	0.01740	32256	32256	-165.90	1220.33	1054.43
-14	0.008683	0.01741	30572	30572	-165.44	1220.31	1054.87
-13	0.009179	0.01741	28983	28983	-164.98	1220.30	1055.32
-12	0.009702	0.01741	27483	27483	-164.52	1220.28	1055.76
-11	0.010252	0.01741	26067	26067	-164.06	1220.26	1056.20
-10	0.010830	0.01741	24730	24730	-163.60	1220.24	1056.64
-9	0.011438	0.01741	23467	23467	-163.14	1220.22	1057.08
-8	0.012077	0.01741	22274	22274	-162.68	1220.20	1057.53
-7	0.012749	0.01742	21147	21147	-162.21	1220.18	1057.97
-6	0.013456	0.01742	20081	20081	-162.75	1220.16	1058.41
-5	0.014197	0.01742	19074	19074	-161.28	1220.13	1058.85
-4	0.014977	0.01742	18121	18121	-160.82	1220.11	1059.29
-3	0.015795	0.01742	17220	17220	-160.35	1220.08	1059.73
-2	0.016654	0.01742	16367	16367	-159.88	1220.05	1060.17
-1	0.017556	0.01742	15561	15561	-159.41	1220.02	1060.62

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
0	0.018502	0.01743	14797	14797	-158.94	1220.00	1061.06
1	0.019495	0.01743	14073	14073	-158.47	1219.96	1061.50
2	0.020537	0.01743	13388	13388	-157.99	1219.93	1061.94
3	0.021629	0.01743	12740	12740	-157.52	1219.90	1062.38
4	0.022774	0.01743	12125	12125	-157.05	1219.87	1062.82
5	0.023975	0.01743	11543	11543	-156.57	1219.83	1063.26
6	0.025233	0.01743	10991	10991	-156.09	1219.80	1063.70
7	0.026552	0.01744	10468	10468	-155.62	1219.76	1064.14
8	0.027933	0.01744	9971	9971	-155.14	1219.72	1064.58
9	0.029379	0.01744	9500	9500	-154.66	1219.68	1065.03
10	0.030894	0.01744	9054	9054	-154.18	1219.64	1065.47
11	0.032480	0.01744	8630	8630	-153.70	1219.60	1065.91
12	0.034140	0.01744	8228	8228	-153.21	1219.56	1066.35
13	0.035878	0.01745	7846	7846	-152.73	1219.52	1066.79
14	0.037696	0.01745	7483	7483	-152.24	1219.47	1067.23
15	0.039597	0.01745	7139	7139	-151.76	1219.43	1067.67
16	0.041586	0.01745	6811	6811	-151.27	1219.38	1068.11
17	0.043666	0.01745	6501	6501	-150.78	1219.33	1068.55
18	0.045841	0.01745	6205	6205	-150.30	1219.28	1068.99
19	0.048113	0.01745	5924	5924	-149.81	1219.23	1069.43
20	0.050489	0.01746	5657	5657	-149.32	1219.18	1069.87
21	0.052970	0.01746	5404	5404	-148.82	1219.13	1070.31
22	0.055563	0.01746	5162	5162	-148.33	1219.08	1070.75
23	0.058271	0.01746	4932	4932	-147.84	1219.02	1071.19
24	0.061099	0.01746	4714	4714	-147.34	1218.97	1071.63
25	0.064051	0.01746	4506	4506	-146.85	1218.91	1072.07
26	0.067133	0.01747	4308	4308	-146.35	1218.85	1072.50
27	0.070349	0.01747	4119	4119	-145.85	1218.80	1072.94
28	0.073706	0.01747	3940	3940	-145.35	1218.74	1073.38
29	0.077207	0.01747	3769	3769	-144.85	1218.68	1073.82
30	0.080860	0.01747	3606	3606	-144.35	1218.61	1074.26
31	0.084669	0.01747	3450	3450	-143.85	1218.55	1074.70
32	0.08865	0.01602	3302.07	3302.09	-0.02	1075.15	1075.14
33	0.09229	0.01602	3178.15	3178.16	0.99	1074.59	1075.58
34	0.09607	0.01602	3059.47	3059.49	2.00	1074.02	1076.01
35	0.09998	0.01602	2945.66	2945.68	3.00	1073.45	1076.45
36	0.10403	0.01602	2836.60	2836.61	4.01	1072.88	1076.89
37	0.10822	0.01602	2732.13	2732.15	5.02	1072.32	1077.33
38	0.11257	0.01602	2631.88	2631.89	6.02	1071.75	1077.77
39	0.11707	0.01602	2535.86	2535.88	7.03	1071.18	1078.21

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
40	0.12172	0.01602	2443.67	2443.69	8.03	1070.62	1078.65
41	0.12654	0.01602	2355.22	2355.24	9.04	1070.05	1079.09
42	0.13153	0.01602	2270.42	2270.43	10.04	1069.48	1079.52
43	0.13669	0.01602	2189.02	2189.04	11.04	1068.92	1079.96
44	0.14203	0.01602	2110.92	2110.94	12.05	1068.35	1080.40
45	0.14755	0.01602	2035.91	2035.92	13.05	1067.79	1080.84
46	0.15326	0.01602	1963.85	1963.87	14.05	1067.22	1081.28
47	0.15917	0.01602	1894.71	1894.73	15.06	1066.66	1081.71
48	0.16527	0.01602	1828.28	1828.30	16.06	1066.09	1082.15
49	0.17158	0.01602	1764.44	1764.46	17.06	1065.53	1082.59
50	0.17811	0.01602	1703.18	1703.20	18.06	1064.96	1083.03
51	0.18484	0.01602	1644.25	1644.26	19.06	1064.40	1083.46
52	0.19181	0.01603	1587.64	1587.65	20.07	1063.83	1083.90
53	0.19900	0.01603	1533.22	1533.24	21.07	1063.27	1084.34
54	0.20643	0.01603	1480.89	1480.91	22.07	1062.71	1084.77
55	0.21410	0.01603	1430.61	1430.62	23.07	1062.14	1085.21
56	0.22202	0.01603	1382.19	1382.21	24.07	1061.58	1085.65
57	0.23020	0.01603	1335.65	1335.67	25.07	1061.01	1086.08
58	0.23864	0.01603	1290.85	1290.87	26.07	1060.45	1086.52
59	0.24735	0.01603	1247.76	1247.78	27.07	1059.89	1086.96
60	0.25635	0.01604	1206.30	1206.32	28.07	1059.32	1087.39
61	0.26562	0.01604	1166.38	1166.40	29.07	1058.76	1087.83
62	0.27519	0.01604	1127.93	1127.95	30.07	1058.19	1088.27
63	0.28506	0.01604	1090.94	1090.96	31.07	1057.63	1088.70
64	0.29524	0.01604	1055.32	1055.33	32.07	1057.07	1089.14
65	0.30574	0.01604	1020.98	1021.00	33.07	1056.50	1089.57
66	0.31656	0.01604	987.95	987.97	34.07	1055.94	1090.01
67	0.32772	0.01605	956.11	956.12	35.07	1055.37	1090.44
68	0.33921	0.01605	925.44	925.45	36.07	1054.81	1090.88
69	0.35107	0.01605	895.86	895.87	37.07	1054.24	1091.31
70	0.36328	0.01605	867.34	867.36	38.07	1053.68	1091.75
71	0.37586	0.01605	839.87	839.88	39.07	1053.11	1092.18
72	0.38882	0.01606	813.37	813.39	40.07	1052.55	1092.61
73	0.40217	0.01606	787.85	787.87	41.07	1051.98	1093.05
74	0.41592	0.01606	763.19	763.21	42.06	1051.42	1093.48
75	0.43008	0.01606	739.42	739.44	43.06	1050.85	1093.92
76	0.44465	0.01606	716.51	716.53	44.06	1050.29	1094.35
77	0.45966	0.01607	694.38	694.40	45.06	1049.72	1094.78
78	0.47510	0.01607	673.05	673.06	46.06	1049.16	1095.22
79	0.49100	0.01607	652.44	652.46	47.06	1048.59	1095.65

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
80	0.50736	0.01607	632.54	632.56	48.06	1048.03	1096.08
81	0.52419	0.01608	613.35	613.37	49.06	1047.46	1096.51
82	0.54150	0.01608	594.82	594.84	50.05	1046.89	1096.95
83	0.55931	0.01608	576.90	576.92	51.05	1046.33	1097.38
84	0.57763	0.01608	559.63	559.65	52.05	1045.76	1097.81
85	0.59647	0.01609	542.93	542.94	53.05	1045.19	1098.24
86	0.61584	0.01609	526.80	526.81	54.05	1044.63	1098.67
87	0.63575	0.01609	511.21	511.22	55.05	1044.06	1099.11
88	0.65622	0.01609	496.14	496.15	56.05	1043.49	1099.54
89	0.67726	0.01610	481.60	481.61	57.04	1042.92	1099.97
90	0.69889	0.01610	467.52	467.53	58.04	1042.36	1100.40
91	0.72111	0.01610	453.91	453.93	59.04	1041.79	1100.83
92	0.74394	0.01611	440.76	440.78	60.04	1041.22	1101.26
93	0.76740	0.01611	428.04	428.06	61.04	1040.65	1101.69
94	0.79150	0.01611	415.74	415.76	62.04	1040.08	1102.12
95	0.81625	0.01612	403.84	403.86	63.03	1039.51	1102.55
96	0.84166	0.01612	392.33	392.34	64.03	1038.95	1102.98
97	0.86776	0.01612	381.20	381.21	65.03	1038.38	1103.41
98	0.89456	0.01612	370.42	370.44	66.03	1037.81	1103.84
99	0.92207	0.01613	359.99	360.01	67.03	1037.24	1104.26
100	0.95031	0.01613	349.91	349.92	68.03	1036.67	1104.69
101	0.97930	0.01613	340.14	340.15	69.03	1036.10	1105.12
102	1.00904	0.01614	330.69	330.71	70.02	1035.53	1105.55
103	1.03956	0.01614	321.53	321.55	71.02	1034.95	1105.98
104	1.07088	0.01614	312.67	312.69	72.02	1034.38	1106.40
105	1.10301	0.01615	304.08	304.10	73.02	1033.81	1106.83
106	1.13597	0.01615	295.76	295.77	74.02	1033.24	1107.26
107	1.16977	0.01616	287.71	287.73	75.01	1032.67	1107.68
108	1.20444	0.01616	279.91	279.92	76.01	1032.10	1108.11
109	1.23999	0.01616	272.34	272.36	77.01	1031.52	1108.54
110	1.27644	0.01617	265.02	265.03	78.01	1030.95	1108.96
111	1.31381	0.01617	257.91	257.93	79.01	1030.38	1109.39
112	1.35212	0.01617	251.02	251.04	80.01	1029.80	1109.81
113	1.39138	0.01618	244.36	244.38	81.01	1029.23	1110.24
114	1.43162	0.01618	237.89	237.90	82.00	1028.66	1110.66
115	1.47286	0.01619	231.62	231.63	83.00	1028.08	1111.09
116	1.51512	0.01619	225.53	225.55	84.00	1027.51	1111.51
117	1.55842	0.01619	219.63	219.65	85.00	1026.93	1111.93
118	1.60277	0.01620	213.91	213.93	86.00	1026.36	1112.36
119	1.64820	0.01620	208.36	208.37	87.00	1025.78	1112.78

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
120	1.69474	0.01620	202.98	202.99	88.00	1025.20	1113.20
121	1.74240	0.01621	197.76	197.76	89.00	1023.62	1113.62
122	1.79117	0.01621	192.69	192.69	90.00	1024.05	1114.05
123	1.84117	0.01622	187.78	187.78	90.99	1024.47	1114.47
124	1.89233	0.01622	182.98	182.99	91.99	1022.90	1114.89
125	1.94470	0.01623	178.34	178.36	92.99	1022.32	1115.31
126	1.99831	0.01623	173.85	173.86	93.99	1021.74	1115.73
127	2.05318	0.01623	169.47	169.49	94.99	1021.16	1116.15
128	2.10934	0.01624	165.23	165.25	95.99	1020.58	1116.57
129	2.16680	0.01624	161.11	161.12	96.99	1020.00	1116.99
130	2.22560	0.01625	157.11	157.12	97.99	1019.42	1117.41
131	2.28576	0.01625	153.22	153.23	98.99	1018.84	1117.83
132	2.34730	0.01626	149.44	149.46	99.99	1018.26	1118.25
133	2.41025	0.01626	145.77	145.78	100.99	1017.68	1118.67
134	2.47463	0.01627	142.21	142.23	101.99	1017.10	1119.08
135	2.54048	0.01627	138.74	138.76	102.99	1016.52	1119.50
136	2.60782	0.01627	135.37	135.39	103.98	1015.93	1119.92
137	2.67667	0.01628	132.10	132.12	104.98	1015.35	1120.34
138	2.74707	0.01628	128.92	128.94	105.98	1014.77	1120.75
139	2.81903	0.01629	125.83	125.85	106.98	1014.18	1121.17
140	2.89260	0.01629	122.82	122.84	107.98	1013.60	1121.58
141	2.96780	0.01630	119.90	119.92	108.98	1013.01	1122.00
142	3.04465	0.01630	117.05	117.07	109.98	1012.43	1122.41
143	3.12320	0.01631	114.29	114.31	110.98	1011.84	1122.83
144	3.20345	0.01631	111.60	111.62	111.98	1011.26	1123.24
145	3.28546	0.01632	108.99	109.00	112.98	1010.67	1123.66
146	3.36924	0.01632	106.44	106.45	113.98	1010.09	1124.07
147	3.45483	0.01633	103.96	103.98	114.98	1009.50	1124.48
148	3.54226	0.01633	101.55	101.57	115.98	1008.91	1124.89
149	3.63156	0.01634	99.21	99.22	116.98	1008.32	1125.31
150	3.72277	0.01634	96.93	96.94	117.98	1007.73	1125.72
151	3.81591	0.01635	94.70	94.72	118.99	1007.14	1126.13
152	3.91101	0.01635	92.54	92.56	119.99	1006.55	1126.54
153	4.00812	0.01636	90.44	90.46	120.99	1005.96	1126.95
154	4.10727	0.01636	88.39	88.41	121.99	1005.37	1127.36
155	4.20848	0.01637	86.40	86.41	122.99	1004.78	1127.77
156	4.31180	0.01637	84.45	84.47	123.99	1004.19	1128.18
157	4.41725	0.01638	82.56	82.58	124.99	1003.60	1128.59
158	4.52488	0.01638	80.72	80.73	125.99	1003.00	1128.99
159	4.63472	0.01639	78.92	78.94	126.99	1002.41	1129.40

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
160	4.7468	0.01639	77.175	77.192	127.99	1001.82	1129.81
161	4.8612	0.01640	75.471	75.488	128.99	1001.22	1130.22
162	4.9778	0.01640	73.812	73.829	130.00	1000.63	1130.62
163	5.0969	0.01641	72.196	72.213	131.00	1000.03	1131.03
164	5.2183	0.01642	70.619	70.636	132.00	999.43	1131.43
165	5.3422	0.01642	69.084	69.101	133.00	998.84	1131.84
166	5.4685	0.01643	67.587	67.604	134.00	998.24	1132.24
167	5.5974	0.01643	66.130	66.146	135.00	997.64	1132.64
168	5.7287	0.01644	64.707	64.723	136.01	997.04	1133.05
169	5.8627	0.01644	63.320	63.336	137.01	996.44	1133.45
170	5.9993	0.01645	61.969	61.989	138.01	995.84	1133.85
171	6.1386	0.01646	60.649	60.666	139.01	995.24	1134.25
172	6.2806	0.01646	59.363	59.380	140.01	994.64	1134.66
173	6.4253	0.01647	58.112	58.128	141.02	994.04	1135.06
174	6.5729	0.01647	56.887	56.904	142.02	993.44	1135.46
175	6.7232	0.01648	55.694	55.711	143.02	992.83	1135.86
176	6.8765	0.01648	54.532	54.549	144.03	992.23	1136.26
177	7.0327	0.01649	53.397	53.414	145.03	991.63	1136.65
178	7.1918	0.01650	52.290	52.307	146.03	991.02	1137.05
179	7.3539	0.01650	51.210	51.226	147.03	990.42	1137.45
180	7.5191	0.01651	50.155	50.171	148.04	989.81	1137.85
181	7.6874	0.01651	49.126	49.143	149.04	989.20	1138.24
182	7.8589	0.01652	48.122	48.138	150.04	988.60	1138.64
183	8.0335	0.01653	47.142	47.158	151.05	987.99	1139.03
184	8.2114	0.01653	46.185	46.202	152.05	987.38	1139.43
185	8.3926	0.01654	45.251	45.267	153.05	986.77	1139.82
186	8.5770	0.01654	44.339	44.356	154.06	986.16	1140.22
187	8.7649	0.01655	43.448	43.465	155.06	985.55	1140.61
188	8.9562	0.01656	42.579	42.595	156.07	984.94	1141.00
189	9.1510	0.01656	41.730	41.746	157.07	984.32	1141.39
190	9.3493	0.01657	40.901	40.918	158.07	983.71	1141.78
191	9.5512	0.01658	40.092	40.108	159.08	983.10	1142.18
192	9.7567	0.01658	39.301	39.317	160.08	982.48	1142.57
193	9.9659	0.01659	38.528	38.544	161.09	981.87	1142.95
194	10.1788	0.01659	37.774	37.790	162.09	981.25	1143.34
195	10.3955	0.01660	37.035	37.052	163.10	980.63	1143.73
196	10.6160	0.01661	36.314	36.331	164.10	980.02	1144.12
197	10.8404	0.01661	35.611	35.628	165.11	979.40	1144.51
198	11.0687	0.01662	34.923	34.940	166.11	978.78	1144.89
199	11.3010	0.01663	34.251	34.268	167.12	978.16	1145.28

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
200	11.5374	0.01663	33.594	33.610	168.13	977.54	1145.66
201	11.7779	0.01664	32.951	32.968	169.13	976.92	1146.05
202	12.0225	0.01665	32.324	32.340	170.14	976.29	1146.43
203	12.2713	0.01665	31.710	31.726	171.14	975.67	1146.81
204	12.5244	0.01666	31.110	31.127	172.15	975.05	1147.20
205	12.7819	0.01667	30.523	30.540	173.16	974.42	1147.58
206	13.0436	0.01667	29.949	29.965	174.16	973.80	1147.96
207	13.3099	0.01668	29.388	29.404	175.17	973.17	1148.34
208	13.5806	0.01669	28.839	28.856	176.18	972.54	1148.72
209	13.8558	0.01669	28.303	28.319	177.18	971.92	1149.10
210	14.1357	0.01670	27.778	27.795	178.19	971.29	1149.48
212	14.7096	0.01671	26.763	26.780	180.20	970.03	1150.23
214	15.3025	0.01673	25.790	25.807	182.22	968.76	1150.98
216	15.9152	0.01674	24.861	24.878	184.24	967.50	1151.73
218	16.5479	0.01676	23.970	23.987	186.25	966.23	1152.48
220	17.2013	0.01677	23.118	23.134	188.27	964.95	1153.22
222	17.8759	0.01679	22.299	22.316	190.29	963.67	1153.96
224	18.5721	0.01680	21.516	21.533	192.31	962.39	1154.70
226	19.2905	0.01682	20.765	20.782	194.33	961.11	1155.43
228	20.0316	0.01683	20.045	20.062	196.35	959.82	1156.16
230	20.7961	0.01684	19.355	19.372	198.37	958.52	1156.89
232	21.5843	0.01686	18.692	18.709	200.39	957.22	1157.62
234	22.3970	0.01688	18.056	18.073	202.41	955.92	1158.34
236	23.2345	0.01689	17.466	17.463	204.44	954.62	1159.06
238	24.0977	0.01691	16.860	16.877	206.46	953.31	1159.77
240	24.9869	0.01692	16.298	16.314	208.49	952.00	1160.48
242	25.9028	0.01694	15.757	15.774	210.51	950.68	1161.19
244	26.8461	0.01695	15.238	15.255	212.54	948.35	1161.90
246	27.8172	0.01697	14.739	14.756	214.57	948.03	1162.60
248	28.8169	0.01698	14.259	14.276	216.60	946.70	1163.29
250	29.8457	0.01700	13.798	13.815	218.63	945.36	1163.99
252	30.9043	0.01702	13.355	13.372	220.66	944.02	1164.68
254	31.9934	0.01703	12.928	12.945	222.69	942.68	1165.37
256	33.1135	0.01705	12.526	12.147	224.73	939.99	1166.72
258	34.2653	0.01707	12.123	12.140	226.76	939.97	1166.73
260	35.4496	0.01708	11.742	11.759	228.79	938.61	1167.40
262	36.6669	0.01710	11.376	11.393	230.83	937.25	1168.08
264	37.9180	0.01712	11.024	11.041	232.87	935.88	1168.74
266	39.2035	0.01714	10.684	10.701	234.90	934.50	1169.41
268	40.5241	0.01715	10.357	10.374	236.94	933.12	1170.07

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
270	41.8806	0.01717	10.042	10.059	238.98	931.74	1170.72
272	43.2736	0.01719	9.737	9.755	241.03	930.35	1171.38
274	44.7040	0.01721	9.445	9.462	243.07	928.95	1172.02
276	46.1723	0.01722	9.162	9.179	245.11	927.55	1172.67
278	47.6794	0.01724	8.890	8.907	247.16	926.15	1173.31
280	49.2260	0.01726	8.627	8.644	249.20	924.74	1173.94
282	50.8128	0.01728	8.373	8.390	251.25	923.32	1174.57
284	52.4406	0.01730	8.128	8.146	253.30	921.90	1175.20
286	54.1103	0.01731	7.892	7.910	255.35	920.47	1175.82
288	55.8225	0.01733	7.664	7.681	257.40	919.03	1176.44
290	57.5780	0.01735	7.444	7.461	259.45	917.59	1177.05
292	59.3777	0.01737	7.231	7.248	261.51	916.15	1177.66
294	61.2224	0.01739	7.026	7.043	263.56	914.69	1178.26
296	63.1128	0.01741	6.827	6.844	265.62	913.24	1178.86
298	65.0498	0.01743	6.635	6.652	267.68	911.77	1179.45
300	67.03	0.01745	6.450	6.467	269.74	910.3	1180.04
302	69.01	0.01747	6.275	6.292	271.79	909.0	1180.79
304	71.09	0.01749	6.102	6.119	273.86	907.5	1181.36
306	73.22	0.01751	5.933	5.951	275.93	906.0	1181.93
308	75.40	0.01753	5.771	5.789	278.00	904.5	1182.50
310	77.64	0.01755	5.614	5.632	280.06	903.0	1183.06
312	79.92	0.01757	5.462	5.480	282.13	901.5	1183.63
314	82.26	0.01759	5.315	5.333	284.21	899.9	1184.11
316	84.65	0.01761	5.172	5.190	286.28	898.4	1184.68
318	87.10	0.01763	5.034	5.052	288.36	896.9	1185.26
320	89.60	0.01765	4.901	4.919	290.43	895.3	1185.73
322	92.16	0.01767	4.772	4.790	292.51	893.8	1186.31
324	94.78	0.01770	4.647	4.665	294.59	892.2	1186.79
326	97.46	0.01772	4.525	4.543	296.67	890.7	1187.37
328	100.20	0.01774	4.408	4.426	298.76	889.1	1187.86
330	103.00	0.01776	4.294	4.312	300.84	887.5	1188.34
332	105.86	0.01778	4.183	4.201	302.93	885.9	1188.83
334	108.78	0.01780	4.076	4.094	305.02	884.3	1189.32
336	111.76	0.01783	3.973	3.991	307.11	882.7	1189.81
338	114.82	0.01785	3.872	3.890	309.21	881.1	1190.31
340	117.93	0.01787	3.774	3.792	311.30	879.5	1190.80
342	121.11	0.01789	3.680	3.698	313.39	877.9	1191.29
344	124.36	0.01792	3.588	3.606	315.49	876.3	1191.79
346	127.68	0.01794	3.499	3.517	317.59	874.6	1192.19
348	131.07	0.01796	3.412	3.430	319.70	873.0	1192.70

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
350	134.53	0.01799	3.328	3.346	321.80	871.3	1193.10
352	138.06	0.01801	3.247	3.265	323.91	869.6	1193.51
354	141.66	0.01804	3.167	3.185	326.02	868.0	1194.02
356	145.34	0.01806	3.091	3.109	328.13	866.3	1194.43
358	149.09	0.01808	3.286	3.304	330.24	864.6	1194.84
360	152.92	0.01811	2.943	2.961	332.35	862.9	1195.25
362	156.82	0.01813	2.873	2.891	334.47	861.2	1195.67
364	160.80	0.01816	2.804	2.822	336.59	859.5	1196.09
366	164.87	0.01818	2.738	2.756	338.71	857.7	1196.41
368	169.01	0.01821	2.673	2.691	340.83	856.0	1196.83
370	173.23	0.01823	5.283	2.628	342.96	854.2	1197.16
372	177.53	0.01826	2.549	2.567	345.08	852.5	1197.58
374	181.92	0.01828	2.325	2.508	347.21	850.7	1197.91
376	186.39	0.01831	2.432	2.450	349.35	848.9	1198.25
378	190.95	0.01834	2.376	2.394	351.48	847.2	1198.68
380	195.60	0.01836	2.321	2.339	353.62	845.4	1199.02
382	200.33	0.01839	2.268	2.286	355.76	843.6	1199.36
384	205.15	0.01842	2.216	2.234	357.90	841.7	1199.60
386	210.06	0.01844	2.165	2.183	360.04	839.9	1199.94
388	215.06	0.01847	2.116	2.134	362.19	838.1	1200.29
390	220.2	0.01850	2.069	2.087	364.34	836.2	1200.54
392	225.3	0.01853	2.021	2.040	366.49	834.4	1200.89
394	230.6	0.01855	1.976	1.995	368.64	832.5	1201.14
396	236.0	0.01858	1.932	1.951	370.80	830.6	1204.40
398	241.5	0.01861	1.889	1.908	372.96	828.7	1201.66
400	247.1	0.01864	1.847	1.866	375.12	826.8	1201.92
405	261.4	0.01871	1.747	1.766	380.53	822.0	1202.53
410	276.5	0.01878	1.654	1.673	385.97	817.2	1203.17
415	292.1	0.01886	1.566	1.585	391.42	812.2	1203.62
420	308.5	0.01894	1.483	1.502	396.89	807.2	1204.09
425	325.6	0.01901	1.406	1.425	402.38	802.1	1204.48
430	343.3	0.01909	1.333	1.352	407.89	796.9	1204.79
435	361.9	0.01918	1.265	1.284	413.42	791.7	1205.12
440	381.2	0.01926	1.200	1.219	418.98	786.3	1205.28
445	401.2	0.01935	1.139	1.158	424.55	780.9	1205.45
450	422.1	0.01943	1.082	1.101	430.20	775.4	1205.60
455	443.8	0.01952	1.027	1.047	435.80	769.8	1205.60
460	466.3	0.01961	0.976	0.996	441.40	764.1	1205.50
465	489.8	0.01971	0.928	0.948	447.10	758.3	1205.40
470	514.1	0.01980	0.883	0.903	452.80	752.4	1205.20

Thermodynamic Properties of Water

TEMP °F.	PRESS PSIA	SPECIFIC VOLUME FT³/LB.			ENTHALPY BTU/LB		
		v_l	v_{lg}	v_g	h_l	h_{lg}	h_g
475	539.3	0.01990	0.840	0.8594	458.5	746.4	1204.9
480	565.5	0.02000	0.799	0.8187	464.3	740.3	1204.6
485	592.6	0.02011	0.760	0.7801	470.1	734.1	1204.2
490	620.7	0.02021	0.723	0.7436	475.9	727.8	1203.7
495	649.8	0.02032	0.689	0.7090	481.8	721.3	1203.1
500	680.0	0.02043	0.656	0.6761	487.7	714.8	1202.5
525	847.1	0.02104	0.514	0.5350	517.8	680.0	1197.8
550	1044.0	0.02175	0.406	0.4249	549.1	641.6	1190.6
575	1274.0	0.02259	0.315	0.3378	581.9	598.6	1180.4
600	1541.0	0.02363	0.244	0.2677	616.7	549.7	1166.4

Properties of Water

TEMPERATURE °F.	SPECIFIC HEAT BTU/LB °F.	DENSITY LB/FT³	SPECIFIC GRAVITY
32 - 100	1.00	62.40	1.000
101 - 150	1.00	61.15	0.980
151 - 200	1.01	59.90	0.960
201 - 250	1.02	58.66	0.940
251 - 300	1.03	57.41	0.920
301 - 350	1.05	55.85	0.895
351 - 400	1.08	53.98	0.865
401 - 450	1.13	51.79	0.830

Water Equation Factors

SYSTEM TYPE	SYSTEM TEMPERATURE RANGE °F.	EQUATION FACTOR
LOW TEMPERATURE (GLYCOL) CHILLED WATER	0 - 40	SEE NOTE 2
CHILLED WATER	40 - 60	500
CONDENSER WATER HEAT PUMP LOOP	60 - 110	500
LOW TEMPERATURE HEATING WATER	110 - 150	490
	151 - 200	485
	201 - 250	480
MEDIUM TEMPERATURE HEATING WATER	251 - 300	475
	301 - 350	470
HIGH TEMPERATURE HEATING WATER	351 - 400	470
	401 - 450	470

Notes:
1. Water equation corrections for temperature, density, and specific heat.
2. For glycol system equation factors, see Section 27.04, Glycol Systems, below.

27.04 Glycol Systems

Ethylene Glycol

% GLYCOL SOLUTION	TEMPERATURE °F.		SPECIFIC HEAT	SPECIFIC GRAVITY (1)	EQUATION FACTOR
	FREEZE POINT	BOILING POINT			
0	+32	212	1.00	1.000	500
10	+26	214	0.97	1.012	491
20	+16	216	0.94	1.027	483
30	+4	220	0.89	1.040	463
40	-12	222	0.83	1.055	438
50	-34	225	0.78	1.067	416
60	-60	232	0.73	1.079	394
70	<-60	244	0.69	1.091	376
80	-49	258	0.64	1.101	352
90	-20	287	0.60	1.109	333
100	+10	287+	0.55	1.116	307

Propylene Glycol

% GLYCOL SOLUTION	TEMPERATURE °F.		SPECIFIC HEAT	SPECIFIC GRAVITY (1)	EQUATION FACTOR
	FREEZE POINT	BOILING POINT			
0	+32	212	1.000	1.000	500
10	+26	212	0.980	1.008	494
20	+19	213	0.960	1.017	488
30	+8	216	0.935	1.026	480
40	-7	219	0.895	1.034	463
50	-28	222	0.850	1.041	442
60	<-60	225	0.805	1.046	421
70	<-60	230	0.750	1.048	393
80	<-60	230+	0.690	1.048	362
90	<-60	230+	0.645	1.045	337
100	<-60	230+	0.570	1.040	296

Note:
1. Specific gravity with respect to water at 60°F.

PART 28

General Notes

28.01 General

A. Provide all materials and equipment and perform all labor required to install complete and operable mechanical systems as indicated on the drawings, as specified and as required by code.

B. Contract document drawings for mechanical work (HVAC, plumbing, and fire protection) are diagrammatic and are intended to convey scope and general arrangement only.

C. Install all mechanical equipment and appurtenances in accordance with manufacturers' recommendations, contract documents, and applicable codes and regulations.

D. Provide vibration isolation for all mechanical equipment to prevent transmission of vibration to building structure.

E. Provide vibration isolators for all piping supports connected to and within 50 feet of isolated equipment (except at base elbow supports and anchor points) throughout mechanical equipment rooms. Do the same for supports of steam mains within 50 feet of boiler or pressure reducing valves.

F. Provide vibration isolators for all piping supports of steam mains within 50 feet of boilers and pressure reducing valves.

G. The location of existing underground utilities is shown in an approximate way only. The contractor shall determine the exact location of all existing utilities before commencing work. The contractor shall pay for and repair all damages caused by failure to exactly locate and preserve any and all underground utilities unless otherwise indicated.

H. Coordinate construction of all mechanical work with architectural, structural, civil, electrical work, etc., shown on other contract document drawings.

I. Maintain a minimum of 6′-8″ clearance to underside of pipes, ducts, conduits, suspended equipment, etc., throughout access routes in mechanical rooms.

J. All tests shall be completed before any mechanical equipment or piping insulation is applied.

K. Locate all temperature, pressure, and flow measuring devices in accessible locations with straight section of pipe or duct up- and downstream as recommended by the manufacturer for good accuracy.

L. Testing, adjusting, and balancing agency shall be a member of the Associated Air Balance Council (AABC) or the National Environmental Balancing Bureau (NEBB). Testing, adjusting, and balancing shall be performed in accordance with the AABC Standards.

M. Where two or more items of the same type of equipment are required, the product of one manufacturer shall be used.

N. Reinforcement, detailing, and placement of concrete shall conform to *ASTM 315* and *ACI 318.* Concrete shall conform to *ASTM C94.* Concrete work shall conform to

ACI 318, part entitled "Construction Requirements." Compressive strength in 28 days shall be 3,000 psi. Total air content of exterior concrete shall be between 5 and 7 percent by volume. Slump shall be between 3 and 4 inches. Concrete shall be cured for 7 days after placement.

O. Coordinate all equipment connections with manufacturers' certified drawings. Coordinate and provide all duct and piping transitions required for final equipment connections to furnished equipment. Field verify and coordinate all duct and piping dimensions before fabrication.

P. All control wire and conduit shall comply with the National Electric Code and Division 16 of the specification.

Q. Concrete housekeeping pads to suit mechanical equipment shall be sized and located by the mechanical contractor. Minimum concrete pad thickness shall be 6 inches. Pad shall extend beyond the equipment a minimum of 6 inches on each side. Concrete housekeeping pads shall be provided by the general contractor. It shall be the responsibility of the mechanical contractor to coordinate size and location of concrete housekeeping pads with general contractor.

R. All mechanical room doors shall be a minimum of 4′-0″ wide.

S. Where beams are indicated to be penetrated with ductwork or piping, coordinate ductwork and piping layout with beam opening size and opening locations. Coordination shall be done prior to fabrication of ductwork, cutting of piping, or fabrication of beams.

T. When mechanical work (HVAC, plumbing, sheet metal, fire protection, etc.) is subcontracted, it shall be the mechanical contractor's responsibility to coordinate subcontractors and the associated contracts. When discrepancies arise pertaining to which contractor provides a particular item of the mechanical contract or which contractor provides final connections for a particular item of the mechanical contract, it shall be brought to the attention of the mechanical contractor, whose decision shall be final.

U. The locations of all items shown on the drawings or called for in the specifications that are not definitely fixed by dimensions are approximate only. The exact locations necessary to secure the best conditions and results must be determined by the project site conditions and shall have the approval of the engineer before being installed. Do not scale drawings.

V. All miscellaneous steel required to ensure proper installation and as shown in details for piping, ductwork, and equipment (unless otherwise noted) shall be furnished and installed by the mechanical contractor.

W. Provide access panels for installation in walls and ceilings, where required, to service dampers, valves, smoke detectors, and other concealed mechanical equipment. Access panels shall be turned over to general contractor for installation.

X. All equipment, piping, ductwork, etc., shall be supported as detailed, specified, and required to provide a vibration free installation.

Y. All ductwork, piping and equipment supported from structural steel shall be coordinated with general contractor. All attachments to steel bar joists, trusses, or joist girders shall be at panel points. Provide beam clamps meeting mss standards.

Welding to structural members shall not be permitted. The use of C-clamps shall not be permitted.

Z. Mechanical equipment, ductwork, and piping shall not be supported from metal deck.

AA. All roof mounted equipment curbs for equipment provided by the mechanical contractor shall be furnished by the mechanical contractor and installed by the general contractor.

BB. Locations and sizes of all floor, wall, and roof openings shall be coordinated with all other trades involved.

CC. All openings in fire walls due to ductwork, piping, conduit, etc., shall be fire stopped with a product similar to 3M or approved equal.

DD. All air conditioning condensate drain lines from each air handling unit and rooftop unit shall be piped full size of the unit drain outlet, with "P" trap, and piped to nearest drain. See details shown on the drawings or the contract specifications for depth of air conditioning condensate trap.

EE. Refer to typical details for ductwork, piping, and equipment installation.

28.02 Piping

A. Provide all materials and equipment and perform all labor required to install complete and operable piping systems as indicated on the drawings, as specified and as required by code.

B. Elevations as shown on the drawings are to the centerline of all pressure piping and to the invert of all gravity piping.

C. Maintain a minimum of 3′6″ of ground cover over all underground HVAC piping (edit depth of ground cover to suit frost line depth and project requirements).

D. Unless otherwise noted, all chilled water and heating water piping shall be ¾ inch size (edit system type or pipe size to suit project requirements).

E. Provide an air vent at the high point of each drop in the heating water, chilled water, and other closed water piping systems (edit system types to suit project requirements). All piping shall grade to low points. Provide hose end drain valves at the bottom of all risers and low points.

F. Unless otherwise noted, all piping is overhead, tight to underside of structure or slab, with space for insulation if required.

G. Install piping so that all valves, strainers, unions, traps, flanges, and other appurtenances requiring access are accessible.

H. All valves shall be installed so that valve remains in service when equipment or piping on equipment side of valve is removed.

I. All balancing valves and butterfly valves shall be provided with position indicators and maximum adjustable stops (memory stops).

J. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7′-0″ above floor level; Chain shall extend to 7′-0″ above floor level.

K. All valves (except control valves) and strainers shall be full size of pipe before reducing size to make connections to equipment and controls.

L. Unions and/or flanges shall be installed at each piece of equipment, in bypasses, and in long piping runs (100 feet or more) to permit disassembly for alteration and repairs.

M. Pitch steam piping downward in the direction of flow ¼ inch in 10 feet (1 inch in 40 feet) minimum. Pitch all steam return lines downward in the direction of condensate flow ½ inch per 10 feet (1 inch in 20 feet) minimum. Where length of branch lines are less than 8 feet, pitch branch lines toward mains ½ inch per foot minimum.

N. Pitch up all steam and condensate runouts to risers and equipment ½ inch per foot. Where this pitch cannot be obtained, runouts over 8 feet in length shall be one size larger than noted.

O. Tap all branch lines from top of steam mains (45 degrees preferred, 90 degrees acceptable).

P. Provide an end of main drip at each rise in the steam main. Provide condensate drips at the bottom of all steam risers, downfed runouts to equipment, radiators, etc., at end of mains and low points, and ahead of all pressure regulators, control valves, isolation valves, and expansion joints.

Q. On straight steam piping runs with no natural drainage points, install drip legs at intervals not exceeding 200 feet where pipe is pitched downward in the direction of steam flow and a maximum of 100 feet where the pipe is pitched up so that condensate flow is opposite of steam flow.

R. Steam traps shall be minimum ¾″ size.

S. Install all piping without forcing or springing.

T. All piping shall clear doors and windows.

U. All valves shall be adjusted for smooth and easy operation.

V. All piping work shall be coordinated with all trades involved. Offsets in piping around obstructions shall be provided at no additional cost to the owner.

W. Provide flexible connections in all piping systems connected to pumps, chillers, cooling towers, and other equipment which require vibration isolation except water coils. Flexible connections shall be provided as close to the equipment as possible or as indicated on the drawings.

X. Slope refrigerant piping one percent in the direction of oil return. Liquid lines may be installed level.

Y. Install horizontal refrigerant hot gas discharge piping With ½″ per 10 feet downward slope away from the compressor.

Z. Install horizontal refrigerant suction lines with ½″ per 10 feet downward slope to the compressor, with no long traps or dead ends which may cause oil to separate from the suction gas and return to the compressor in damaging slugs.

AA. Provide line size liquid indicators in main liquid line leaving condenser or receiver. Install moisture-liquid indicators in liquid lines between filter dryers and thermostatic expansion valves and in liquid line to receiver.

BB. Provide line size strainer upstream of each automatic valve. Provide shutoff valve on each side of strainer.

CC. Provide permanent filter dryers in low temperature systems and systems using hermetic compressors.

DD. Provide replaceable cartridge filter dryers with three valve bypass assembly for solenoid valves, adjacent to receivers.

EE. Provide refrigerant charging valve connections in liquid line between receiver shutoff valve and expansion valve.

28.03 Plumbing

A. Provide all materials and equipment and perform all labor required to install complete and operable plumbing systems as indicated on the drawings, as specified and as required by code.

B. Run all soil waste and vent piping with 2% minimum grade unless otherwise noted (edit slope to suit project requirements). Horizontal vent piping shall be graded to drip back to the soil or waste pipe by gravity.

C. Elevations as shown on the drawings are to the centerline of all pressure piping and to the invert of all gravity piping.

D. Adjust sewer inverts to keep tops of pipe in line where pipe size changes.

E. Maintain a minimum of 3′6″ of ground cover over all underground water mains and a minimum of 3′0″ of ground cover over all underground sewers and drains (edit depth of ground cover to suit frost line depth and project requirements).

F. Provide shutoff valves in all domestic water piping system branches in which branch piping serves two or more fixtures.

G. Unless otherwise noted, all domestic cold and hot water piping shall be ½ inch size (edit system type or pipe size to suit project requirements).

H. Unless otherwise noted, all piping is overhead, tight to underside of slab, with space for insulation if required.

I. Install piping so that all valves, strainers, unions, traps, flanges, and other appurtenances requiring access are accessible.

J. Where domestic cold and hot water piping drops into a pipe chase, the size shown for the pipe drops shall be used to the last fixture.

K. Install all piping without forcing or springing.

L. All piping shall clear doors and windows.

M. All piping shall grade to low points. Provide hose end drain valves at the bottom of all risers and low points.

N. Unions and/or flanges shall be installed at each piece of equipment, in bypasses, and in long piping runs (100 feet or more) to permit disassembly for alteration and repairs.

O. All valves shall be adjusted for smooth and easy operation.

P. All valves (except control valves) and strainers shall be full size of pipe before reducing size to make connections to equipment and controls.

Q. Provide chainwheel operators for all valves in equipment rooms mounted greater than 7′-0″ above floor level; Chain shall extend to 7′-0″ above floor level.

R. Provide all plumbing fixtures and equipment with accessible stops.

S. Unless otherwise noted, drains shall be installed at the low point of roofs, areaways, floors, etc.

T. Provide cleanouts in sanitary and storm drainage systems at ends of runs, at changes in direction, near the base of stacks, every 50 feet in horizontal runs and elsewhere as indicated (edit horizontal cleanout spacing to suit code and project requirements).

U. All cleanouts shall be full size of pipe for pipe sizes 6 inches and smaller and shall be 6 inches for pipe sizes larger than 6 inches.

V. All balancing valves and butterfly valves shall be provided with position indicators and maximum adjustable stops (memory stops).

W. All valves shall be installed so that valve remains in service when equipment or piping on equipment side of valve is removed.

X. All piping work shall be coordinated with all trades involved. Offsets in piping around obstructions shall be provided at no additional cost to the owner.

Y. Provide flexible connections in all piping systems connected to pumps and other equipment which require vibration isolation. Flexible connections shall be provided as close to the equipment as possible or as indicated on the drawings.

28.04 HVAC/Sheet Metal

A. Provide all materials and equipment and perform all labor required to install complete and operable HVAC systems as indicated on the drawings, as specified and as required by code.

B. Certain items such as rises and drops in ductwork, access doors, volume dampers, etc., are indicated on the contract document drawings for clarity for a specific location requirement and shall not be interpreted as the extent of the requirements for these items.

C. In corridors where ceiling speakers and air diffusers are indicated between the same light fixtures, install both devices at the quarter points between the same fixture.

D. Unless otherwise shown, locate all room thermostats and humidistats 4′-0″ (centerline) above finished floor. Notify the engineer of any rooms where the above location cannot be maintained or where there is a question on location.

E. All ductwork shall clear doors and windows.

F. All ductwork dimensions, as shown on the drawings, are internal clear dimensions and duct size shall be increased to compensate for duct lining thickness.

G. Provide all 90 degree square elbows with double radius turning vanes unless otherwise indicated. Elbows in dishwasher, kitchen, and laundry exhaust shall be unvaned smooth radius construction with a radius equal to 1½ times the width of the duct. Provide access doors upstream of all elbows with turning vanes.

H. Coordinate diffuser, register, and grille locations with architectural reflected ceiling plans, lighting, and other ceiling items and make minor duct modifications to suit.

I. Field erected and factory assembled air handling unit coils shall be arranged for removal from the upstream side without dismantling supports. Provide galvanized structural steel supports for all coils (except lowest coil) in banks over two coils high to permit independent removal of any coil.

J. All air handling units shall operate without moisture carryover.

K. Locate all mechanical equipment (single duct, dual duct, variable volume, constant volume and fan powered boxes, fan coil units, cabinet heaters, unit heaters, unit ventilators, coils, steam humidifiers, etc.) for unobstructed access to unit access panels, controls and valving.

L. Finned tube radiation enclosures shall be wall to wall unless otherwise indicated.

M. Provide flexible connections in all ductwork systems (supply, return, and exhaust) connected to air handling units, fans, and other equipment which require vibration isolation. Flexible connections shall be provided at the point of connection to the equipment unless otherwise indicated.

N. Unless otherwise noted, all ductwork is overhead, tight to the underside of the structure, with space for insulation if required.

O. Runs of flexible duct shall not exceed 5 feet (edit maximum length of flexible duct to suit project; 5 feet maximum recommended length, 8 feet maximum length).

P. All ductwork shall be coordinated with all trades involved. Offsets in ducts, including divided ducts and transitions around obstructions, shall be provided at no additional cost to the owner.

Q. Provide access doors in ductwork to provide access for all smoke detectors, fire dampers, smoke dampers, volume dampers, humidifiers, coils, and other items located in the ductwork which require service and/or inspection.

R. Provide access doors in ductwork for operation, adjustment, and maintenance of all fans, valves, and mechanical equipment.

S. All ducts shall be grounded across flexible connections with flexible copper grounding straps. Grounding straps shall be bolted or soldered to both the equipment and the duct.

T. Smoke detectors shall be furnished and wired by the electrical contractor. The mechanical contractor shall be responsible for mounting the smoke detector in ductwork as shown on the drawings and in accordance with manufacturer's printed instructions.

U. Terminate gas vents for unit heaters, water heaters, high pressure parts washer, high pressure cleaner, and other gas appliances a minimum of 3′0″ above roof with rain cap (edit appliances and height above roof to meet code and to suit project requirements).

V. See specifications for ductwork gauges, bracing, hangers, and other requirements.

W. Exterior louvers are indicated for information only. Detailed descriptions are provided in the architectural specifications.

X. Exterior louvers are indicated for information only. Louver sizes, locations, and details shall be coordinated with general contractor.

Y. Exterior louvers are indicated for information only. Louver sizes, locations, mounting, and details shall be coordinated with other trades involved.

28.05 Fire Protection

A. Provide all materials and equipment and perform all labor required to install complete and operable fire protection systems as indicated on the drawings, as specified and complying with the standards of the National Fire Protection Association, Industrial Risk Insurers, Factory Mutual, and all state and local regulations.

B. The entire building sprinkler system shall be hydraulically designed unless otherwise noted on the drawings. Head spacing in general and water quantity shall be based on Light Hazard Occupancy (edit occupancy classification to suit project requriements; see NFPA 13–Light Hazard Occupancy, Ordinary Hazard Group I Occupancy, Ordinary Hazard Group II Occupancy, Extra Hazard Group I Occupancy, Extra Hazard Group II Occupancy).

C. The entire building sprinkler system shall be pipe schedule designed unless otherwise noted on the drawings. Head spacing in general and water quantity shall be based on Light Hazard Occupancy (edit occupancy classification to suit project requirements. See NFPA 13–Light Hazard Occupancy, Ordinary Hazard Group I Occupancy, Ordinary Hazard Group II Occupancy, Extra Hazard Group I Occupancy, Extra Hazard Group II Occupancy).

D. Provide an automatic wet pipe sprinkler system throughout the entire building, complete in all respects and ready for operation including all test and drain lines, pressure gauges, hangers and supports, signs, and other standard appurtenances. Wiring shall be provided under the electrical division.

E. Provide an automatic dry pipe sprinkler system throughout the entire building, complete in all respects and ready for operation including all test and drain lines, pressure gauges, dry pipe valves, air compressors, hangers and supports, signs, and other standard appurtenances. Wiring shall be provided under the electrical division.

F. See architectural drawings for exact location of fire extinguisher cabinets, fire hose cabinets, and Siamese connections.

G. All shutoff valves in sprinkler, standpipe, and combined systems shall be approved indicating type.

H. Coordinate sprinkler head locations with the architectural reflected ceiling plans, lighting, and other ceiling items and make minor modifications to suit.

I. Sprinklers installed in ceilings of finished areas shall be symmetrical in relation to ceiling system components and centered in the ceiling tile.

PART 29

Appendix A: Ductwork

29.01 Ductwork Systems

Ductwork Sizing Criteria

SYSTEM TYPE	MAXIMUM FRICTION RATE IN.W.G./100 FT.	MINIMUM VELOCITY FT./MIN.	MAXIMUM VELOCITY FT./MIN.	COMMENTS / REASONS
GENERAL AIR HANDLING SYSTEMS				
LOW PRESSURE DUCTS	0.10 (0.15)	—	1,500 - 1,800	When CFM > 6,000 Velocity Governs; When CFM < 6,000 Friction Rate Governs; Applicable for Supply, Return, Exhaust and Outside Air Systems
MEDIUM PRESSURE DUCTS	0.20 (0.25)	—	2,000 - 2500,	When CFM > 6,000 Velocity Governs; When CFM < 6,000 Friction Rate Governs; Applicable for Supply Systems Only
HIGH PRESSURE DUCTS	0.40 (0.45)	—	2,500 - 3,500	When CFM > 5,000 Velocity Governs; When CFM < 5,000 Friction Rate Governs; Applicable for Supply Systems Only
TRANSFER AIR DUCTS	0.03 - 0.05	—	1,000	When CFM > 3,200 Velocity Governs; When CFM < 3,200 Friction Rate Governs;
OUTSIDE AIR SHAFTS	0.05 - 0.10	—	1,000	When CFM > 1,200 Velocity Governs; When CFM < 1,200 Friction Rate Governs;
GRAVITY RELIEF AIR SHAFTS	0.03 - 0.05	—	1,000	When CFM > 3,200 Velocity Governs; When CFM < 3,200 Friction Rate Governs;
GENERAL EXHAUST AND SPECIAL EXHAUST SYSTEMS				
GENERAL EXHAUST DUCTS	0.10 (0.15)	—	1,500 - 1,800	When CFM > 6,000 Velocity Governs; When CFM < 6,000 Friction Rate Governs;
TOILET EXHAUST DUCTS	0.10 (0.15)	—	1,500 - 1,800	When CFM > 6,000 Velocity Governs; When CFM < 6,000 Friction Rate Governs;
KITCHEN HOOD EXHAUST DUCTS	—	1,500	2,200	BOCA: 1,500 FPM Min. - 2,200 FPM Max.; SBCCI: 1,500 FPM Min.; UBC: 1,500 FPM Min. - 2,500 FPM Max.; NFPA: 1,500 FPM Min.
DISHWASHER EXHAUST DUCTS	0.10 (0.15)	1,500	2,200	
ACID, AMMONIA, & SOLVENT MAINS	0.50 (0.60)	1,000	3,000	Mains & Risers 1,500 - 3,000 FPM; Branches & Laterals 1,000 - 2,000 FPM
ACID, AMMONIA, & SOLVENT STACKS	—	3,000	4,000	
SILANE DUCTS	—	250	—	Velocity across the neck of the cyclinder or cabinet window or access port
LOUVERS				
INTAKE	—	—	500	Maximum Velocity through Free Area; Assuming 50% Free Area - Max. Velocity 250 FPM through Gross Louver Area
EXHAUST OR RELIEF	—	—	700	Maximum Velocity through Free Area; Assuming 50% Free Area - Max. Velocity 350 FPM through Gross Louver Area

Notes:

1. Friction Rates in parenthesis should only be used when space constraints dictate.
2. Maximum aspect ratio 4:1 unless space constraints dictate greater aspect ratios.
3. When diffusers, registers, and grilles are mounted to supply, return, and exhaust ducts, duct velocities should not exceed 1,500 FPM or noise will result.

Ductwork Support

DUCTWORK TYPE	MAXIMUM HANGER SPACING FEET
Horizontal Ducts less than 4 square feet	8
Horizontal Ducts 4 to 10 square feet	6
Horizontal Ducts greater than 10 square feet	4
Vertical Round Ducts	12
Vertical Rectangular Ducts	10

Ductwork Cost Ratios

SMACNA PRESSURE CLASS	INSTALLED COST RATIO
± 1/2"	1.00
± 1"	1.05
± 2"	1.15
± 3"	1.40
+ 4"	1.50
+ 6"	1.60
+ 10"	1.80

ASPECT RATIOS	INSTALLED COST RATIO	OPERATING COST RATIO
1:1	1.00	1.000
2:1	1.13	1.001
3:1	1.28	1.005
4:1	1.45	1.010
5:1	1.65	1.012
6:1	1.85	1.020
7:1	2.08	1.030

Friction Loss Correction Factors for Ducts

VELOCITY Fpm	MATERIAL							
	GALV. STEEL STAINLESS STEEL	DUCT LINER	ALUMINUM	CARBON STEEL	FIBEROUS GLASS (2)	PVC	CONCRETE OR CONC. BLOCK (1)	DRYWALL
500	1.00	1.25	0.98	0.93	1.25	0.93	1.5-1.9	1.25
600	1.00	1.28	0.98	0.92	1.27	0.92	1.5-1.9	1.27
700	1.00	1.30	0.98	0.92	1.30	0.92	1.5-2.0	1.30
800	1.00	1.31	0.97	0.91	1.31	0.91	1.5-2.0	1.31
900	1.00	1.32	0.97	0.90	1.31	0.90	1.5-2.0	1.31
1000	1.00	1.33	0.97	0.90	1.32	0.90	1.6-2.1	1.32
1200	1.00	1.36	0.97	0.89	1.34	0.89	1.6-2.1	1.34
1400	1.00	1.38	0.96	0.88	1.36	0.88	1.6-2.1	1.36
1600	1.00	1.40	0.96	0.87	1.38	0.87	1.6-2.2	1.38
1800	1.00	1.41	0.96	0.86	1.39	0.86	1.6-2.3	1.39
2000	1.00	1.42	0.96	0.85	1.40	0.85	1.7-2.3	1.40
2500	1.00	1.45	0.95	0.84	1.42	0.84	1.7-2.3	1.42
3000	1.00	1.47	0.95	0.83	1.43	0.83	1.7-2.3	1.43
3500	1.00	1.49	0.95	0.83	1.44	0.83	1.8-2.4	1.44
4000	1.00	1.50	0.94	0.82	1.45	0.82	1.8-2.4	1.45
4500	1.00	1.52	0.94	0.81	1.46	0.81	1.8-2.4	1.46
5000	1.00	1.54	0.94	0.80	1.48	0.80	1.8-2.4	1.48
5500	1.00	1.55	0.93	0.79	1.49	0.79	1.8-2.4	1.49
6000	1.00	1.56	0.93	0.78	1.50	0.78	1.8-2.4	1.50

Notes:

1. First number indicated is for smooth concrete; second number indicated is for rough concrete.
2. Flexible ductwork has a friction loss correction factor of 1.5 to 2.0 times the value read from friction loss tables, ductulators, etc.

Velocities vs. Velocity Pressures

VELOCITY Fpm	VELOCITY PRESSURE In.WG.	VELOCITY Fpm	VELOCITY PRESSURE In.WG.	VELOCITY Fpm	VELOCITY PRESSURE In.WG.
50	0.0002	2,050	0.262	4,050	1.023
100	0.0006	2,100	0.275	4,100	1.048
150	0.001	2,150	0.288	4,150	1.074
200	0.002	2,200	0.302	4,200	1.100
250	0.004	2,250	0.316	4,250	1.126
300	0.006	2,300	0.330	4,300	1.153
350	0.008	2,350	0.344	4,350	1.180
400	0.010	2,400	0.359	4,400	1.207
450	0.013	2,450	0.374	4,450	1.235
500	0.016	2,500	0.390	4,500	1.262
550	0.019	2,550	0.405	4,550	1.291
600	0.022	2,600	0.421	4,600	1.319
650	0.026	2,650	0.438	4,650	1.348
700	0.031	2,700	0.454	4,700	1.377
750	0.035	2,750	0.471	4,750	1.407
800	0.040	2,800	0.489	4,800	1.436
850	0.045	2,850	0.506	4,850	1.466
900	0.050	2,900	0.524	4,900	1.497
950	0.056	2,950	0.543	4,950	1.528
1,000	0.062	3,000	0.561	5,000	1.559
1,050	0.069	3,050	0.580	5,050	1.590
1,100	0.075	3,100	0.599	5,100	1.622
1,150	0.082	3,150	0.619	5,150	1.654
1,200	0.090	3,200	0.638	5,200	1.686
1,250	0.097	3,250	0.659	5,250	1.718
1,300	0.105	3,300	0.679	5,300	1.751
1,350	0.114	3,350	0.700	5,350	1.784
1,400	0.122	3,400	0.721	5,400	1.818
1,450	0.131	3,450	0.742	5,450	1.852
1,500	0.140	3,500	0.764	5,500	1.886
1,550	0.150	3,550	0.786	5,550	1.920
1,600	0.160	3,600	0.808	5,600	1.955
1,650	0.170	3,650	0.831	5,650	1.990
1,700	0.180	3,700	0.853	5,700	2.026
1,750	0.191	3,750	0.877	5,750	2.061
1,800	0.202	3,800	0.900	5,800	2.097
1,850	0.213	3,850	0.924	5,850	2.134
1,900	0.225	3,900	0.948	5,900	2.170
1,950	0.237	3,950	0.973	5,950	2.207
2,000	0.249	4,000	0.998	6,000	2.244

Velocities vs. Velocity Pressures

VELOCITY Fpm	VELOCITY PRESSURE In.WG.	VELOCITY Fpm	VELOCITY PRESSURE In.WG.	VELOCITY Fpm	VELOCITY PRESSURE In.WG.
6,050	2.282	8,050	4.040	10,050	6.297
6,100	2.320	8,100	4.090	10,100	6.360
6,150	2.358	8,150	4.141	10,150	6.423
6,200	2.397	8,200	4.192	10,200	6.486
6,250	2.435	8,250	4.243	10,250	6.550
6,300	2.474	8,300	4.295	10,300	6.614
6,350	2.514	8,350	4.347	10,350	6.678
6,400	2.554	8,400	4.399	10,400	6.743
6,450	2.594	8,450	4.452	10,450	6.808
6,500	2.634	8,500	4.504	10,500	6.873
6,550	2.675	8,550	4.558	10,550	6.939
6,600	2.716	8,600	4.611	10,600	7.005
6,650	2.757	8,650	4.665	10,650	7.071
6,700	2.799	8,700	4.719	10,700	7.138
6,750	2.841	8,750	4.773	10,750	7.205
6,800	2.883	8,800	4.828	10,800	7.272
6,850	2.925	8,850	4.883	10,850	7.339
6,900	2.968	8,900	4.938	10,900	7.407
6,950	3.011	8,950	4.994	10,950	7.475
7,000	3.055	9,000	5.050	11,000	7.544
7,050	3.099	9,050	5.106	11,050	7.612
7,100	3.143	9,100	5.163	11,100	7.681
7,150	3.187	9,150	5.220	11,150	7.751
7,200	3.232	9,200	5.277	11,200	7.820
7,250	3.277	9,250	5.334	11,250	7.890
7,300	3.322	9,300	5.392	11,300	7.961
7,350	3.368	9,350	5.450	11,350	8.031
7,400	3.414	9,400	5.509	11,400	8.102
7,450	3.460	9,450	5.567	11,450	8.173
7,500	3.507	9,500	5.627	11,500	8.245
7,550	3.554	9,550	5.686	11,550	8.317
7,600	3.601	9,600	5.746	11,600	8.389
7,650	3.649	9,650	5.807	11,650	8.461
7,700	3.696	9,700	5.866	11,700	8.534
7,750	3.745	9,750	5.927	11,750	8.607
7,800	3.793	9,800	5.988	11,800	8.681
7,850	3.842	9,850	6.049	11,850	8.755
7,900	3.891	9,900	6.110	11,900	8.829
7,950	3.940	9,950	6.172	11,950	8.903
8,000	3.990	10,000	6.234	12,000	8.978

Sheet Metal Gauges

SHEET METAL GAUGE	THICKNESS INCHES	REMARKS	SHEET METAL GAUGE	THICKNESS INCHES	REMARKS
0	0.3125	WELDED DUCTWORK ONLY	19	0.0437	SMACNA DUCTWORK CONSTRUCTION
1	0.2810		20	0.0375	
2	0.2650		21	0.0343	
3	0.2500		22	0.0312	
4	0.2340		23	0.0280	
5	0.2187		24	0.0250	
6	0.2030		25	0.0218	
7	0.1875		26	0.0187	
8	0.1720		27	0.0170	GAUGES NOT PERMITTED FOR DUCTWORK CONSTRUCTION
9	0.1560		28	0.0156	
10	0.1400		29	0.0140	
11	0.1250		30	0.0125	
12	0.1090		31	0.0109	
13	0.0937		32	0.0100	
14	0.0780		33	0.0093	
15	0.0700		34	0.0085	
16	0.0625	SMACNA DUCTWORK CONSTRUCTION	35	0.0078	
17	0.0560		36	0.0070	
18	0.0500				

Sheet Metal Gauges and Weights

SHEET METAL GAUGE	MATERIAL WEIGHT, Lb./Sq.Ft.		
	GALVANIZED STEEL	300 SERIES STAINLESS STEEL	ALUMINUM
26	0.906	0.748	0.224
24	1.156	0.987	0.282
22	1.406	1.231	0.352
20	1.656	1.491	0.451
18	2.156	2.016	0.563
16	2.656	2.499	0.718
14	3.281	3.154	0.901
12	4.531	4.427	1.141
10	5.781	5.670	1.436

SMACNA HVAC Ductwork Sheet Metal Gauges

MAXIMUM DUCT DIMENSION	SMACNA PRESSURE CLASS						
	±1/2	±1	±2	±3	+4	+6	+10
To 12	26	26	26	24	24	24	24
13 - 18	26	26	26	24	24	24	24
19 - 24	26	26	26	24	24	22	20
25 - 30	26	26	24	22	22	20	18
31 - 36	26	26	22	20	20	18	18
37 - 42	26	24	22	20	18	18	18
43 - 48	26	24	20	18	18	18	18
49 - 54	26	22	18	18	18	18	18
55 - 60	24	22	18	18	18	18	18
61 - 66	22	18	18	18	18	18	18
67 - 72	22	18	18	18	18	18	18
73 - 78	22	18	18	18	18	18	16
79 - 84	22	18	18	18	18	18	16
85 - 90	22	18	18	18	18	18	16
91 - 96	22	18	18	18	18	18	16
97+	18	18	18	18	18	18	16

Notes:

1. Table is based on 5 feet maximum reinforcing spacing.
2. Lighter sheet metal gauges may be used with additional reinforcing and heavier gauges may be used with less reinforcing (See SMACNA manuals).
3. Commercial installations recommend 24 gauge minimum.

Galvanized Rectangular Duct Weight

WIDTH + DEPTH Inches	SHEET METAL GAUGE						SURFACE AREA Sq.Ft./ Lin.Ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
8	1.51	1.93	2.34	2.76	3.59	4.43	1.33
9	1.70	2.17	2.64	3.11	4.04	4.98	1.50
10	1.89	2.41	2.93	3.45	4.49	5.53	1.67
11	2.08	2.65	3.22	3.80	4.94	6.09	1.83
12	2.27	2.89	3.52	4.14	5.39	6.64	2.00
13	2.45	3.13	3.81	4.49	5.84	7.19	2.17
14	2.64	3.37	4.10	4.83	6.29	7.75	2.34
15	2.83	3.61	4.39	5.18	6.74	8.30	2.50
16	3.02	3.85	4.69	5.52	7.19	8.85	2.67
17	3.21	4.09	4.98	5.87	7.64	9.41	2.83
18	3.40	4.34	5.27	6.21	8.09	9.96	3.00
19	3.59	4.58	5.57	6.56	8.53	10.51	3.17
20	3.78	4.82	5.86	6.90	8.98	11.07	3.34
21	3.96	5.06	6.15	7.25	9.43	11.62	3.50
22	4.15	5.30	6.44	7.59	9.88	12.17	3.67
23	4.34	5.54	6.74	7.94	10.33	12.73	3.83
24	4.53	5.78	7.03	8.28	10.78	13.28	4.00
25	4.72	6.02	7.32	8.63	11.23	13.83	4.17
26	4.91	6.26	7.62	8.97	11.68	14.39	4.34
27	-	6.50	7.91	9.32	12.13	14.94	4.50
28	-	6.74	8.20	9.66	12.58	15.49	4.67
29	-	6.98	8.49	10.01	13.03	16.05	4.83
30	-	7.23	8.79	10.35	13.48	16.60	5.00
31	-	7.47	9.08	10.70	13.92	17.15	5.17
32	-	7.71	9.37	11.04	14.37	17.71	5.34
33	-	7.95	9.67	11.39	14.82	18.26	5.50
34	-	8.20	9.96	11.73	15.27	18.81	5.67
35	-	8.43	10.25	12.08	15.72	19.37	5.83
36	-	8.67	10.55	12.42	16.17	19.92	6.00
37	-	8.91	10.84	12.77	16.62	20.47	6.17
38	-	9.15	11.13	13.11	17.07	21.03	6.34
39	-	9.39	11.42	13.46	17.52	21.58	6.50
40	-	9.63	11.72	13.80	17.97	22.13	6.67
41	-	9.87	12.01	14.15	18.42	22.69	6.83
42	-	10.12	12.30	14.49	18.87	23.24	7.00
43	-	10.36	12.60	14.84	19.31	23.79	7.17
44	-	10.60	12.89	15.18	19.76	24.35	7.34
45	-	10.84	13.18	15.53	20.21	24.90	7.50
46	-	11.08	13.47	15.87	20.66	25.45	7.67
47	-	11.32	13.77	16.22	21.11	26.00	7.83

Galvanized Rectangular Duct Weight

WIDTH + DEPTH Inches	SHEET METAL GAUGE						SURFACE AREA Sq.Ft./ Lin.Ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
48	-	11.56	14.06	16.56	21.56	26.56	8.00
49	-	11.80	14.35	16.91	22.01	27.11	8.17
50	-	12.04	14.65	17.25	22.46	27.67	8.34
51	-	12.28	14.94	17.60	22.91	28.22	8.50
52	-	12.52	15.23	17.94	23.36	28.77	8.67
53	-	12.76	15.52	18.29	23.81	29.32	8.83
54	-	13.01	15.82	18.63	24.26	29.88	9.00
55	-	13.25	16.11	18.98	24.70	30.43	9.17
56	-	13.49	16.40	19.32	25.15	30.99	9.34
57	-	13.73	16.70	19.67	25.60	31.54	9.50
58	-	13.97	16.99	20.01	26.05	32.09	9.67
59	-	14.21	17.28	20.36	26.50	32.65	9.83
60	-	14.45	17.58	20.70	26.95	33.20	10.00
61	-	-	17.87	21.05	27.40	33.75	10.17
62	-	-	18.16	21.39	27.85	34.31	10.34
63	-	-	18.45	21.74	28.30	34.86	10.50
64	-	-	18.75	22.08	28.75	35.41	10.67
65	-	-	19.04	22.43	29.20	35.97	10.83
66	-	-	19.33	22.77	29.65	36.52	11.00
67	-	-	19.63	23.12	30.09	37.07	11.17
68	-	-	19.92	23.46	30.54	37.63	11.34
69	-	-	20.21	23.81	30.99	38.18	11.50
70	-	-	20.50	24.15	31.44	38.73	11.67
71	-	-	20.80	24.50	31.89	39.29	11.83
72	-	-	21.09	24.84	32.34	39.84	12.00
73	-	-	21.38	25.19	32.79	40.39	12.17
74	-	-	21.68	25.53	33.24	40.95	12.34
75	-	-	21.97	25.88	33.69	41.50	12.50
76	-	-	22.26	26.22	34.14	42.05	12.67
77	-	-	22.55	26.57	34.59	42.61	12.83
78	-	-	22.85	26.91	35.04	43.16	13.00
79	-	-	23.14	27.26	35.48	43.71	13.17
80	-	-	23.43	27.60	35.93	44.27	13.34
81	-	-	23.73	27.95	36.38	44.82	13.50
82	-	-	24.02	28.29	36.83	45.37	13.67
83	-	-	24.31	28.64	37.28	45.93	13.83
84	-	-	24.61	28.98	37.73	46.48	14.00
85	-	-	24.90	29.33	39.18	47.03	14.17
86	-	-	25.19	29.67	38.63	48.59	14.34
87	-	-	25.48	30.02	39.08	48.14	14.50

Galvanized Rectangular Duct Weight

WIDTH + DEPTH Inches	SHEET METAL GAUGE						SURFACE AREA Sq.Ft./ Lin.Ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
88	-	-	25.78	30.36	39.53	48.69	14.67
89	-	-	26.07	30.71	39.98	49.25	14.83
90	-	-	26.36	31.05	40.43	49.80	15.00
91	-	-	26.66	31.40	40.87	50.35	15.17
92	-	-	26.95	31.74	41.32	50.91	15.34
93	-	-	27.24	32.09	41.77	51.46	15.50
94	-	-	27.53	32.43	42.22	52.01	15.67
95	-	-	27.83	32.78	42.67	52.57	15.83
96	-	-	28.12	33.12	43.12	53.12	16.00
97	-	-	28.41	33.47	43.57	53.67	16.17
98	-	-	28.71	33.81	44.02	54.23	16.34
99	-	-	29.00	34.16	44.47	54.78	16.50
100	-	-	29.29	34.50	44.92	55.33	16.67
101	-	-	29.58	34.85	45.37	55.89	16.83
102	-	-	29.88	35.19	45.82	56.44	17.00
103	-	-	30.17	35.54	46.26	56.99	17.17
104	-	-	30.46	35.88	46.71	57.55	17.34
105	-	-	30.76	36.23	47.16	58.10	17.50
106	-	-	31.05	36.57	47.61	58.65	17.67
107	-	-	31.34	36.92	48.06	59.21	17.83
108	-	-	31.64	37.26	48.51	59.76	18.00
109	-	-	31.93	37.61	48.96	60.31	18.17
110	-	-	32.22	37.95	49.41	60.87	18.34
111	-	-	32.51	38.30	49.86	61.42	18.50
112	-	-	32.81	38.64	50.31	61.97	18.67
113	-	-	33.10	38.99	50.76	62.53	18.83
114	-	-	33.39	39.33	51.21	63.08	19.00
115	-	-	33.69	39.68	51.65	63.63	19.17
116	-	-	33.98	40.02	52.10	64.19	19.34
117	-	-	34.27	40.37	52.55	64.74	19.50
118	-	-	34.56	40.71	53.00	65.29	19.67
119	-	-	34.86	41.06	53.45	65.85	19.83
120	-	-	35.15	41.40	53.90	66.40	20.00
121	-	-	35.44	41.75	54.35	66.95	20.17
122	-	-	35.74	42.09	54.80	67.51	20.34
123	-	-	36.03	42.44	55.25	68.06	20.50
124	-	-	36.32	42.78	55.70	68.61	20.67
125	-	-	36.61	43.13	56.15	69.17	20.83
126	-	-	36.91	43.47	56.60	69.72	21.00
127	-	-	37.20	43.82	57.04	70.27	21.17

Galvanized Rectangular Duct Weight

WIDTH + DEPTH Inches	SHEET METAL GAUGE						SURFACE AREA Sq.Ft./ Lin.Ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
128	-	-	37.49	44.16	57.49	70.83	21.34
129	-	-	37.79	44.51	57.94	71.38	21.50
130	-	-	38.08	44.85	58.39	71.93	21.67
131	-	-	38.37	45.20	58.84	72.49	21.83
132	-	-	38.67	45.54	59.29	73.04	22.00
133	-	-	38.96	45.89	59.74	73.59	22.17
134	-	-	39.25	46.23	60.19	74.15	22.34
135	-	-	39.54	46.58	60.64	74.70	22.50
136	-	-	39.84	46.92	61.09	75.25	22.67
137	-	-	40.13	47.27	61.54	75.81	22.83
138	-	-	40.42	47.61	61.99	76.36	23.00
139	-	-	40.72	47.96	62.43	76.91	23.17
140	-	-	41.01	48.30	62.88	77.46	23.34
141	-	-	41.30	48.65	63.33	78.02	23.50
142	-	-	41.59	48.99	63.78	78.57	23.67
143	-	-	41.88	49.34	64.23	79.13	23.83
144	-	-	42.18	49.68	64.68	79.68	24.00
145	-	-	42.47	50.03	65.13	80.23	24.17
146	-	-	42.77	50.37	65.58	80.79	24.34
147	-	-	43.06	50.72	66.03	81.34	24.50
148	-	-	43.35	51.06	66.48	81.89	24.67
149	-	-	43.64	51.41	66.93	82.45	24.83
150	-	-	43.94	51.75	67.38	83.00	25.00
151	-	-	44.23	52.10	67.82	83.55	25.17
152	-	-	44.52	52.44	68.27	84.11	25.34
153	-	-	44.82	52.79	68.72	84.66	25.50
154	-	-	45.11	53.13	69.17	85.21	25.67
155	-	-	45.40	53.48	69.62	85.77	25.83
156	-	-	45.70	53.82	70.07	86.32	26.00
157	-	-	45.99	54.17	70.52	86.87	26.17
158	-	-	46.28	54.51	70.97	87.43	26.34
159	-	-	46.57	54.86	71.42	87.98	26.50
160	-	-	46.87	55.20	71.87	88.53	26.67
161	-	-	47.16	55.55	72.32	89.09	26.83
162	-	-	47.45	55.89	72.77	89.64	27.00
163	-	-	47.75	56.24	73.21	90.19	27.17
164	-	-	48.04	56.58	73.66	90.75	17.34
165	-	-	48.33	56.93	74.11	91.30	27.50
166	-	-	48.62	57.27	74.56	91.85	27.67
167	-	-	48.92	57.62	75.01	92.41	27.83

Galvanized Rectangular Duct Weight

WIDTH + DEPTH Inches	SHEET METAL GAUGE						SURFACE AREA Sq.Ft./ Lin.Ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
168	-	-	49.21	57.96	75.46	92.96	28.00
169	-	-	49.50	58.31	75.91	93.51	28.17
170	-	-	49.80	58.65	76.36	94.07	28.34
171	-	-	50.09	59.00	76.81	94.62	28.50
172	-	-	50.38	59.34	77.26	95.17	28.67
173	-	-	50.67	59.69	77.71	95.73	28.83
174	-	-	50.97	60.03	78.16	96.28	29.00
175	-	-	51.26	60.38	78.60	96.83	29.17
176	-	-	51.55	60.72	79.05	97.39	29.34
177	-	-	51.85	61.07	79.50	97.94	29.50
178	-	-	52.14	61.41	79.95	98.49	29.67
179	-	-	52.43	61.76	80.40	99.05	29.83
180	-	-	52.73	62.10	80.85	99.60	30.00
181	-	-	53.02	62.45	81.30	100.15	30.17
182	-	-	53.31	62.79	81.75	100.71	30.34
183	-	-	53.60	63.14	82.20	101.26	30.50
184	-	-	53.90	63.48	82.65	101.81	30.67
185	-	-	54.19	63.83	83.10	102.37	30.83
186	-	-	54.48	64.17	83.55	102.92	31.00
187	-	-	54.78	64.52	83.99	103.47	31.17
188	-	-	55.07	64.86	84.44	104.03	31.34
189	-	-	55.36	65.21	84.89	104.58	31.50
190	-	-	55.65	65.55	85.34	105.13	31.67
191	-	-	55.95	65.90	85.79	105.69	31.83
192	-	-	56.24	66.24	86.24	106.24	32.00
193	-	-	56.53	66.59	86.69	106.79	32.17
194	-	-	56.83	66.93	87.14	107.35	32.34
195	-	-	57.12	67.28	87.59	107.90	32.50
196	-	-	57.41	67.62	88.04	108.45	32.67
197	-	-	57.70	67.97	88.49	109.01	32.83
198	-	-	58.00	68.31	88.94	109.56	33.00
199	-	-	58.29	68.66	89.38	110.11	33.17
200	-	-	58.58	69.00	89.83	110.67	33.34
201	-	-	58.88	69.35	90.28	111.22	33.50
202	-	-	59.17	69.69	90.73	111.77	33.67
203	-	-	59.46	70.04	91.18	112.33	33.83
204	-	-	59.76	70.38	91.63	112.88	34.00
205	-	-	60.05	70.73	92.08	113.43	34.17
206	-	-	60.34	71.07	92.53	113.99	34.34
207	-	-	60.63	71.42	92.98	114.54	34.50

Galvanized Rectangular Duct Weight

WIDTH + DEPTH Inches	SHEET METAL GAUGE						SURFACE AREA Sq.Ft./ Lin.Ft.
	26 (12")	24 (24")	22 (48")	20 (60")	18 (60+")	16	
208	-	-	60.93	71.76	93.43	115.09	34.67
209	-	-	61.22	72.11	93.88	115.65	34.83
210	-	-	61.51	72.45	94.33	116.20	35.00
211	-	-	61.81	72.80	94.77	116.75	35.17
212	-	-	62.10	73.14	95.22	117.31	35.34
213	-	-	62.39	73.49	95.67	117.86	35.50
214	-	-	62.68	73.83	96.12	118.41	35.67
215	-	-	62.98	74.18	96.57	118.97	35.83
216	-	-	63.27	74.52	97.02	119.52	36.00
217	-	-	63.56	74.87	97.47	120.07	36.17
218	-	-	63.86	75.21	97.92	120.63	36.34
219	-	-	64.15	75.56	98.37	121.18	36.50
220	-	-	64.44	75.90	98.82	121.73	36.67
221	-	-	64.73	76.25	99.27	122.29	36.83
222	-	-	65.03	76.59	99.72	122.84	37.00
223	-	-	65.32	76.94	100.16	123.39	37.17
224	-	-	65.61	77.28	100.61	123.95	37.34
225	-	-	65.91	77.63	101.06	124.50	37.50
226	-	-	66.20	77.97	101.51	125.05	37.67
227	-	-	66.49	78.32	101.96	125.61	37.83
228	-	-	66.79	78.66	102.41	126.16	38.00
229	-	-	67.08	79.01	102.86	126.71	38.17
230	-	-	67.37	79.35	103.31	127.27	38.34
231	-	-	67.66	79.70	103.76	127.82	38.50
232	-	-	67.96	80.04	104.21	128.37	38.67
233	-	-	68.25	80.39	104.66	128.93	38.83
234	-	-	68.54	80.73	105.11	129.48	39.00
235	-	-	68.84	81.08	105.55	130.03	39.17
236	-	-	69.13	81.42	106.00	130.59	39.34
237	-	-	69.42	81.77	106.45	131.14	39.50
238	-	-	69.71	82.11	106.90	131.69	39.67
239	-	-	70.01	82.46	107.35	132.25	39.83
240	-	-	70.30	82.80	107.80	132.80	40.00

Notes:

1. Table includes 25% allowance for bracing, hangers, reinforcing, joints and seams. Add 10% for insulated ductwork systems.
2. The first column is the sum of the width and depth of the duct (i.e., a 20 × 10 duct equals 30 inches).
3. Columns 2 through 7 give weight of galvanized steel ducts in pounds per lineal foot.
4. Column 8 gives the ductwork surface area used for estimating insulation.
5. Numbers in parenthesis below sheet metal gauges indicate maximum duct dimension for the indicated gauge.

Galvanized Round Duct Weight

DIAMETER	GAUGE						SURFACE AREA Sq.Ft./ Lin.Ft.
	26	24	22	20	18	16	
3	0.89	1.13	1.38	1.63	2.12	2.61	0.79
4	1.19	1.51	1.84	2.17	2.82	3.48	1.05
5	1.48	1.89	2.30	2.71	3.53	4.35	1.31
6	1.78	2.27	2.76	3.25	4.23	5.22	1.57
7	2.08	2.65	3.22	3.79	4.94	6.08	1.83
8	2.37	3.03	3.68	4.34	5.64	6.95	2.09
9	2.67	3.40	4.14	4.88	6.35	7.82	2.36
10	2.96	3.78	4.60	5.42	7.06	8.69	2.62
11	326	4.16	5.06	5.96	7.76	9.56	2.88
12	3.56	4.54	5.52	6.50	8.47	10.43	3.14
14	4.15	5.30	6.44	7.59	9.88	12.17	3.67
16	4.74	6.05	7.36	8.67	11.29	13.91	4.19
18	5.34	6.81	8.28	9.75	12.70	15.65	4.71
20	5.93	7.57	9.20	10.84	14.11	17.38	5.24
22	6.52	8.32	10.12	11.92	15.52	19.12	5.76
24	7.12	9.08	11.04	13.01	16.93	20.86	6.28
26	7.71	9.84	11.96	14.09	18.34	22.60	6.81
28	8.30	10.59	12.88	15.17	19.76	24.34	7.33
30	8.89	11.35	13.80	16.26	21.17	26.08	7.85
32	9.49	12.11	14.72	17.34	22.58	27.81	8.38
34	10.08	12.86	15.64	18.43	23.99	29.55	8.90
36	10.67	13.62	16.56	19.51	25.40	31.29	9.42
38	11.27	14.38	17.48	20.59	26.81	33.03	9.95
40	11.86	15.13	18.40	21.68	28.22	34.77	10.47
42	12.45	15.89	19.32	22.76	29.63	36.51	11.00
44	13.05	16.65	20.24	23.84	31.04	38.24	11.52
46	13.64	17.40	21.17	24.93	32.46	39.98	12.04
48	14.23	18.16	22.09	26.01	33.87	41.72	12.57
50	---	18.92	23.01	27.10	35.28	43.46	13.09
52	---	19.67	23.93	28.18	36.69	45.20	13.61
54	---	20.43	24.85	29.26	38.10	46.94	14.14
56	---	21.18	25.77	30.35	39.51	48.67	14.66
58	---	21.94	26.69	31.43	40.92	50.41	15.18
60	---	22.70	27.61	32.52	42.33	52.15	15.71
62	---	23.45	28.53	33.60	43.74	53.89	16.23
64	---	24.21	29.45	34.68	45.16	55.63	16.76
66	---	24.97	30.37	35.77	46.57	57.37	17.28
68	---	25.72	31.29	36.85	47.98	59.10	17.80
70	---	26.48	32.21	37.93	49.39	60.84	18.33
72	---	27.24	33.13	39.02	50.80	62.58	18.85

Galvanized Round Duct Weight

DIAMETER	GAUGE						SURFACE AREA Sq.Ft./ Lin.Ft.
	26	24	22	20	18	16	
74	---	27.99	34.05	40.10	52.21	64.32	19.37
76	---	28.75	34.97	41.19	53.62	66.06	19.90
78	---	29.51	35.89	42.27	55.03	67.80	20.42
80	---	30.26	36.81	43.35	56.44	69.53	20.94
82	---	31.02	37.73	44.44	57.86	71.27	21.47
84	---	31.78	38.65	45.52	59.27	73.01	21.99
86	---	32.53	39.57	46.61	60.68	74.75	22.51
88	---	33.29	40.49	47.69	62.09	76.49	23.04
90	---	34.05	41.41	48.77	63.50	78.23	23.56
92	---	34.80	42.33	49.86	64.91	79.96	24.09
94	---	35.56	43.25	50.94	66.32	81.70	24.61
96	---	36.32	44.17	52.02	66.73	83.44	25.13
98	---	37.07	45.09	53.11	69.14	85.18	25.66
100	---	37.83	46.01	54.19	70.55	86.92	26.18
102	---	38.59	46.93	55.28	71.97	88.66	26.70
104	---	39.34	47.85	56.36	73.38	90.39	27.23
106	---	40.10	48.77	57.44	74.79	92.13	27.75
108	---	40.86	49.69	58.53	76.20	93.87	28.27
110	---	41.61	50.61	59.61	77.61	95.61	28.80
112	---	42.37	51.53	60.70	79.02	97.35	29.32
114	---	43.13	52.45	61.78	80.43	99.09	29.85
116	---	43.88	53.37	62.86	81.84	100.82	30.37
118	---	44.64	54.29	63.95	83.25	102.56	30.89
120	---	45.40	55.21	65.03	84.67	104.30	31.42
122	---	46.15	56.13	66.11	86.08	106.04	31.94
124	---	46.91	57.05	67.20	8749	107.78	32.46
126	---	47.67	57.97	68.28	88.90	109.52	32.99
128	---	48.42	58.89	69.37	90.31	111.25	33.51
130	---	49.18	59.81	70.45	91.72	112.99	34.03
132	---	49.94	60.73	71.53	93.13	114.73	34.56
134	---	50.69	61.66	72.62	94.54	116.47	35.08
136	---	51.45	62.58	73.70	95.95	118.21	35.60
138	---	52.21	63.50	74.79	97.37	119.95	36.12
140	---	52.96	64.42	75.87	98.78	121.68	36.65
142	---	53.72	65.34	76.95	100.19	123.42	37.18
144	---	54.48	66.26	78.04	101.60	125.16	37.70

Notes:

1. Table includes 25% allowance for bracing, hangers, reinforcing, joints, and seams. Add 10% for insulated ductwork systems.
2. Table gives weight of galvanized steel ducts in pounds per lineal foot.

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
3 x 8	5.1	0.15	1.57	24	2.3
3 x 9	5.6	0.18	1.83	24	2.6
3 x 11	6.0	0.22	2.09	24	3.1
3 x 12	6.4	0.25	2.36	24	3.4
3 x 14	6.7	0.29	2.62	24	3.8
3 x 15	7.0	0.32	2.88	24	4.2
3 x 17	7.3	0.36	3.14	24	4.5
3 x 19	7.5	0.39	3.40	24	4.9
3 x 22	8.0	0.46	3.93	24	5.7
4 x 7	5.7	0.18	1.57	24	2.3
4 x 9	6.2	0.22	1.83	24	2.6
4 x 10	6.7	0.26	2.09	24	3.1
4 x 12	7.2	0.31	2.36	24	3.4
4 x 13	7.6	0.35	2.62	24	3.8
4 x 15	8.0	0.40	2.88	24	4.2
4 x 17	8.4	0.44	3.14	24	4.5
4 x 18	8.5	0.48	3.40	24	4.9
4 x 20	9.0	0.52	3.68	24	5.3
4 x 21	9.5	0.57	3.93	24	5.7
5 x 8	6.6	0.25	1.83	24	2.6
5 x 10	7.3	0.30	2.09	24	3.0
5 x 11	7.9	0.35	2.36	24	3.4
5 x 13	8.4	0.41	2.62	24	3.8
5 x 14	8.8	0.46	2.88	24	4.2
5 x 16	9.3	0.52	3.14	24	4.5
5 x 18	9.5	0.57	3.40	24	4.9
5 x 19	10.0	0.63	3.66	24	5.3
5 x 21	10.5	0.68	3.93	24	5.7
6 x 8	6.9	0.26	1.83	24	2.6
6 x 9	7.7	0.33	2.09	24	3.0
6 x 11	8.4	0.39	2.36	24	3.4
6 x 12	8.9	0.46	2.62	24	3.8
6 x 14	9.6	0.53	2.88	24	4.2
6 x 15	10.1	0.59	3.14	24	4.5
6 x 17	10.5	0.65	3.40	24	4.9
6 x 19	11.0	0.72	3.66	24	5.3
6 x 20	11.5	0.79	3.93	24	5.7

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
6 x 22	11.8	0.85	4.18	24	6.0
6 x 23	12.0	0.92	4.45	24	6.4
6 x 25	12.5	0.98	4.71	22	8.3
6 x 28	13.2	1.11	5.23	22	9.2
6 x 30	13.5	1.18	5.50	22	9.7
6 x 31	13.8	1.24	5.76	22	10.1
6 x 33	14.0	1.31	6.02	22	10.6
6 x 34	14.3	1.38	6.28	22	11.0
6 x 36	14.5	1.44	6.54	22	11.5
6 x 37	14.9	1.50	6.80	22	12.0
6 x 39	15.0	1.57	7.07	22	12.4
6 x 41	15.4	1.64	7.33	22	12.9
6 x 44	15.9	1.77	7.85	22	13.8
6 x 45	16.0	1.83	8.12	22	14.3
6 x 52	17.0	2.09	9.16	20	19.0
6 x 59	18.0	2.42	10.47	20	21.7
7 x 10	8.7	0.42	2.36	24	3.4
7 x 12	9.4	0.50	2.62	24	3.8
7 x 13	10.1	0.57	2.88	24	4.2
7 x 15	10.7	0.65	3.14	24	4.5
7 x 16	11.0	0.73	3.40	24	4.9
7 x 18	11.7	0.80	3.67	24	5.3
7 x 20	12.0	0.88	3.93	24	5.7
7 x 21	12.5	0.95	4.19	24	6.1
7 x 23	13.0	1.03	4.45	24	6.4
8 x 10	9.0	0.44	2.36	24	3.4
8 x 11	9.8	0.53	2.62	24	3.8
8 x 13	10.6	0.62	2.88	24	4.2
8 x 14	11.2	0.70	3.14	24	4.5
8 x 16	11.5	0.79	3.40	24	4.9
8 x 17	12.0	0.87	3.67	24	5.3
8 x 18	12.4	0.90	3.80	24	5.5
8 x 19	13.0	0.96	3.93	24	5.7
8 x 21	13.5	1.05	4.18	24	6.1
8 x 22	14.0	1.13	4.45	24	6.4
8 x 24	14.4	1.23	4.71	24	6.8
8 x 27	15.2	1.40	5.23	22	9.2
8 x 30	15.9	1.57	5.76	22	10.2
8 x 33	16.6	1.74	6.28	22	11.0
8 x 35	17.0	1.83	6.54	22	11.5

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
8 x 36	17.3	1.92	6.80	22	12.0
8 x 39	17.9	2.09	7.33	22	12.9
8 x 43	18.6	2.27	7.85	22	13.8
8 x 46	19.1	2.44	8.37	22	14.7
8 x 49	19.6	2.62	8.89	20	18.4
8 x 50	20.0	2.71	9.16	20	19.0
8 x 52	20.2	2.80	9.42	20	19.5
8 x 58	21.0	3.14	10.47	20	21.7
8 x 65	22.0	3.49	11.52	20	23.8
8 x 71	23.0	3.84	12.57	18	33.9
8 x 77	24.0	4.19	13.61	18	36.7
9 x 12	10.8	0.64	2.88	24	4.2
9 x 14	11.5	0.74	3.14	24	4.6
9 x 15	12.0	0.83	3.40	24	4.9
9 x 17	12.9	0.93	3.67	24	5.3
9 x 18	13.5	1.03	3.93	24	5.7
9 x 20	14.0	1.13	4.19	24	6.1
9 x 22	14.5	1.23	4.45	24	6.4
9 x 23	15.0	1.33	4.71	24	6.8
10 x 12	11.0	0.66	2.88	24	4.2
10 x 13	11.9	0.77	3.14	24	4.5
10 x 15	12.5	0.87	3.40	24	4.9
10 x 16	13.4	1.00	3.66	24	5.3
10 x 18	14.0	1.09	3.93	24	5.7
10 x 19	14.5	1.20	4.19	24	6.1
10 x 20	14.7	1.25	4.18	24	6.1
10 x 21	15.0	1.31	4.45	24	6.4
10 x 23	15.7	1.42	4.71	24	6.8
10 x 24	16.0	1.53	4.97	24	7.2
10 x 26	16.7	1.63	5.23	22	9.2
10 x 27	17.0	1.75	5.50	22	9.7
10 x 29	17.7	1.86	5.76	22	10.2
10 x 30	18.0	1.96	6.02	22	10.6
10 x 32	18.5	2.07	6.28	22	11.1
10 x 34	19.0	2.18	6.54	22	11.5
10 x 35	19.3	2.29	6.80	22	12.0
10 x 38	20.1	2.51	7.33	22	12.9
10 x 41	20.8	2.73	7.85	22	13.8
10 x 43	21.0	2.84	8.12	22	14.3
10 x 45	21.5	2.95	8.37	22	14.7

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
10 x 48	22.1	3.16	8.89	22	15.6
10 x 51	22.8	3.39	9.42	20	19.5
10 x 52	23.0	3.49	9.69	20	20.1
10 x 54	23.3	3.60	9.95	20	20.6
10 x 57	23.8	3.82	10.56	20	21.9
10 x 60	24.4	4.04	11.00	20	22.8
10 x 63	25.0	4.25	11.52	20	23.8
10 x 67	25.5	4.47	12.05	20	24.9
10 x 70	26.0	4.69	12.51	20	25.9
10 x 73	26.4	4.91	13.10	18	35.3
10 x 76	27.0	5.13	13.61	18	36.7
11 x 14	13.0	0.90	3.40	24	4.9
11 x 16	13.6	1.02	3.67	24	5.3
11 x 17	14.0	1.14	3.93	24	5.7
11 x 19	15.0	1.26	4.19	24	6.1
11 x 22	16.3	1.50	4.71	24	6.8
11 x 24	17.0	1.62	4.97	24	7.2
12 x 14	13.0	0.92	3.40	24	4.9
12 x 15	13.8	1.05	3.67	24	5.3
12 x 17	14.5	1.18	3.93	24	5.7
12 x 18	15.3	1.31	4.19	24	6.1
12 x 20	16.0	1.44	4.45	24	6.4
12 x 21	16.7	1.57	4.71	24	6.8
12 x 25	18.0	1.83	5.24	22	9.2
12 x 28	19.1	2.09	5.76	22	10.1
12 x 31	20.1	2.36	6.28	22	11.1
12 x 34	20.9	2.62	6.81	22	12.0
12 x 37	21.9	2.88	7.33	22	12.9
12 x 40	22.7	3.14	7.85	22	13.8
12 x 42	23.0	3.27	8.12	22	14.3
12 x 43	23.5	3.40	8.37	22	14.7
12 x 45	24.0	3.53	8.64	22	15.2
12 x 47	24.3	3.67	8.89	22	15.6
12 x 50	25.0	3.93	9.42	20	19.5
12 x 53	25.7	4.19	9.95	20	20.6
12 x 56	26.3	4.45	10.56	20	21.9
12 x 59	26.9	4.71	11.00	20	22.8
12 x 62	27.5	4.98	11.52	20	23.8

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
12 x 65	28.1	5.23	12.05	20	24.9
12 x 69	28.7	5.51	12.57	20	26.0
12 x 72	29.2	5.76	13.10	18	35.3
12 x 78	30.0	6.28	14.14	18	38.1
12 x 81	31.0	6.54	14.66	18	39.5
14 x 17	16.0	1.37	4.19	24	6.1
14 x 19	17.0	1.53	4.45	24	6.4
14 x 20	17.5	1.68	4.71	24	6.8
14 x 22	18.0	1.83	4.97	24	7.2
14 x 23	18.9	1.98	5.23	24	7.6
14 x 27	20.2	2.30	5.76	22	10.1
14 x 28	21.0	2.44	6.02	22	10.6
14 x 30	21.3	2.60	6.28	22	11.0
14 x 31	22.0	2.75	6.54	22	11.5
14 x 33	22.4	2.91	6.80	22	12.0
14 x 34	23.0	3.05	7.07	22	12.4
14 x 36	23.4	3.21	7.33	22	12.9
14 x 38	24.0	3.36	7.59	22	13.3
14 x 39	24.4	3.51	7.85	22	13.8
14 x 41	25.0	3.67	8.12	22	14.3
14 x 42	25.3	3.84	8.37	22	14.7
14 x 45	26.1	4.12	8.89	22	15.6
14 x 49	26.9	4.43	9.42	20	19.5
14 x 52	27.7	4.74	9.95	20	20.6
14 x 55	28.4	5.04	10.56	20	21.9
14 x 58	29.1	5.35	11.00	20	22.8
14 x 61	29.8	5.65	11.52	20	23.9
14 x 64	30.5	5.96	12.05	20	24.9
14 x 67	31.1	6.27	12.57	20	26.0
14 x 71	31.7	6.57	13.10	18	35.9
14 x 77	33.0	7.18	14.14	18	38.1
16 x 19	18.0	1.75	4.71	24	6.8
16 x 21	19.0	1.92	4.97	24	7.2
16 x 22	19.5	2.08	5.23	24	7.6
16 x 24	20.0	2.27	5.50	24	7.9
16 x 25	20.9	2.44	5.76	22	10.2
16 x 29	22.3	2.79	6.28	22	11.0
16 x 30	23.0	2.97	6.54	22	11.5
16 x 32	23.5	3.13	6.80	22	12.0
16 x 33	24.0	3.32	7.07	22	12.4

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
16 x 35	24.7	3.48	7.33	22	12.9
16 x 36	25.0	3.67	7.59	22	13.3
16 x 38	25.7	3.84	7.85	22	13.8
16 x 41	26.8	4.19	8.38	22	14.7
16 x 44	27.7	4.53	8.89	22	15.6
16 x 46	28.0	4.71	9.16	22	16.1
16 x 47	28.6	4.88	9.42	22	16.6
16 x 49	29.0	5.06	9.69	20	20.1
16 x 51	29.4	5.23	9.95	20	20.6
16 x 54	30.2	5.59	10.47	20	21.7
16 x 57	31.0	5.93	11.00	20	22.8
16 x 60	31.8	6.28	11.52	20	23.8
16 x 63	32.5	6.61	12.05	20	24.9
16 x 66	33.3	6.98	12.57	20	26.0
16 x 69	34.0	7.33	13.09	20	27.1
16 x 76	35.0	8.03	14.14	18	38.1
16 x 79	36.0	8.38	14.66	18	39.5
18 x 21	19.9	2.16	5.23	24	7.6
18 x 23	21.0	2.36	5.50	24	7.9
18 x 24	21.6	2.56	5.76	24	8.3
18 x 26	22.0	2.75	6.02	22	10.6
18 x 27	23.1	2.95	6.28	22	11.0
18 x 29	24.0	3.14	6.54	22	11.5
18 x 31	24.5	3.35	6.80	22	12.0
18 x 32	25.0	3.53	7.07	22	12.4
18 x 34	25.7	3.73	7.33	22	12.9
18 x 37	27.0	4.13	7.85	22	13.8
18 x 40	28.1	4.53	8.37	22	14.7
18 x 43	29.1	4.92	8.89	22	15.6
18 x 46	30.2	5.31	9.42	22	16.6
18 x 49	31.1	5.70	9.95	20	20.6
18 x 53	32.0	6.10	10.56	20	21.9
18 x 56	32.9	6.49	11.00	20	22.8
18 x 59	33.7	6.88	11.52	20	23.8
18 x 62	34.5	7.26	12.05	20	24.9
18 x 65	35.3	7.67	12.51	20	25.9
18 x 68	36.0	8.07	13.10	20	27.1
18 x 71	37.0	8.44	13.61	18	36.7
18 x 78	38.0	9.23	14.66	18	39.5

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
20 x 26	23.6	3.05	6.28	22	11.0
20 x 29	25.2	3.49	6.81	22	12.0
20 x 31	26.0	3.71	7.07	22	12.4
20 x 33	26.6	3.93	7.33	22	12.9
20 x 34	27.0	4.15	7.59	22	13.3
20 x 36	28.0	4.36	7.85	22	13.8
20 x 39	29.2	4.81	8.37	22	14.7
20 x 40	30.0	5.02	8.64	22	15.2
20 x 42	30.3	5.23	8.89	22	15.6
20 x 44	31.0	5.45	9.16	22	16.1
20 x 45	31.4	5.67	9.42	22	16.6
20 x 47	32.0	5.89	9.69	22	17.0
20 x 48	32.5	6.11	9.95	22	17.5
20 x 51	33.4	6.55	10.56	20	21.9
20 x 55	34.4	6.98	11.00	20	22.8
20 x 58	35.3	7.41	11.52	20	23.8
20 x 61	36.2	7.86	12.05	20	24.9
20 x 64	37.1	8.29	12.57	20	26.0
20 x 67	37.9	8.71	13.10	20	27.1
20 x 77	40.0	10.04	14.66	18	39.5
22 x 25	23.9	3.12	6.28	22	11.0
22 x 28	25.6	3.60	6.81	22	12.0
22 x 31	27.2	4.08	7.33	22	12.9
22 x 35	28.7	4.56	7.85	22	13.8
22 x 38	30.0	5.04	8.38	22	14.7
22 x 39	31.0	5.28	8.64	22	15.2
22 x 41	31.3	5.52	8.90	22	15.6
22 x 42	32.0	5.76	9.16	22	16.1
22 x 44	32.5	6.00	9.42	22	16.6
22 x 46	33.0	6.24	9.69	22	17.0
22 x 47	33.7	6.48	9.95	22	17.5
22 x 50	34.8	6.96	10.47	20	21.7
22 x 53	35.8	7.44	11.00	20	22.8
22 x 57	36.7	7.92	11.52	20	23.8
22 x 60	37.8	8.40	12.04	20	24.9
22 x 63	38.7	8.88	12.57	20	26.0
22 x 66	39.6	9.36	13.09	20	27.1
22 x 69	40.4	9.84	13.61	20	28.2
22 x 75	42.0	10.80	14.66	18	39.5
22 x 82	44.0	11.76	15.71	18	42.3

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
24 x 27	25.9	3.66	6.81	22	12.0
24 x 30	28.1	4.19	7.33	22	12.9
24 x 33	29.3	4.71	7.85	22	13.8
24 x 37	30.8	5.23	8.38	22	14.7
24 x 40	32.2	5.76	8.90	22	15.6
24 x 41	33.0	6.02	9.16	22	16.1
24 x 43	33.5	6.28	9.42	22	16.6
24 x 44	34.0	6.54	9.69	22	17.1
24 x 46	34.7	6.80	9.95	22	17.5
24 x 49	35.9	7.33	10.47	20	21.7
24 x 52	37.0	7.85	11.00	20	22.8
24 x 55	38.1	8.38	11.52	20	23.8
24 x 59	39.2	8.90	12.04	20	24.9
24 x 62	40.1	9.42	12.57	20	26.0
24 x 65	41.1	9.95	13.09	20	27.1
24 x 68	42.0	10.47	13.61	20	28.2
24 x 74	44.0	11.52	14.66	18	39.5
26 x 29	27.9	4.25	7.33	22	12.9
26 x 32	29.7	4.82	7.85	22	13.8
26 x 35	31.3	5.39	8.38	22	14.7
26 x 39	32.8	5.96	8.90	22	15.6
26 x 42	34.3	6.52	9.42	22	16.6
26 x 45	35.6	7.09	9.95	22	17.5
26 x 48	36.9	7.66	10.47	22	18.4
26 x 51	38.1	8.22	11.00	20	22.8
26 x 54	39.3	8.79	11.52	20	23.8
26 x 57	40.4	9.36	12.04	20	24.9
26 x 61	41.5	9.93	12.57	20	26.0
26 x 64	42.5	10.49	13.09	20	27.1
26 x 67	43.5	11.06	13.61	20	28.2
26 x 70	44.4	11.63	14.14	20	29.3
28 x 31	29.9	4.88	7.85	22	13.8
28 x 34	31.7	5.50	8.38	22	14.7
28 x 37	33.4	6.11	8.90	22	15.6
28 x 41	34.9	6.72	9.42	22	16.6
28 x 44	36.4	7.33	9.95	22	17.5
28 x 47	37.8	7.94	10.47	22	18.4
28 x 50	39.1	8.55	11.00	20	22.8
28 x 53	40.3	9.16	11.52	20	23.8
28 x 56	41.5	9.77	12.04	20	24.9

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
28 x 59	42.6	10.38	12.57	20	26.0
28 x 63	43.8	10.99	13.09	20	27.1
28 x 66	44.8	11.60	13.61	20	28.2
28 x 69	45.8	12.22	14.14	20	29.3
30 x 33	32.0	5.56	8.38	22	14.7
30 x 36	33.7	6.22	8.90	22	15.6
30 x 39	35.4	6.87	9.42	22	16.6
30 x 43	37.0	7.53	9.95	22	17.5
30 x 46	38.5	8.18	10.47	22	18.4
30 x 49	39.9	8.84	11.00	20	22.8
30 x 52	41.2	9.49	11.52	20	23.8
30 x 55	42.5	10.15	12.06	20	25.0
30 x 58	43.7	10.80	12.57	20	26.0
30 x 61	44.9	11.46	13.09	20	27.1
30 x 64	46.0	12.11	13.61	20	28.2
30 x 68	47.1	12.77	14.14	20	29.3
30 x 71	48.2	13.42	14.66	18	39.5
32 x 35	34.0	6.28	8.90	22	15.6
32 x 38	35.8	6.98	9.42	22	16.6
32 x 41	37.4	7.68	9.95	22	17.5
32 x 45	39.0	8.38	10.47	22	18.4
32 x 48	40.5	9.08	11.00	22	15.3
32 x 51	42.0	9.77	11.52	20	23.8
32 x 54	43.3	10.47	12.04	20	24.9
32 x 57	44.6	11.17	12.57	20	26.0
32 x 60	45.9	11.87	13.09	20	27.1
32 x 63	47.1	12.57	13.61	20	28.2
32 x 67	48.3	13.26	14.14	20	29.3
32 x 70	49.4	13.96	14.66	20	30.3
34 x 37	36.0	7.05	9.42	22	16.6
34 x 40	37.8	7.79	9.95	22	17.5
34 x 43	39.5	8.52	10.47	22	18.4
34 x 47	41.1	9.27	11.00	22	19.3
34 x 50	42.6	10.01	11.52	20	23.8
34 x 53	44.1	10.75	12.04	20	24.9
34 x 56	45.5	11.50	12.57	20	26.0
34 x 59	46.8	12.24	13.09	20	27.1
34 x 62	48.1	12.98	13.61	20	28.2

Galvanized Flat Oval Ductwork Weight

NOMINAL FLAT OVAL SIZE	EQUIV. ROUND	CROSS SECTIONAL AREA SQ.FT.	SURFACE AREA SQ.FT./ LN.FT.	GAUGE	WEIGHT LBS./ LN.FT.
34 x 65	49.3	13.72	14.14	20	29.3
34 x 69	50.5	14.46	14.66	20	30.3
34 x 72	51.6	15.20	15.18	18	31.4
36 x 39	38.0	7.85	9.95	22	17.5
36 x 42	39.8	8.64	10.47	22	18.4
36 x 45	41.5	9.42	11.00	22	19.4
36 x 49	43.1	10.21	11.52	20	23.8
36 x 52	44.7	11.00	12.04	20	24.9
36 x 55	46.2	11.78	12.57	20	26.0
36 x 58	47.6	12.57	13.09	20	27.1
36 x 61	48.9	13.35	13.61	20	28.2
36 x 64	50.2	14.14	14.14	20	29.3
36 x 67	51.1	14.92	14.66	20	30.3
36 x 71	52.7	15.71	15.18	18	40.9
38 x 41	40.0	8.70	10.47	22	18.4
38 x 44	41.8	9.53	11.00	22	19.3
38 x 47	43.5	10.36	11.52	22	20.3
38 x 51	45.2	11.19	12.04	20	24.9
38 x 54	46.7	12.02	12.57	20	26.0
38 x 57	48.2	12.85	13.09	20	27.1
38 x 60	49.7	13.68	13.61	20	28.2
38 x 63	51.0	14.51	14.14	20	29.3
38 x 66	52.4	15.34	14.66	20	30.3
38 x 69	53.7	16.16	15.18	20	31.4
40 x 43	42.0	9.60	11.00	22	19.3
40 x 46	43.8	10.47	11.52	22	20.3
40 x 49	45.6	11.34	12.04	20	24.9
40 x 53	47.2	12.21	12.57	20	26.0
40 x 56	48.8	13.09	13.09	20	27.1
40 x 59	50.4	13.96	13.61	20	28.2
40 x 62	51.8	14.83	14.14	20	29.3
40 x 65	53.2	15.71	14.66	20	30.3
40 x 68	54.5	16.58	15.18	20	31.4
40 x 71	55.8	17.45	15.71	18	42.3

Notes:

1. Equivalent round is the diameter of the round duct which will have the capacity and friction equivalent to the flat oval duct size.
2. To obtain the rectangular duct size, use the Trane Ductulator and equivalent round duct size.
3. Table includes 25% allowance for bracing, hangers, reinforcing, joints, and seams. Add 10% for insulated ductwork systems.
4. Table lists standard sizes as manufactured by United Sheet Metal, a Division of United McGill Corporation.

Equivalent Rectangular Duct Dimensions

DUCT DIA. IN.	RECT. SIZE IN.	ASPECT RATIO							
		1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
6	WIDTH	---	6						
	HEIGHT	---	5						
7	WIDTH	6	8						
	HEIGHT	6	6						
8	WIDTH	7	9	9	11				
	HEIGHT	7	7	6	6				
9	WIDTH	8	9	11	11	12	14		
	HEIGHT	8	7	7	6	6	6		
10	WIDTH	9	10	12	12	14	14	15	17
	HEIGHT	9	8	8	7	7	6	6	6
11	WIDTH	10	11	12	14	14	16	18	17
	HEIGHT	10	9	8	8	7	7	7	6
12	WIDTH	11	13	14	14	16	16	18	19
	HEIGHT	11	10	9	8	8	7	7	7
13	WIDTH	12	14	15	16	18	18	20	19
	HEIGHT	12	11	10	9	9	8	8	7
14	WIDTH	13	14	17	18	18	20	20	22
	HEIGHT	13	11	11	10	9	9	8	8
15	WIDTH	14	15	17	18	20	20	23	25
	HEIGHT	14	12	11	10	10	9	9	9
16	WIDTH	15	16	18	19	20	23	23	25
	HEIGHT	15	13	12	11	10	10	9	9
17	WIDTH	16	18	20	21	22	25	25	28
	HEIGHT	16	14	13	12	11	11	10	10
18	WIDTH	16	19	21	23	24	25	28	28
	HEIGHT	16	15	14	13	12	11	11	10
19	WIDTH	17	20	21	23	24	27	28	30
	HEIGHT	17	16	14	13	12	12	11	11
20	WIDTH	18	20	23	25	26	27	30	30
	HEIGHT	18	16	15	14	13	12	12	11
21	WIDTH	19	21	24	26	28	29	30	33
	HEIGHT	19	17	16	15	14	13	12	12
22	WIDTH	20	23	26	26	28	32	33	36
	HEIGHT	20	18	17	15	14	14	13	13
23	WIDTH	21	24	26	28	30	32	35	36
	HEIGHT	21	19	17	16	15	14	14	13
24	WIDTH	22	25	27	30	32	34	35	39
	HEIGHT	22	20	18	17	16	15	14	14
25	WIDTH	23	25	29	30	32	36	38	39
	HEIGHT	23	20	19	17	16	16	15	14
26	WIDTH	24	26	30	32	34	36	38	41
	HEIGHT	24	21	20	18	17	16	15	15
27	WIDTH	25	28	30	33	36	38	40	41
	HEIGHT	25	22	20	19	18	17	16	15

Equivalent Rectangular Duct Dimensions

DUCT DIA. IN.	RECT. SIZE IN.	ASPECT RATIO							
		1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
28	WIDTH	26	29	32	35	36	38	43	44
	HEIGHT	26	23	21	20	18	17	17	16
29	WIDTH	27	30	33	35	38	41	43	44
	HEIGHT	27	24	22	20	19	18	17	16
30	WIDTH	27	31	35	37	40	43	45	47
	HEIGHT	27	25	23	21	20	19	18	17
31	WIDTH	28	31	35	39	40	43	45	50
	HEIGHT	28	25	23	22	20	19	18	18
32	WIDTH	29	33	36	39	42	45	48	50
	HEIGHT	29	26	24	22	21	20	19	18
33	WIDTH	30	34	38	40	44	47	50	52
	HEIGHT	30	27	25	23	22	21	20	19
34	WIDTH	31	35	39	42	44	47	50	52
	HEIGHT	31	28	26	24	22	21	20	19
35	WIDTH	32	36	39	42	46	50	53	55
	HEIGHT	32	29	26	24	23	22	21	20
36	WIDTH	33	36	41	44	48	50	53	55
	HEIGHT	33	29	27	25	24	22	21	20
38	WIDTH	35	39	44	47	50	54	58	61
	HEIGHT	35	31	29	27	25	24	23	22
40	WIDTH	37	41	45	49	52	56	60	63
	HEIGHT	37	33	30	28	26	25	24	23
42	WIDTH	38	43	48	51	56	59	63	66
	HEIGHT	38	34	32	29	28	26	25	24
44	WIDTH	40	45	50	54	58	61	65	69
	HEIGHT	40	36	33	31	29	27	26	25
46	WIDTH	42	48	53	56	60	65	68	72
	HEIGHT	42	38	35	32	30	29	27	26
48	WIDTH	44	49	54	60	62	68	70	74
	HEIGHT	44	39	36	34	31	30	28	27
50	WIDTH	46	51	57	61	66	70	75	77
	HEIGHT	46	41	38	35	33	31	30	28
52	WIDTH	48	54	59	63	68	72	78	83
	HEIGHT	48	43	39	36	34	32	31	30
54	WIDTH	49	55	62	67	70	77	80	85
	HEIGHT	49	44	41	38	35	34	32	31
56	WIDTH	51	58	63	68	74	79	83	88
	HEIGHT	51	46	42	39	37	35	33	32
58	WIDTH	53	60	66	70	76	81	85	91
	HEIGHT	53	48	44	40	38	36	34	33
60	WIDTH	55	61	68	74	78	83	90	94
	HEIGHT	55	49	45	42	39	37	36	34
62	WIDTH	57	64	71	75	82	88	93	96
	HEIGHT	57	51	47	43	41	39	37	35

Equivalent Rectangular Duct Dimensions

DUCT DIA. IN.	RECT. SIZE IN.	ASPECT RATIO 1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
64	WIDTH	59	65	72	79	84	90	95	99
	HEIGHT	59	52	48	45	42	40	38	36
66	WIDTH	60	68	75	81	86	92	98	105
	HEIGHT	60	54	50	46	43	41	39	38
68	WIDTH	62	70	77	82	90	95	100	107
	HEIGHT	62	56	51	47	45	42	40	39
70	WIDTH	64	71	80	86	92	99	105	110
	HEIGHT	64	57	53	49	46	44	42	40
72	WIDTH	66	74	81	88	94	101	108	113
	HEIGHT	66	59	54	50	47	45	43	41
74	WIDTH	68	76	84	91	98	104	110	116
	HEIGHT	68	61	56	52	49	46	44	42
76	WIDTH	70	78	86	93	100	106	113	118
	HEIGHT	70	62	57	53	50	47	45	43
78	WIDTH	71	80	89	95	102	110	115	121
	HEIGHT	71	64	59	54	51	49	46	44
80	WIDTH	73	83	90	98	104	113	118	124
	HEIGHT	73	66	60	56	52	50	47	45
82	WIDTH	75	84	93	100	108	115	123	129
	HEIGHT	75	67	62	57	54	51	49	47
84	WIDTH	77	86	95	103	110	117	125	132
	HEIGHT	77	69	63	59	55	52	50	48
86	WIDTH	79	88	98	105	112	119	128	135
	HEIGHT	79	70	65	60	56	53	51	49
88	WIDTH	80	90	99	107	116	124	130	138
	HEIGHT	80	72	66	61	58	55	52	50
90	WIDTH	82	93	102	110	118	126	133	140
	HEIGHT	82	74	68	63	59	56	53	51
92	WIDTH	84	94	104	112	120	128	138	143
	HEIGHT	84	75	69	64	60	57	55	52
94	WIDTH	86	96	107	116	124	131	140	146
	HEIGHT	86	77	71	66	62	58	56	53
96	WIDTH	88	99	108	117	126	135	143	151
	HEIGHT	88	79	72	67	63	60	57	55
98	WIDTH	90	100	111	119	128	137	145	154
	HEIGHT	90	80	74	68	64	61	58	56
100	WIDTH	91	103	113	123	132	140	148	157
	HEIGHT	91	82	75	70	66	62	59	57
102	WIDTH	93	105	116	124	134	142	153	160
	HEIGHT	93	84	77	71	67	63	61	58
104	WIDTH	95	106	117	128	136	146	155	162
	HEIGHT	95	85	78	73	68	65	62	59

Equivalent Rectangular Duct Dimensions

DUCT DIA. IN.	RECT. SIZE IN.	ASPECT RATIO						
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
6	WIDTH HEIGHT							
7	WIDTH HEIGHT							
8	WIDTH HEIGHT							
9	WIDTH HEIGHT							
10	WIDTH HEIGHT							
11	WIDTH HEIGHT	18 6	21 6					
12	WIDTH HEIGHT	21 7	21 6	24 6				
13	WIDTH HEIGHT	21 7	25 7	24 6	30 6			
14	WIDTH HEIGHT	24 8	25 7	28 7	30 6	36 6		
15	WIDTH HEIGHT	24 8	28 8	28 7	35 7	36 6	42 6	
16	WIDTH HEIGHT	27 9	28 8	32 8	35 7	42 7	42 6	48 6
17	WIDTH HEIGHT	27 9	32 9	32 8	35 7	42 7	49 7	48 6
18	WIDTH HEIGHT	30 10	32 9	36 9	40 8	42 7	49 7	56 7
19	WIDTH HEIGHT	30 10	35 10	36 9	40 8	48 8	49 7	56 7
20	WIDTH HEIGHT	33 11	35 10	40 10	45 9	48 8	56 8	56 7
21	WIDTH HEIGHT	33 11	39 11	40 10	45 9	54 9	56 8	64 8
22	WIDTH HEIGHT	36 12	39 11	44 11	50 10	54 9	56 8	64 8
23	WIDTH HEIGHT	39 13	42 12	44 11	50 10	54 9	63 8	64 8
24	WIDTH HEIGHT	39 13	42 12	48 12	55 11	60 10	63 9	72 9
25	WIDTH HEIGHT	42 14	46 13	48 12	55 11	60 10	70 10	72 9
26	WIDTH HEIGHT	42 14	46 13	52 13	55 11	66 11	70 10	72 9
27	WIDTH HEIGHT	45 15	49 14	52 13	60 12	66 11	70 10	80 10

Equivalent Rectangular Duct Dimensions

DUCT DIA. IN.	RECT. SIZE IN.	ASPECT RATIO						
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
28	WIDTH	45	49	56	60	66	77	80
	HEIGHT	15	14	14	12	11	11	10
29	WIDTH	48	53	56	65	72	77	88
	HEIGHT	16	15	14	13	12	11	11
30	WIDTH	48	53	60	65	72	77	88
	HEIGHT	16	15	15	13	12	11	11
31	WIDTH	51	56	60	70	78	84	88
	HEIGHT	17	16	15	14	13	12	11
32	WIDTH	54	56	60	70	78	84	96
	HEIGHT	18	16	15	14	13	12	12
33	WIDTH	54	60	64	75	78	91	96
	HEIGHT	18	17	16	15	13	13	12
34	WIDTH	57	60	64	75	84	91	96
	HEIGHT	19	17	16	15	14	13	12
35	WIDTH	57	63	68	75	84	91	104
	HEIGHT	19	18	17	15	14	13	13
36	WIDTH	60	63	68	80	90	98	104
	HEIGHT	20	18	17	16	15	14	13
38	WIDTH	63	67	72	85	96	105	112
	HEIGHT	21	19	18	17	16	15	14
40	WIDTH	66	70	76	90	96	105	120
	HEIGHT	22	20	19	18	16	15	15
42	WIDTH	69	74	80	90	102	112	120
	HEIGHT	23	21	20	18	17	16	15
44	WIDTH	72	81	84	95	108	119	128
	HEIGHT	24	23	21	19	18	17	16
46	WIDTH	75	84	88	100	114	126	136
	HEIGHT	25	24	22	20	19	18	17
48	WIDTH	78	88	92	105	120	126	136
	HEIGHT	26	25	23	21	20	18	17
50	WIDTH	81	91	96	110	120	133	144
	HEIGHT	27	26	24	22	20	19	18
52	WIDTH	84	95	100	115	126	140	152
	HEIGHT	28	27	25	23	21	20	19
54	WIDTH	90	98	104	120	132	147	160
	HEIGHT	30	28	26	24	22	21	20
56	WIDTH	93	102	108	125	138	147	160
	HEIGHT	31	29	27	25	23	21	20
58	WIDTH	96	105	112	130	144	154	168
	HEIGHT	32	30	28	26	24	22	21
60	WIDTH	99	109	116	130	144	161	
	HEIGHT	33	31	29	26	24	23	
62	WIDTH	102	112	120	135	150	168	
	HEIGHT	34	32	30	27	25	24	

Equivalent Rectangular Duct Dimensions

DUCT DIA. IN.	RECT. SIZE IN.	ASPECT RATIO						
		3.00	3.50	4.00	5.00	6.00	7.00	8.00
64	WIDTH	105	116	124	140	156		
	HEIGHT	35	33	31	28	26		
66	WIDTH	108	119	128	145	162		
	HEIGHT	36	34	32	29	27		
68	WIDTH	111	123	132	150	168		
	HEIGHT	37	35	33	30	28		
70	WIDTH	114	126	136	155			
	HEIGHT	38	36	34	31			
72	WIDTH	117	130	140	160			
	HEIGHT	39	37	35	32			
74	WIDTH	123	133	144	165			
	HEIGHT	41	38	36	33			
76	WIDTH	126	137	148	165			
	HEIGHT	42	39	37	33			
78	WIDTH	129	140	152				
	HEIGHT	43	40	38				
80	WIDTH	132	144	156				
	HEIGHT	44	41	39				
82	WIDTH	135	147	160				
	HEIGHT	45	42	40				
84	WIDTH	138	151	164				
	HEIGHT	46	43	41				
86	WIDTH	141	154	168				
	HEIGHT	47	44	42				
88	WIDTH	144	158					
	HEIGHT	48	45					
90	WIDTH	147	161					
	HEIGHT	49	46					
92	WIDTH	150	165					
	HEIGHT	50	47					
94	WIDTH	153	168					
	HEIGHT	51	48					
96	WIDTH	159						
	HEIGHT	53						
98	WIDTH	162						
	HEIGHT	54						
100	WIDTH	165						
	HEIGHT	55						
102	WIDTH	168						
	HEIGHT	56						
104	WIDTH							
	HEIGHT							

Notes:

1. **Shaded areas exceed the recommended maximum 4:1 aspect ratio.**

Round/Rectangular Duct Equivalents

A/B	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11
3.0	3.3											
3.5	3.5	3.8										
4.0	3.8	4.1	4.4									
4.5	4.0	4.3	4.6	4.9								
5.0	4.2	4.6	4.9	5.2	5.5							
5.5	4.4	4.8	5.1	5.4	5.7	6.0						
6	4.6	5.0	5.3	5.7	6.0	6.3	6.6					
7	4.9	5.3	5.7	6.1	6.4	6.8	7.1	7.7				
8	5.2	5.7	6.1	6.5	6.9	7.2	7.6	8.2	8.7			
9	5.5	6.0	6.4	6.9	7.3	7.6	8.0	8.7	9.3	9.8		
10	5.7	6.3	6.7	7.2	7.6	8.0	8.4	9.1	9.8	10.4	10.9	
11	6.0	6.5	7.0	7.5	8.0	8.4	8.8	9.5	10.2	10.9	11.5	12.0
12	6.2	6.8	7.3	7.8	8.3	8.7	9.1	9.9	10.7	11.3	12.0	12.6
13	6.4	7.0	7.6	8.1	8.6	9.0	9.5	10.3	11.1	11.8	12.4	13.1
14	6.6	7.2	7.8	8.4	8.9	9.3	9.8	10.8	11.4	12.2	12.9	13.5
15	6.8	7.5	8.0	8.6	9.1	9.6	10.1	11.0	11.8	12.6	13.3	14.0
16	7.0	7.7	8.3	8.8	9.4	9.9	10.4	11.3	12.2	13.0	13.7	14.4
17	7.2	7.9	8.5	9.1	9.6	10.2	10.7	11.6	12.5	13.4	14.1	14.9
18	7.3	8.0	8.7	9.3	9.9	10.4	11.0	11.9	12.9	13.7	14.5	15.3
19	7.5	8.2	8.9	9.5	10.1	10.7	11.2	12.2	13.2	14.1	14.9	15.7
20	7.7	8.4	9.1	9.7	10.3	10.9	11.5	12.6	13.5	14.4	15.2	16.0
22	8.0	8.7	9.5	10.1	10.8	11.4	12.0	13.0	14.1	15.0	15.9	16.8
24	8.3	9.1	9.8	10.5	11.2	11.8	12.4	13.5	14.6	15.6	16.5	17.4
26	8.5	9.4	10.1	10.9	11.5	12.2	12.8	14.0	15.1	16.2	17.1	18.1
28	8.8	9.6	10.4	11.2	11.9	12.6	13.2	14.5	15.6	16.7	17.7	18.7
30	9.0	9.9	10.7	11.5	12.2	13.0	13.6	14.9	16.1	17.2	18.3	19.3
32		10.2	11.0	11.8	12.6	13.3	14.0	15.3	16.5	17.7	18.8	19.8
34		10.4	11.3	12.2	12.9	13.6	14.4	15.7	17.0	18.2	19.3	20.4
36		10.7	11.5	12.4	13.2	14.0	14.7	16.1	17.4	18.6	19.8	20.9
38			11.8	12.7	13.5	14.3	15.0	16.5	17.8	19.0	20.2	21.4
40			12.0	13.1	13.8	14.7	15.3	16.8	18.2	19.5	20.7	21.8
42				13.2	14.0	14.9	15.6	17.1	18.5	19.9	21.1	22.3
44				13.4	14.3	15.1	15.9	17.5	18.9	20.3	31.5	22.7
46				13.7	14.6	15.4	16.2	17.8	19.3	20.6	21.9	23.2
48					14.8	15.7	16.5	18.1	19.6	21.0	22.3	23.6
50					15.1	15.9	16.8	18.4	19.9	21.4	22.7	24.0
52						16.2	17.1	18.7	20.2	21.7	23.1	24.4
54						16.4	17.3	19.0	20.6	22.0	23.5	24.8
56						16.7	17.6	19.3	20.9	22.4	23.8	25.2
58							17.8	19.5	21.2	22.7	24.2	25.5
60							18.1	19.8	21.5	23.0	24.5	25.9
62								20.1	21.7	23.3	24.8	26.3
64								20.3	22.0	23.6	25.1	26.6
66								20.6	22.3	23.9	25.5	26.9
68								20.8	22.6	24.2	25.8	27.3
70								21.1	22.8	24.5	26.1	27.6
72									23.1	24.8	26.4	27.9
74									23.3	25.1	26.7	28.2
76									23.6	25.3	27.0	28.5
78									23.8	25.6	27.3	28.8
80									24.1	25.8	27.5	29.1
82										26.1	27.8	29.4
84										26.4	28.1	29.7
86										26.6	28.3	30.0
88										26.8	28.6	30.3
90										27.1	28.9	30.6
92											29.1	30.8
94											29.4	31.1
96											29.6	31.4
98											29.9	31.7
100											30.1	31.9

Round/Rectangular Duct Equivalents

A/B	12	13	14	15	16	17	18	19	20	22	24	26
3.0												
3.5												
4.0												
4.5												
5.0												
5.5												
6												
7												
8												
9												
10												
11												
12	13.1											
13	13.7	14.2										
14	14.2	14.7	15.3									
15	14.6	15.3	15.8	16.4								
16	15.1	15.7	16.4	16.9	17.5							
17	15.6	16.2	16.8	17.4	18.0	18.6						
18	16.0	16.7	17.3	17.9	18.5	19.1	19.7					
19	16.4	17.1	17.8	18.4	19.0	19.6	20.2	20.8				
20	16.8	17.5	18.2	18.9	19.5	20.1	20.7	21.3	21.9			
22	17.6	18.3	19.1	19.8	20.4	21.1	21.7	22.3	22.9	24.0		
24	18.3	19.1	19.9	20.6	21.3	22.0	22.7	23.3	23.9	25.1	26.2	
26	19.0	19.8	20.6	21.4	22.1	22.9	23.5	24.2	24.9	26.1	27.3	28.4
28	19.6	20.5	21.3	22.1	22.9	23.7	24.4	25.1	25.8	27.1	28.3	29.5
30	20.2	21.1	22.0	22.9	23.7	24.4	25.2	25.9	26.6	28.0	29.3	30.5
32	20.8	21.8	22.7	23.5	24.4	25.2	26.0	26.7	27.5	28.9	30.2	31.5
34	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	29.7	31.0	32.4
36	21.9	22.9	23.9	24.8	25.7	26.6	27.4	28.2	29.0	30.5	32.0	33.3
38	22.4	23.5	24.5	25.4	26.4	27.2	28.1	28.9	29.8	31.3	32.8	34.2
40	22.9	24.0	25.0	26.0	27.0	27.9	28.8	29.6	30.5	32.1	33.6	35.1
42	23.4	24.5	25.6	26.6	27.6	28.5	29.4	30.3	31.2	32.8	34.4	35.9
44	23.9	25.0	26.1	27.1	28.1	29.1	30.0	30.9	31.8	33.5	35.1	36.7
46	24.4	25.5	26.6	27.7	28.7	29.7	30.6	31.6	32.5	34.2	35.9	37.4
48	24.8	26.0	27.1	28.2	29.2	30.2	31.2	32.2	33.1	34.9	36.6	38.2
50	25.2	26.4	27.6	28.7	29.8	30.8	31.8	32.8	33.7	35.5	37.2	38.9
52	25.7	26.9	28.0	29.2	30.3	31.3	32.3	33.3	34.3	36.2	37.9	39.6
54	26.1	27.3	28.5	29.7	30.8	31.8	32.9	33.9	34.9	36.8	38.6	40.3
56	26.5	27.7	28.9	30.1	31.2	32.3	33.4	34.4	35.4	37.4	39.2	41.0
58	26.9	28.2	29.4	30.6	31.7	32.8	33.9	35.0	36.0	38.0	39.8	41.6
60	27.3	28.6	29.8	31.0	32.2	33.3	34.4	35.5	36.5	38.5	40.4	42.3
62	27.6	28.9	30.2	31.5	32.6	33.8	34.9	36.0	37.1	39.1	41.0	42.9
64	28.0	29.3	30.6	31.9	33.1	34.3	35.4	36.5	37.6	39.6	41.6	43.5
66	28.4	29.7	31.0	32.3	33.5	34.7	35.9	37.0	38.1	40.2	42.2	44.1
68	28.7	30.1	31.4	32.7	33.9	35.2	36.3	37.5	38.6	40.7	42.8	44.7
70	29.1	30.4	31.8	33.1	34.4	35.6	36.8	37.9	39.1	41.2	43.3	45.3
72	29.4	30.8	32.2	33.5	34.8	36.0	37.2	38.4	39.5	41.7	43.8	45.8
74	29.7	31.2	32.5	33.9	35.2	36.4	37.7	38.8	40.0	42.2	44.4	46.4
76	30.0	31.5	32.9	34.3	35.6	36.8	38.1	39.3	40.5	42.7	44.9	47.0
78	30.4	31.8	33.3	34.6	36.0	37.2	38.5	39.7	40.9	43.2	45.4	47.5
80	30.7	32.2	33.6	35.0	36.3	37.6	38.9	40.2	41.4	43.7	45.9	48.0
82	31.0	32.5	34.0	35.4	36.7	38.0	39.3	40.6	41.8	44.1	46.4	48.5
84	31.3	32.8	34.3	35.7	37.1	38.4	39.7	41.0	42.2	44.6	46.9	49.0
86	31.6	33.1	34.6	36.1	37.4	38.8	40.1	41.4	42.6	45.0	47.3	49.6
88	31.9	33.4	34.9	36.4	37.8	39.2	40.5	41.8	43.1	45.5	47.8	50.0
90	32.2	33.8	35.3	36.7	38.2	39.5	40.9	42.2	43.5	45.9	48.3	50.5
92	32.5	34.1	35.6	37.1	38.5	39.9	41.3	42.6	43.9	46.4	48.7	51.0
94	32.8	34.4	35.9	37.4	38.9	40.3	41.7	43.0	44.3	46.8	49.2	51.5
96	33.0	34.7	36.2	37.7	39.2	40.6	42.0	43.3	44.7	47.2	49.6	52.0
98	33.3	35.0	36.5	38.1	39.5	41.0	42.4	43.7	45.1	47.6	50.1	52.5
100	33.6	35.2	36.8	38.4	39.8	41.3	42.7	44.1	45.4	48	50.5	52.9

Round/Rectangular Duct Equivalents

A/B	28	30	32	34	36	38	40	42	44	46	48	50
3.0												
3.5												
4.0												
4.5												
5.0												
5.5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
22												
24												
26												
28	30.6											
30	31.7	32.8										
32	32.7	33.9	35.0									
34	33.7	34.9	36.1	37.2								
36	34.6	35.9	37.1	38.2	39.4							
38	35.6	36.8	38.1	39.3	40.4	41.5						
40	36.4	37.8	39.0	40.3	41.5	42.6	43.7					
42	37.3	38.7	40.0	41.3	42.5	43.7	44.8	45.9				
44	38.1	39.5	40.9	42.2	43.5	44.7	45.8	47.0	48.1			
46	38.9	40.4	41.8	43.1	44.4	45.7	46.9	48.0	49.2	50.3		
48	39.7	41.2	42.6	44.0	45.3	46.6	47.9	49.1	50.2	51.4	52.5	
50	40.5	42.0	43.6	44.9	46.2	47.5	48.8	50.0	51.2	52.4	53.6	54.7
52	41.2	42.8	44.3	45.7	47.1	48.4	49.7	51.0	52.2	53.4	54.6	55.7
54	41.9	43.5	45.1	46.5	48.0	49.3	50.7	52.0	53.2	54.4	55.6	56.8
56	42.7	44.3	45.8	47.3	48.8	50.2	51.6	52.9	54.2	55.4	56.6	57.8
58	43.3	45.0	46.6	48.1	49.6	51.0	52.4	53.8	55.1	56.4	57.6	58.8
60	44.0	45.7	47.3	48.9	50.4	51.9	53.3	54.7	60.0	57.3	58.6	59.8
62	44.7	46.4	48.0	49.6	51.2	52.7	54.1	55.5	56.9	58.2	59.5	60.8
64	45.3	47.1	48.7	50.4	51.9	53.5	54.9	56.4	57.8	59.1	60.4	61.7
66	46.0	47.7	49.4	51.1	52.7	54.2	55.7	57.2	58.6	60.0	61.3	62.6
68	46.6	48.4	50.1	51.8	53.4	55.0	56.5	58.0	59.4	60.8	62.2	63.6
70	47.2	49.0	50.8	52.5	54.1	55.7	57.3	58.8	60.3	61.7	63.1	64.4
72	47.8	49.6	51.4	53.2	54.8	56.5	58.0	59.6	61.1	62.5	63.9	65.3
74	48.4	50.3	52.1	53.8	55.5	57.2	58.8	60.3	61.9	63.3	64.8	66.2
76	48.9	50.9	52.7	54.5	56.2	57.9	59.5	61.1	62.6	64.1	65.6	67.0
78	49.5	51.4	53.3	55.1	56.9	58.6	60.2	61.8	63.4	64.9	66.4	67.9
80	50.1	52.0	53.9	55.8	57.5	59.3	60.9	62.6	64.1	65.7	67.2	68.7
82	50.6	52.6	54.6	56.4	58.2	59.9	61.6	63.3	64.9	66.5	68.0	69.5
84	51.1	53.2	55.1	57.0	58.8	60.6	62.3	64.0	65.6	67.2	68.7	70.3
86	51.7	53.7	55.7	57.6	59.4	61.2	63.0	64.7	66.3	67.9	69.5	71.0
88	52.2	54.3	56.3	58.2	60.1	61.9	63.6	65.4	67.0	68.7	70.2	71.8
90	52.7	54.8	56.8	58.8	60.7	62.5	64.3	66.0	67.7	69.4	71.0	72.6
92	53.2	55.3	57.4	59.3	61.3	63.1	64.9	66.7	68.4	70.1	71.7	73.3
94	53.7	55.9	57.9	59.9	61.9	63.7	65.6	67.3	69.1	70.8	72.4	74.0
96	54.2	56.4	58.4	60.5	62.4	64.3	66.2	68.0	69.7	71.5	73.1	74.8
98	54.7	56.9	59.0	61.1	63.0	64.9	66.8	68.6	70.4	72.2	73.8	75.5
100	55.2	57.4	59.5	61.6	63.6	65.5	67.4	69.2	71	72.8	74.5	76.2

Round/Rectangular Duct Equivalents

A/B	52	54	56	58	60	62	64	66	68	70	72	74
50												
52	56.8											
54	57.9	59.0										
56	59.0	60.1	61.2									
58	60.0	61.2	62.3	63.4								
60	61.0	62.2	63.4	64.5	65.6							
62	62.0	63.2	64.4	65.5	66.7	67.8						
64	63.0	64.2	65.4	66.6	67.7	69.9	70.0					
66	63.9	65.2	66.4	67.6	68.8	69.9	71.0	72.1				
68	64.9	66.2	67.4	68.6	69.8	71.0	72.1	73.2	74.3			
70	65.8	67.1	68.3	69.6	70.8	72.0	73.2	74.3	75.4	76.5		
72	66.7	68.0	69.3	70.6	71.8	73.0	74.2	75.4	76.5	77.6	78.7	
74	67.5	68.9	70.2	71.5	72.7	74.0	75.2	76.4	77.5	78.7	79.8	80.9
76	68.4	69.8	71.1	72.4	73.7	75.0	76.2	77.4	78.6	79.7	80.9	82.0
78	69.3	70.6	72.0	73.3	74.6	75.9	77.1	78.4	79.6	80.7	81.9	83.0
80	70.1	71.6	72.9	74.2	75.4	76.9	78.1	79.4	80.6	81.8	82.9	84.1
82	70.9	72.3	73.7	75.1	76.4	77.8	79.0	80.3	81.5	82.8	84.0	85.1
84	71.7	72.6	74.6	76.0	77.3	78.7	80.0	81.3	82.5	83.8	85.0	86.1
86	72.5	73.3	75.4	76.8	78.2	79.6	80.9	82.2	83.5	84.7	85.9	87.1
88	73.3	74.0	76.3	77.7	79.1	80.5	81.8	83.1	84.4	85.7	86.9	88.1
90	74.1	75.6	77.1	78.5	79.9	81.3	82.7	84.0	85.3	86.6	87.9	89.1
92	74.9	76.4	77.9	79.3	80.8	82.2	83.5	85.4	86.2	87.5	88.8	90.1
94	75.6	77.2	78.7	80.1	81.6	83.0	84.4	86.0	87.1	88.4	89.7	91.0
96	76.3	77.9	79.4	80.9	82.4	83.8	85.3	86.6	88.0	89.3	90.7	91.9
98	77.1	78.7	80.2	81.7	83.2	84.7	86.1	87.5	88.9	90.2	91.6	92.9
100	77.8	79.4	81	82.5	84	85.5	86.9	88.3	89.7	91.1	92.4	93.8

Round/Rectangular Duct Equivalents

A/B	76	78	80	82	84	86	88	90	92	94	96	98
70												
72												
74												
76	83.1											
78	84.2	85.3										
80	85.2	86.4	87.5									
82	86.3	87.4	88.5	89.6								
84	87.3	88.5	89.6	90.7	91.8							
86	88.3	89.5	90.7	91.8	92.9	94.0						
88	89.3	90.5	91.7	92.9	94.0	95.1	96.2					
90	90.3	91.5	92.7	93.9	95.0	96.2	97.3	98.4				
92	91.3	92.5	93.7	94.9	96.1	97.2	98.4	99.5	100.6			
94	92.3	93.5	94.7	95.9	97.1	98.3	99.4	100.6	101.1	102.8		
96	93.2	94.5	95.7	96.9	98.1	99.3	100.5	101.6	102.7	103.8	104.9	
98	94.2	95.5	96.7	97.9	99.1	100.3	101.5	102.7	103.8	104.9	106.0	107.1
100	95.1	96.4	97.6	98.9	100.1	101.3	102.5	103.7	104.8	106	107.1	108.2

Notes:

1. **Shaded areas and bold numbers exceed the recommended maximum 4:1 aspect ratio.**

PART 30

Appendix B: Hydronic Piping Systems

30.01 Hydronic Piping Systems

A. *Table Notes: Hydronic Piping Systems–Copper, Steel, and Stainless Steel Pipe:*

1. Maximum Recommended Pressure Drop: 4 Ft./100 Ft.
2. Maximum Recommended Velocity (Occupied Areas): 8 Fps.
3. Maximum Recommended Velocity (Unoccupied Areas, Shafts, Tunnels, etc.): 10 FPS.
4. Standard steel pipe and Type L copper pipe are the most common pipe materials used in HVAC applications.
5. Tables are applicable to closed and open hydronic piping systems.
6. Pipe Sizes 5″, 22″, 26″, 28″, 32″, and 34″ are not standard sizes and not readily available in all locations.
7. Types K, L, and M copper pipe are available in sizes through 12 inch.
8. Standard and XS steel pipe are available in sizes through 96 inch.
9. XXS steel pipe is available in sizes through 12 inch.
10. Schedule 40 steel pipe is available in sizes through 96 inch.
11. Schedule 80 and 160 steel pipe are available in sizes through 24 inch.
12. Schedule 5 and 10 stainless steel pipe are available in sizes through 24 inch.
13. Standard and Schedule 40 steel pipe have the same dimensions and flow for 10 inch and smaller.
14. XS and Schedule 80 steel pipe have the same dimensions and flow for 8 inch and smaller.
15. XXS and Schedule 160 have no relationship for dimensions or flow.

Hydronic Piping Systems–Type K Copper Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.0	1.2	1.4					
3/4	2.4	3.0	3.5		Pressure	Drop	Governs	
1	5.2	6.4	7.4		with these	Pipe	Sizes	
1-1/4	9	12	13					
1-1/2	15	18	21	21				
2	31	38	44	38				
2-1/2	55	67	78	58	73			
3	87	107	123	83	103	124		
4	183	224	258	146	182	219		
5	324	397	458	226	283	339	452	
6	515	631	729	323	403	484	645	
8	1,064	1,304		563	704	845	1,126	1,408
10	1,887	Velocity	Governs	874	1,093	1,311	1,749	2,186
12	3,015	with these	Pipe Sizes	1,254	1,567	1,880	2,507	3,134

Hydronic Piping Systems—Type L Copper Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.1	1.3	1.5		Pressure	Drop	Governs	
3/4	2.8	3.4	4.0		with these	Pipe	Sizes	
1	5.7	6.9	8.0					
1-1/4	10	12	14					
1-1/2	16	19	22	22				
2	32	39	45	39				
2-1/2	57	69	80	59	74			
3	90	111	128	85	106	127		
4	189	231	267	149	187	224		
5	337	412	476	233	291	349	465	
6	540	662	764	335	418	502	669	
8	1,117	1,368		584	730	877	1,169	1,461
10	1,980	Velocity	Governs	907	1,134	1,361	1,814	2,268
12	3,191	with these	Pipe Sizes	1,310	1,637	1,965	2,619	3,274

Hydronic Piping Systems—Type M Copper Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.2	1.5	1.7		Pressure	Drop	Governs	
3/4	3.1	3.7	4.3		with these	Pipe	Sizes	
1	6.1	7.5	8.6					
1-1/4	10	13	15	16				
1-1/2	16	20	23	23				
2	33	41	47	40				
2-1/2	58	72	83	61	76			
3	93	114	132	87	109	131		
4	192	236	272	152	190	227		
5	342	419	484	236	295	354	472	
6	549	672	776	339	423	508	677	
8	1,140	1,396		593	742	890	1,187	1,484
10	2,020	Velocity	Governs	922	1,152	1,382	1,843	2,304
12	3,228	with these	Pipe Sizes	1,321	1,652	1,982	2,643	3,304

Hydronic Piping Systems—Standard Steel Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.5	1.9	2.1					
3/4	3.2	3.9	4.5		Pressure	Drop	Governs	
1	6.0	7.4	8.5		with these	Pipe	Sizes	
1-1/4	12	15	18	19				
1-1/2	19	23	26	25				
2	36	44	51	42	52			
2-1/2	57	70	80	60	75			
3	100	123	142	92	115	138		
4	204	250	289	159	198	238		
5	368	451	521	249	312	374	499	
6	595	729	841	360	450	540	720	
8	1,216	1,489		624	780	936	1,247	1,559
10	2,198			983	1,229	1,475	1,966	2,458
12	3,512			1,410	1,763	2,115	2,820	3,525
14				1,719	2,149	2,579	3,438	4,298
16				2,277	2,847	3,416	7,834	5,693
18				2,914	3,642	4,371	5,827	7,284
20				3,629	4,536	5,443	7,257	9,071
22				4,422	5,527	6,633	8,843	11,054
24				5,293	6,616	7,940	10,586	13,233
26				6,243	7,804	9,364	12,486	15,607
28				7,271	9,089	10,907	14,542	18,178
30				8,378	10,472	12,566	16,755	20,944
32				9,562	11,953	14,344	19,125	23,906
34				10,826	13,532	16,238	21,651	27,064
36	Velocity	Governs	with	12,167	15,209	18,251	24,334	30,418
42	these	Pipe	Sizes	16,662	20,827	24,992	33,323	41,654
48				21,861	27,327	32,792	43,722	54,653
54				27,766	34,707	41,649	55,532	69,414
60				34,375	42,969	51,563	68,751	85,938
72				49,710	62,137	74,564	99,419	124,274
84				67,864	84,830	101,796	135,728	169,660
96				88,838	111,048	133,257	177,677	222,096

Hydronic Piping Systems—XS Steel Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.1	1.3	1.5					
3/4	2.4	3.0	3.4		Pressure	Drop	Governs	
1	4.7	5.8	6.7		with these	Pipe	Sizes	
1-1/4	10	12	14					
1-1/2	15	19	22	22				
2	30	37	43	37				
2-1/2	48	59	69	53	66			
3	87	106	123	82	103	124		
4	179	219	253	143	179	215		
5	325	399	460	227	284	340	454	
6	520	637	736	325	406	487	650	
8	1,080	1,322		569	712	854	1,139	1,423
10	2,047			931	1,164	1,396	1,862	2,327
12	3,325			1,352	1,690	2,028	2,704	3,380
14				1,655	2,069	2,482	3,310	4,137
16				2,203	2,754	3,305	7,834	5,508
18				2,830	3,537	4,245	5,660	7,075
20				3,535	4,419	5,302	7,070	8,837
22				4,318	5,398	6,477	8,637	10,796
24				5,180	6,475	7,770	10,360	12,950
26				6,120	7,650	9,180	12,240	15,300
28				7,138	8,923	10,708	14,277	17,846
30				8,235	10,294	12,353	16,470	20,588
32				9,410	11,763	14,115	18,820	23,525
34				10,663	13,329	15,995	21,327	26,659
36	Velocity	Governs	with	11,995	14,994	17,993	23,990	29,988
42	these	Pipe	Sizes	16,460	20,575	24,690	32,921	41,151
48				21,630	27,038	32,446	43,261	54,076
54				27,506	34,382	41,258	55,011	68,764
60				34,086	42,607	51,129	68,172	85,215
72				49,361	61,702	74,042	98,723	123,403
84				67,457	84,321	101,185	134,914	168,642
96				88,373	110,466	132,559	176,745	220,931

Hydronic Piping Systems—XXS Steel Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	0.1	0.2	0.2					
3/4	0.6	0.7	0.8		Pressure	Drop	Governs	
1	1.4	1.7	1.9		with these	Pipe	Sizes	
1-1/4	4	5	6					
1-1/2	7	8	10					
2	15	19	22	22				
2-1/2	24	29	34	31				
3	47	58	67	52	65			
4	108	132	152	97	122	146		
5	209	256	296	162	202	242		
6	341	417	482	235	294	352	470	
8	825	1,010		463	579	694	926	1,157
10	1,545	Velocity	Governs	750	937	1,125	1,499	1,874
12	2,639	with these	Pipe Sizes	1,132	1,414	1,697	2,263	2,829

Hydronic Piping Systems—Schedule 40 Steel Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.5	1.9	2.1					
3/4	3.2	3.9	4.5		Pressure	Drop	Governs	
1	6.0	7.4	8.5		with these	Pipe	Sizes	
1-1/4	12	15	18	19				
1-1/2	19	23	26	25				
2	36	44	51	42	52			
2-1/2	57	70	80	60	75			
3	100	123	142	92	115	138		
4	204	250	289	159	198	238		
5	368	451	521	249	312	374	499	
6	595	729	841	360	450	540	720	
8	1,216	1,489		624	780	936	1,247	1,559
10	2,198			983	1,229	1,475	1,966	2,458
12	3,465			1,396	1,744	2,093	2,791	3,489
14				1,687	2,109	2,531	3,374	4,218
16				2,203	2,754	3,305	7,834	5,508
18				2,789	3,486	4,183	5,577	6,972
20				3,466	4,333	5,199	6,932	8,665
22				---	---	---	---	---
24				5,013	6,266	7,519	10,026	12,532
26				---	---	---	---	---
28				---	---	---	---	---
30				7,954	9,942	11,930	15,907	19,884
32				9,183	11,479	13,775	18,366	22,958
34				10,422	13,027	15,633	20,844	26,055
36	Velocity	Governs	with	11,655	14,569	17,482	23,310	29,137
42	these	Pipe	Sizes	16,061	20,077	24,092	32,123	40,153
48				21,173	26,466	31,759	42,345	52,932
54				26,989	33,736	40,484	53,978	67,473
60				33,511	41,888	50,266	67,021	83,776
72				48,669	60,836	73,003	97,337	121,671
84				66,647	83,308	99,970	133,293	166,617
96				87,445	109,306	131,167	174,890	218,612

Hydronic Piping Systems—Schedule 80 Steel Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.1	1.3	1.5					
3/4	2.4	3.0	3.4		Pressure	Drop	Governs	
1	4.7	5.8	6.7		with these	Pipe	Sizes	
1-1/4	10	12	14					
1-1/2	15	19	22	22				
2	30	37	43	37				
2-1/2	48	59	69	53	66			
3	87	106	123	82	103	124		
4	179	219	253	143	179	215		
5	325	399	460	227	284	340	454	
6	520	637	736	325	406	487	650	
8	1,080	1,322		569	712	854	1,139	1,423
10	1,947			896	1,120	1,344	1,791	2,239
12	3,057			1,267	1,584	1,901	2,534	3,168
14				1,530	1,912	2,295	3,060	3,825
16				2,006	2,508	3,009	7,834	5,016
18				2,546	3,183	3,820	5,093	6,366
20				3,151	3,938	4,726	6,302	7,877
22	Velocity	Governs	with	3,819	4,774	5,729	7,639	9,549
24	these	Pipe	Sizes	4,553	5,692	6,830	9,107	11,383

Hydronic Piping Systems—Schedule 160 Steel Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	0.7	0.9	1.0					
3/4	1.5	1.8	2.1		Pressure	Drop	Governs	
1	3.1	3.8	4.4		with these	Pipe	Sizes	
1-1/4	8	10	11					
1-1/2	11	14	16					
2	21	26	30	28				
2-1/2	38	47	54	44	55			
3	67	82	95	68	84			
4	135	166	191	116	145	174		
5	244	299	346	182	228	273		
6	396	485	560	264	330	395	527	
8	805	986		455	568	682	909	1,136
10	1,433	1,755		707	884	1,061	1,415	1,769
12	2,259			1,004	1,255	1,506	2,008	2,510
14	2,928			1,226	1,532	1,839	2,451	3,064
16				1,608	2,010	2,412	7,834	4,020
18				2,041	2,551	3,062	4,082	5,103
20				2,527	3,159	3,790	5,054	6,317
22	Velocity	Governs	with	3,085	3,856	4,628	6,170	7,713
24	these	Pipe	Sizes	3,653	4,566	5,479	7,305	9,132

Hydronic Piping Systems—Schedule 5 Stainless Steel Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	2.2	2.6	3.0					
3/4	4.3	5.2	6.0		Pressure	Drop	Governs	
1	8.3	10.2	11.7		with these	Pipe	Sizes	
1-1/4	16	20	23	23				
1-1/2	24	29	34	31				
2	44	54	63	49	62			
2-1/2	73	89	103	72	90			
3	125	153	176	109	136	163		
4	248	303	350	184	230	276		
5	428	524	605	280	350	420	559	
6	686	840	970	402	502	603	804	
8	1,392	1,705		692	865	1,038	1,384	1,730
10	2,471			1,076	1,345	1,614	2,152	2,690
12				1,515	1,894	2,272	3,030	3,787
14				1,835	2,293	2,752	3,669	4,587
16				2,404	3,006	3,607	7,834	6,011
18				3,057	3,822	4,586	6,115	7,643
20	Velocity	Governs	with	3,771	4,714	5,656	7,542	9,427
22	these	Pipe	Sizes	4,579	5,723	6,868	9,157	11,447
24				5,437	6,796	8,156	10,874	13,593

Hydronic Piping Systems—Schedule 10 Stainless Steel Pipe

PIPE SIZE	WATER FLOW - GPM							
	FRICTION RATE - FT/100 FT			VELOCITY - FT/SEC.				
	2.0	3.0	4.0	4.0	5.0	6.0	8.0	10.0
1/2	1.9	2.3	2.7					
3/4	3.8	4.7	5.4		Pressure	Drop	Governs	
1	6.8	8.3	9.6		with these	Pipe	Sizes	
1-1/4	14	17	20	20				
1-1/2	21	25	29	28				
2	40	49	56	46	57			
2-1/2	67	83	95	68	85			
3	118	144	166	104	130	156		
4	237	290	335	178	222	267		
5	417	511	590	275	343	412	549	
6	672	823	951	396	495	594	791	
8	1,359	1,664		679	849	1,019	1,359	1,698
10	2,433			1,063	1,329	1,595	2,126	2,658
12				1,503	1,879	2,255	3,006	3,758
14				1,818	2,272	2,726	3,635	4,544
16				2,390	2,988	3,585	7,834	5,976
18				3,041	3,802	4,562	6,083	7,604
20	Velocity	Governs	with	3,748	4,685	5,622	7,496	9,370
22	these	Pipe	Sizes	4,553	5,692	6,830	9,107	11,383
24				5,408	6,760	8,111	10,815	13,519

Bypass and Warming Valves

MAIN VALVE NOMINAL PIPE SIZE	NOMINAL PIPE SIZE	
	SERIES A WARMING VALVES	SERIES B BYPASS VALVES
4	1/2	1
5	3/4	1-1/4
6	3/4	1-1/4
8	3/4	1-1/2
10	1	1-1/2
12	1	2
14	1	2
16	1	3
18	1	3
20	1	3
24	1	4
30	1	4
36	1	6
42	1	6
48	1	8
54	1	8
60	1	10
72	1	10
84	1	12
96	1	12

Notes:

1. Series A covers steam service for warming up before the main line is opened and for balancing pressures where lines are of limited volume.
2. Series B covers lines conveying gases or liquids where bypassing may facilitate the operation of the main valve by balancing the pressures on both sides of the disc or discs thereof. The valves in the larger sizes may be of the bolted on type.

Hydronic System Design Temperatures and Pressures

WATER TEMPERATURE °F.	VAPOR PRESSURE PSIG	SYSTEM OPERATING PRESSURE ANTIFLASH MARGIN						
		10 °F.	20 °F.	30 °F.	40 °F.	50 °F.	60 °F.	70 °F.
200	-3.2	-0.6	2.5	6	10	15	21	27
210	-0.6	2.5	6	10	15	21	27	35
212	0.0	3	7	11	16	22	29	36
215	0.9	4	8	13	18	24	31	39
220	2.5	6	10	15	21	27	35	43
225	4.2	8	13	18	24	30	39	48
230	6.1	10	15	21	27	35	43	52
240	10.3	15	21	27	34	43	52	63
250	15.1	21	27	34	43	52	63	75
260	20.7	27	34	43	52	63	75	88
270	27.2	34	43	52	63	75	88	103
275	30.7	39	47	58	69	81	96	111
280	34.5	43	52	63	75	88	103	120
290	42.8	52	63	75	88	103	120	138
300	52.3	63	75	88	103	120	138	159
310	62.9	75	88	103	120	138	159	181
320	74.9	88	103	120	138	159	181	206
325	81.4	96	111	129	148	170	193	219
330	88.3	103	120	138	159	181	206	232
340	103.2	120	138	159	181	206	232	262
350	119.8	138	159	181	206	232	262	294
360	138.2	159	181	206	232	262	294	329
370	158.5	181	206	232	262	294	329	367
375	169.5	193	219	247	277	311	347	387
380	180.9	206	232	262	294	329	367	407
390	205.5	232	262	294	329	367	407	452
400	232.4	262	294	329	367	407	452	500
410	261.8	294	329	367	407	452	500	551
420	293.8	329	367	407	452	500	551	606
425	310.9	347	387	429	475	524	578	635
430	328.6	367	407	452	500	551	606	665
440	366.5	407	452	500	551	606	665	729
450	407.4	452	500	551	606	665	729	797
455	429.1	475	525	578	635	697	762	832

Notes:

1. Safety: High temperature hydronic systems when operated at higher system temperatures and higher system pressures will result in lower chance of water hammer and the damaging effects of pipe leaks. These high temperature heating water systems are also safer than lower temperature heating water systems because system leaks subcool to temperatures below scalding due to the sudden decrease in pressure and the production of water vapor.
2. The antiflash margin of 40°F. minimum is recommended for nitrogen or mechanically pressurized systems.

30.02 Glycol Systems

Ethylene Glycol

% GLYCOL SOLUTION	TEMPERATURE °F.		SPECIFIC HEAT	SPECIFIC GRAVITY (1)	EQUATION FACTOR
	FREEZE POINT	BOILING POINT			
0	+32	212	1.00	1.000	500
10	+26	214	0.97	1.012	491
20	+16	216	0.94	1.027	483
30	+4	220	0.89	1.040	463
40	-12	222	0.83	1.055	438
50	-34	225	0.78	1.067	416
60	-60	232	0.73	1.079	394
70	<-60	244	0.69	1.091	376
80	-49	258	0.64	1.101	352
90	-20	287	0.60	1.109	333
100	+10	287+	0.55	1.116	307

Notes:
1. Specific gravity with respect to water at 60°F.

Propylene Glycol

% GLYCOL SOLUTION	TEMPERATURE °F.		SPECIFIC HEAT	SPECIFIC GRAVITY (1)	EQUATION FACTOR
	FREEZE POINT	BOILING POINT			
0	+32	212	1.000	1.000	500
10	+26	212	0.980	1.008	494
20	+19	213	0.960	1.017	488
30	+8	216	0.935	1.026	480
40	-7	219	0.895	1.034	463
50	-28	222	0.850	1.041	442
60	<-60	225	0.805	1.046	421
70	<-60	230	0.750	1.048	393
80	<-60	230+	0.690	1.048	362
90	<-60	230+	0.645	1.045	337
100	<-60	230+	0.570	1.040	296

Notes:
1. Specific gravity with respect to water at 60°F.

30.03 Air Conditioning (AC) Condensate Piping

A. AC Condensate Flow:

1. Range:	0.02–0.08 GPM/Ton
2. Average:	0.04 GPM/Ton
3. Unitary Packaged AC Equipment:	0.006 GPM/Ton
4. Air Handling Units (100% outside Air):	0.100 GPM/1000 CFM
5. Air Handling Units (50% Outdoor Air):	0.065 GPM/1000 CFM
6. Air Handling Units (25% Outdoor Air):	0.048 GPM/1000 CFM
7. Air Handling Units (15% Outdoor Air):	0.041 GPM/1000 CFM
8. Air Handling Units (0% Outdoor Air):	0.030 GPM/1000 CFM

B. AC Condensate Pipe Sizing:

1. Minimum Pipe Sizes are given in the following table:

Air Conditioning Condensate Pipe Sizing

AC TONS	MINIMUM DRAIN SIZE
0 -20	1"
21 - 40	1-1/4"
41 - 60	1-1/2"
61 - 100	2"
101 - 250	3"
251 & LARGER	4"

2. Pipe size shall not be smaller than drain pan outlet. Minimum size below grade and below ground floor shall be 2½″ (4″ Allegheny Co., PA). Drain shall have slope of not less than ⅛″ per foot.
3. Some localities require AC condensate to be discharged to storm sewers, some require AC condensate to be discharged to sanitary sewers, and some permit AC condensate to be discharged to either storm or sanitary sewers. Verify pipe sizing and discharge requirements with local authorities and codes.

PART 31

Appendix C: Steam Piping Systems

31.01 Steam Systems

Steam System Design Criteria

SYSTEM TYPE	INITIAL STEAM PRESSURE PSIG	MAXIMUM PRESSURE DROP PSIG/100 FT.	MAXIMUM TOTAL SYSTEM PRESSURE DROP PSIG	MAXIMUM VELOCITY FPM
LOW PRESSURE Velocity Range 4,000 - 6,000 FPM	1 3 5	1/8 1/8 1/4	0.2 0.6 1.0	4,000 4,000 6,000
	7 10 12 15	1/4 1/2 1/2 1/2	1.5 2.0 2.5 3	6,000 6,000 6,000 6,000
MEDIUM PRESSURE Velocity Range 6,000 - 12,000 FPM	20 25 30	1/2 1/2 - 1 1/2 - 1	4 5 5 - 6	8,000 8,000 8,000
	40 50 60	1 1 1	6 - 8 8 - 10 10 - 12	10,000 10,000 12,000
	75 85 100	1 - 2 1 - 2 1 - 2	12 - 15 12 - 15 15 - 20	12,000 12,000 12,000
HIGH PRESSURE Velocity Range 6,000 - 15,000 FPM	120 125 150	2 2 2	20 - 24 20 - 24 24 - 30	15,000 15,000 15,000
	175 200 225	2 2 - 5 2 - 5	24 - 30 30 - 40 30 - 40	15,000 15,000 15,000
	250 275 300	2 - 5 2 - 5 2 - 5	30 - 50 30 - 50 40 - 60	15,000 15,000 15,000

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
0	14.7	212.0	26.800	180.2	970.4	1,150.6
1	15.7	215.3	25.212	183.5	968.2	1,151.7
2	16.7	218.5	23.798	186.7	966.2	1,152.9
3	17.7	221.5	22.536	189.7	964.3	1,154.0
4	18.7	224.4	21.407	192.6	962.4	1,155.0
5	19.7	227.1	20.387	195.4	960.6	1,156.0
6	20.7	229.8	19.467	198.1	958.9	1,157.0
7	21.7	232.3	18.626	200.7	957.3	1,158.0
8	22.7	234.8	17.855	203.1	955.7	1,158.8
9	23.7	237.1	17.147	205.5	954.2	1,159.7
10	24.7	239.4	16.496	207.8	952.7	1,160.5
11	25.7	241.6	15.895	210.1	951.2	1,161.3
12	26.7	243.7	15.337	212.2	949.8	1,162.0
13	27.7	245.8	14.817	214.4	948.4	1,162.8
14	28.7	247.8	14.334	216.4	947.1	1,163.5
15	29.7	249.8	13.881	218.3	945.8	1,164.1
16	30.7	251.7	13.458	220.3	944.5	1,164.8
17	31.7	253.5	13.059	222.2	943.3	1,165.5
18	32.7	255.3	12.685	224.0	942.1	1,166.1
19	33.7	257.1	12.332	225.8	940.9	1,166.7
20	34.7	258.8	11.998	227.5	939.7	1,167.2
21	35.7	260.5	11.684	229.2	938.5	1,167.7
22	36.7	262.1	11.385	230.9	937.4	1,168.3
23	37.7	263.7	11.102	232.5	936.3	1,168.8
24	38.7	265.3	10.833	234.1	935.2	1,169.3
25	39.7	266.8	10.577	235.7	934.1	1,169.8
26	40.7	268.3	10.333	237.3	933.1	1,170.4
27	41.7	269.8	10.101	238.7	932.1	1,170.8
28	42.7	271.2	9.879	240.2	931.1	1,171.3
29	43.7	272.6	9.666	241.7	930.1	1,171.8
30	44.7	274.0	9.463	243.1	929.1	1,172.2
31	45.7	275.4	9.269	244.5	928.2	1,172.7
32	46.7	276.8	9.082	245.9	927.2	1,173.1
33	47.7	278.1	8.904	247.2	926.3	1,173.5
34	48.7	279.4	8.732	248.5	925.4	1,173.9
35	49.7	280.6	8.567	249.9	924.5	1,174.4
36	50.7	281.9	8.408	251.1	923.6	1,174.7
37	51.7	283.1	8.255	252.4	922.7	1,175.1
38	52.7	284.4	8.109	253.7	921.8	1,175.5
39	53.7	285.6	7.966	254.9	921.0	1,175.9

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
40	54.7	286.7	7.843	256.1	920.1	1,176.2
41	55.7	287.9	7.697	257.3	919.3	1,176.6
42	56.7	289.1	7.570	258.5	918.4	1,176.9
43	57.7	290.2	7.447	259.6	917.6	1,177.2
44	58.7	291.3	7.327	260.8	916.8	1,177.6
45	59.7	292.4	7.212	261.9	916.0	1,177.9
46	60.7	293.5	7.100	263.0	915.2	1,178.2
47	61.7	294.6	6.992	264.2	914.4	1,178.6
48	62.7	295.6	6.887	265.3	913.6	1,178.9
49	63.7	296.7	6.785	266.3	912.9	1,179.2
50	64.7	297.7	6.686	267.4	912.1	1,179.5
51	65.7	298.7	6.591	268.4	911.4	1,179.8
52	66.7	299.7	6.498	269.4	910.6	1,180.0
53	67.7	300.7	6.407	270.5	909.9	1,180.4
54	68.7	301.7	6.391	271.5	909.2	1,180.7
55	69.7	302.7	6.234	272.5	908.5	1,181.0
56	70.7	303.6	6.151	273.5	907.7	1,181.2
57	71.7	304.6	6.070	274.5	907.0	1,181.5
58	72.7	305.5	5.991	275.4	906.3	1,181.7
59	73.7	306.4	5.915	276.4	905.6	1,182.0
60	74.7	307.4	5.840	277.3	905.0	1,182.3
61	75.7	308.3	5.768	278.3	904.3	1,182.6
62	76.7	309.2	5.696	279.2	903.6	1,182.8
63	77.7	310.1	5.627	280.1	902.9	1,183.0
64	78.7	310.9	5.560	281.0	902.3	1,183.3
65	79.7	311.8	5.494	281.9	901.6	1,183.5
66	80.7	312.7	5.430	282.8	901.0	1,183.8
67	81.7	313.5	5.367	283.7	900.3	1,184.0
68	82.7	314.4	5.306	284.6	899.7	1,184.3
69	83.7	315.2	5.246	285.5	899.0	1,184.5
70	84.7	316.0	5.187	286.3	898.4	1,184.7
71	85.7	316.9	5.130	287.2	897.8	1,185.0
72	86.7	317.7	5.075	288.0	897.1	1,185.1
73	87.7	318.5	5.020	288.9	896.5	1,185.4
74	88.7	319.3	4.966	289.7	895.9	1,185.6
75	89.7	320.1	4.914	290.5	895.3	1,185.8
76	90.7	320.9	4.863	291.3	894.7	1,186.0
77	91.7	321.6	4.813	292.1	894.1	1,186.2
78	92.7	322.4	4.764	292.9	893.5	1,186.4
79	93.7	323.2	4.715	293.7	892.9	1,186.6

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
80	94.7	323.9	4.668	294.5	892.3	1,186.8
81	95.7	324.7	4.623	295.3	891.7	1,187.0
82	96.7	325.4	4.578	296.1	891.1	1,187.2
83	97.7	326.2	4.533	296.9	890.6	1,187.5
84	98.7	326.9	4.489	297.6	890.0	1,187.6
85	99.7	327.6	4.447	298.4	889.4	1,187.8
86	100.7	328.4	4.405	299.1	888.8	1,187.9
87	101.7	329.1	4.364	299.9	888.3	1,188.2
88	102.7	329.8	4.324	300.6	887.7	1,188.3
89	103.7	330.5	4.284	301.4	887.1	1,188.5
90	104.7	331.2	4.245	302.1	886.6	1,188.7
91	105.7	331.9	4.207	302.8	886.1	1,188.9
92	106.7	332.6	4.170	303.5	885.5	1,189.0
93	107.7	333.3	4.133	304.3	885.0	1,189.3
94	108.7	333.9	4.098	305.0	884.4	1,189.4
95	109.7	334.6	4.062	305.7	883.9	1,189.6
96	110.7	335.3	4.048	306.4	883.3	1,189.7
97	111.7	336.0	3.993	307.1	882.8	1,189.9
98	112.7	336.6	3.959	307.8	882.2	1,190.0
99	113.7	337.3	3.926	308.4	881.8	1,190.2
100	114.7	337.9	3.894	309.1	881.2	1,190.3
101	115.7	338.6	3.862	309.8	880.7	1,190.5
102	116.7	339.2	3.830	310.5	880.2	1,190.7
103	117.7	339.9	3.799	311.1	879.7	1,190.8
104	118.7	340.5	3.769	311.8	879.2	1,191.0
105	119.7	341.1	3.739	312.5	878.7	1,191.2
106	120.7	341.7	3.710	313.1	878.1	1,191.2
107	121.7	342.4	3.681	313.8	877.6	1,191.4
108	122.7	343.0	3.652	314.4	877.1	1,191.5
109	123.7	343.6	3.624	315.1	876.6	1,191.7
110	124.7	344.2	3.596	315.7	876.1	1,191.8
111	125.7	344.8	3.569	316.3	875.6	1,191.9
112	126.7	345.4	3.543	317.0	875.1	1,192.1
113	127.7	346.0	3.516	317.6	874.6	1,192.2
114	128.7	346.6	3.490	318.2	874.2	1,192.4
115	129.7	347.2	3.465	318.9	873.7	1,192.6
116	130.7	347.8	3.440	319.5	873.2	1,192.7
117	131.7	348.4	3.415	320.1	872.7	1,192.8
118	132.7	348.9	3.390	320.7	872.2	1,192.9
119	133.7	349.5	3.366	321.3	871.7	1,193.0

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
120	134.7	350.1	3.342	321.9	871.3	1,193.2
121	135.7	350.7	3.319	322.5	870.8	1,193.3
122	136.7	351.2	3.296	323.1	870.3	1,193.4
123	137.7	351.8	3.273	323.7	869.8	1,193.5
124	138.7	352.4	3.251	324.3	869.4	1,193.7
125	139.7	352.9	3.228	324.9	868.9	1,193.8
126	140.7	353.5	3.206	325.5	868.4	1,193.9
127	141.7	354.0	3.185	326.0	868.0	1,194.0
128	142.7	354.6	3.163	326.6	867.5	1,194.1
129	143.7	355.1	3.142	327.2	867.0	1,194.2
130	144.7	355.7	3.121	327.8	866.6	1,194.4
131	145.7	356.2	3.101	328.4	866.1	1,194.5
132	146.7	356.7	3.081	328.9	865.7	1,194.6
133	147.7	357.3	3.061	329.5	865.2	1,194.7
134	148.7	357.8	3.042	330.0	864.8	1,194.8
135	149.7	358.3	3.022	330.6	864.3	1,194.9
136	150.7	358.8	3.003	331.1	863.9	1,195.0
137	151.7	359.4	2.984	331.7	863.4	1,195.1
138	152.7	359.9	2.965	332.2	863.0	1,195.2
139	153.7	360.4	2.947	332.8	862.5	1,195.3
140	154.7	360.9	2.928	333.3	862.1	1,195.4
141	155.7	361.4	2.910	333.9	861.6	1,195.5
142	156.7	361.9	2.893	334.4	861.2	1,195.6
143	157.7	362.4	2.875	334.9	860.8	1,195.7
144	158.7	362.9	2.858	335.5	860.4	1,195.9
145	159.7	363.4	2.841	336.0	859.9	1,195.9
146	160.7	363.9	2.824	336.5	859.5	1,196.0
147	161.7	364.4	2.807	337.1	859.0	1,196.1
148	162.7	364.9	2.791	337.6	858.6	1,196.2
149	163.7	365.4	2.775	338.1	858.2	1,196.3
150	164.7	365.9	2.759	338.6	857.8	1,196.4
151	165.7	366.4	2.743	339.1	857.3	1,196.4
152	166.7	366.9	2.727	339.7	856.9	1,196.6
153	167.7	367.4	2.712	340.2	856.5	1,196.7
154	168.7	367.9	2.696	340.7	856.1	1,196.8
155	169.7	368.3	2.681	341.2	855.7	1,196.9
156	170.7	368.8	2.666	341.7	855.3	1,197.0
157	171.7	369.3	2.651	342.2	854.8	1,197.0
158	172.7	369.7	2.636	342.7	854.4	1,197.1
159	173.7	370.2	2.621	343.2	854.0	1,197.2

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
160	174.7	370.7	2.607	343.7	853.6	1,197.3
161	175.7	371.1	2.593	344.2	853.2	1,197.4
162	176.7	371.6	2.579	344.7	852.8	1,197.5
163	177.7	372.1	2.565	345.2	852.4	1,197.6
164	178.7	372.5	2.551	345.7	852.0	1,197.7
165	179.7	373.0	2.537	346.1	851.6	1,197.7
166	180.7	373.4	2.524	346.6	851.2	1,197.8
167	181.7	373.9	2.511	347.1	850.8	1,197.9
168	182.7	374.4	2.498	347.6	850.4	1,198.0
169	183.7	374.8	2.484	348.1	850.0	1,198.1
170	184.7	375.2	2.471	348.5	849.6	1,198.1
171	185.7	375.7	2.459	349.0	849.2	1,198.2
172	186.7	376.1	2.446	349.5	848.8	1,198.3
173	187.7	376.6	2.434	350.0	848.4	1,198.4
174	188.7	377.0	2.421	350.4	848.1	1,198.5
175	189.7	377.4	2.409	350.9	847.7	1,198.6
176	190.7	377.9	2.397	351.4	847.2	1,198.6
177	191.7	378.3	2.385	351.8	846.9	1,198.7
178	192.7	378.8	2.373	352.3	846.5	1,198.8
179	193.7	379.2	2.361	352.8	846.1	1,198.9
180	194.7	379.6	2.349	353.2	845.7	1,198.9
181	195.7	380.0	2.337	353.7	845.3	1,199.0
182	196.7	380.5	2.326	354.1	844.9	1,199.0
183	197.7	380.9	2.315	354.6	844.5	1,199.1
184	198.7	381.3	2.304	355.1	844.1	1,199.2
185	199.7	381.7	2.292	355.5	843.8	1,199.3
186	200.7	382.2	2.281	355.9	843.4	1,199.3
187	201.7	382.6	2.271	356.3	843.1	1,199.4
188	202.7	383.0	2.260	356.8	842.7	1,199.5
189	203.7	383.4	2.249	357.2	842.3	1,199.5
190	204.7	383.8	2.238	357.7	841.9	1,199.6
191	205.7	384.2	2.228	358.1	841.6	1,199.7
192	206.7	384.6	2.218	358.5	841.2	1,199.7
193	207.7	385.0	2.207	359.0	840.8	1,199.8
194	208.7	385.4	2.197	359.4	840.5	1,199.9
195	209.7	385.8	2.187	359.9	840.1	1,200.0
196	210.7	386.3	2.177	360.3	839.7	1,200.0
197	211.7	386.7	2.167	360.7	839.4	1,200.1
198	212.7	387.1	2.158	361.2	838.9	1,200.1
199	213.7	387.5	2.148	361.6	838.6	1,200.2

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
200	214.7	387.9	2.138	362.1	838.2	1,200.3
201	215.7	388.2	2.128	362.5	837.8	1,200.3
202	216.7	388.6	2.119	362.9	837.5	1,200.4
203	217.7	389.0	2.110	363.3	837.1	1,200.4
204	218.7	389.4	2.100	363.8	836.8	1,200.6
205	219.7	389.8	2.091	364.2	836.4	1,200.6
206	220.7	390.2	2.082	364.6	836.0	1,200.6
207	221.7	390.6	2.073	365.0	835.7	1,200.7
208	222.7	391.0	2.064	365.4	835.3	1,200.7
209	223.7	391.4	2.055	365.8	835.0	1,200.8
210	224.7	391.8	2.046	366.2	834.6	1,200.8
211	225.7	392.1	2.037	366.6	834.2	1,200.8
212	226.7	392.5	2.028	367.0	833.9	1,200.9
213	227.7	392.9	2.020	367.5	833.5	1,201.0
214	228.7	393.3	2.011	367.9	833.2	1,201.1
215	229.7	393.6	2.003	368.3	832.8	1,201.1
216	230.7	394.0	1.994	368.7	832.5	1,201.2
217	231.7	394.4	1.986	369.1	832.1	1,201.2
218	232.7	394.8	1.978	369.5	831.8	1,201.3
219	233.7	395.2	1.970	369.9	831.4	1,201.3
220	234.7	395.5	1.961	370.3	831.1	1,201.4
221	235.7	395.9	1.953	370.7	830.8	1,201.5
222	236.7	396.3	1.945	371.1	830.4	1,201.5
223	237.7	396.6	1.937	371.5	830.1	1,201.6
224	238.7	397.0	1.929	371.9	829.7	1,201.6
225	239.7	397.4	1.921	372.3	829.4	1,201.7
226	240.7	397.7	1.914	372.7	829.0	1,201.7
227	241.7	398.1	1.906	373.0	828.7	1,201.7
228	242.7	398.4	1.898	373.4	828.3	1,201.7
229	243.7	398.8	1.891	373.8	828.0	1,201.8
230	244.7	399.2	1.883	374.2	827.6	1,201.8
231	245.7	399.5	1.876	374.6	827.3	1,201.9
232	246.7	399.9	1.869	375.0	826.9	1,201.9
233	247.7	400.2	1.862	375.3	826.6	1,201.9
234	248.7	400.6	1.854	375.7	826.2	1,201.9
235	249.7	400.9	1.847	376.1	825.9	1,202.0
236	250.7	401.3	1.840	376.5	825.6	1,202.1
237	251.7	401.6	1.833	376.8	825.3	1,202.1
238	252.7	402.0	1.826	377.2	824.9	1,202.1
239	253.7	402.3	1.819	377.6	824.6	1,202.2

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
240	254.7	402.7	1.812	378.0	824.3	1,202.3
241	255.7	403.0	1.805	378.4	824.0	1,202.4
242	256.7	403.4	1.798	378.7	823.7	1,202.4
243	257.7	403.7	1.791	379.1	823.3	1,202.4
244	258.7	404.1	1.785	379.5	822.9	1,202.4
245	259.7	404.4	1.778	379.9	822.6	1,202.5
246	260.7	404.7	1.771	380.3	822.3	1,202.6
247	261.7	405.1	1.765	380.6	822.0	1,202.6
248	262.7	405.4	1.758	381.0	821.6	1,202.6
249	263.7	405.8	1.752	381.3	821.3	1,202.6
250	264.7	406.1	1.745	381.7	821.0	1,202.7
251	265.7	406.4	1.739	382.1	820.7	1,202.8
252	266.7	406.8	1.733	382.4	820.4	1,202.8
253	267.7	407.1	1.726	382.8	820.0	1,202.8
254	268.7	407.4	1.720	383.2	819.6	1,202.8
255	269.7	407.8	1.714	383.6	819.3	1,202.9
256	270.7	408.1	1.707	383.9	819.0	1,202.9
257	271.7	408.4	1.701	384.3	818.7	1,203.0
258	272.7	408.8	1.695	384.6	818.4	1,203.0
259	273.7	409.1	1.689	385.0	818.0	1,203.0
260	274.7	409.4	1.683	385.3	817.7	1,203.0
261	275.7	409.7	1.677	385.7	817.4	1,203.1
262	276.7	410.1	1.671	386.0	817.1	1,203.1
263	277.7	410.4	1.666	386.4	816.7	1,203.1
264	278.7	410.7	1.660	386.7	816.4	1,203.1
265	279.7	411.1	1.654	387.1	816.1	1,203.2
266	280.7	411.4	1.648	387.5	815.8	1,203.3
267	281.7	411.7	1.642	387.8	815.5	1,203.3
268	282.7	412.0	1.637	388.2	815.2	1,203.4
269	283.7	412.3	1.631	388.5	814.9	1,203.4
270	284.7	412.7	1.625	388.9	814.6	1,203.5
271	285.7	413.0	1.620	389.2	814.3	1,203.5
272	286.7	413.3	1.614	389.5	814.0	1,203.5
273	287.7	413.6	1.609	389.9	813.6	1,203.5
274	288.7	413.9	1.603	390.3	813.3	1,203.6
275	289.7	414.2	1.598	390.6	813.0	1,203.6
276	290.7	414.5	1.593	390.9	812.7	1,203.6
277	291.7	414.9	1.587	391.3	812.3	1,203.6
278	292.7	415.2	1.582	391.6	812.0	1,203.6
279	293.7	415.5	1.577	392.0	811.7	1,203.7

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
280	294.7	415.8	1.571	392.3	811.4	1,203.7
281	295.7	416.1	1.566	392.6	811.1	1,203.7
282	296.7	416.4	1.561	393.0	810.8	1,203.8
283	297.7	416.7	1.556	393.3	810.5	1,203.8
284	298.7	417.0	1.551	393.7	810.2	1,203.9
285	299.7	417.3	1.546	394.0	809.9	1,203.9
286	300.7	417.6	1.541	394.3	809.6	1,203.9
287	301.7	417.9	1.536	394.7	809.3	1,204.0
288	302.7	418.2	1.531	395.0	809.0	1,204.0
289	303.7	418.5	1.526	395.3	808.7	1,204.0
290	304.7	418.8	1.521	395.7	808.4	1,204.1
291	305.7	419.2	1.516	396.0	808.1	1,204.1
292	306.7	419.5	1.511	396.3	807.8	1,204.1
293	307.7	419.8	1.507	396.6	807.5	1,204.1
294	308.7	420.1	1.502	397.0	807.2	1,204.2
295	309.7	420.4	1.497	397.3	806.9	1,204.2
296	310.7	420.6	1.492	397.6	806.6	1,204.2
297	311.7	420.9	1.488	397.9	806.3	1,204.2
298	312.7	421.2	1.483	398.3	806.0	1,204.3
299	313.7	421.5	1.478	398.6	805.7	1,204.3
300	314.7	421.8	1.474	398.9	805.4	1,204.3
310	324.7	424.7	1.429	402.1	802.4	1,204.5
320	334.7	427.6	1.387	405.3	799.4	1,204.7
330	344.7	430.4	1.347	408.3	796.5	1,204.8
340	354.7	433.1	1.310	411.3	793.7	1,205.0
350	364.7	435.7	1.274	414.3	790.9	1,205.2
360	374.7	438.3	1.240	417.1	788.1	1,205.2
370	384.7	440.9	1.208	420.0	785.4	1,205.4
380	394.7	443.4	1.178	422.8	782.6	1,205.4
390	404.7	445.8	1.149	425.5	780.0	1,205.5
400	414.7	448.2	1.121	428.2	777.4	1,205.6
410	424.7	450.6	1.095	430.8	774.8	1,205.6
420	434.7	452.9	1.069	433.4	772.2	1,205.6
430	444.7	455.2	1.045	436.0	769.6	1,205.6
440	454.7	457.4	1.022	438.6	767.0	1,205.6
450	464.7	459.6	1.000	441.0	764.5	1,205.5
460	474.7	461.8	0.979	443.5	762.0	1,205.5
470	484.7	463.9	0.958	445.9	759.5	1,205.4
480	494.7	466.0	0.939	448.3	757.1	1,205.4
490	504.7	468.1	0.920	450.6	754.7	1,205.3

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
500	514.7	470.1	0.901	453.0	752.2	1,205.2
510	524.7	472.1	0.884	455.2	749.9	1,205.1
520	534.7	474.1	0.867	457.5	747.5	1,205.0
530	544.7	476.0	0.851	459.8	745.1	1,204.9
540	554.7	478.0	0.835	461.9	742.8	1,204.7
550	564.7	479.9	0.820	464.1	740.5	1,204.6
560	574.7	481.7	0.805	466.3	738.2	1,204.5
570	584.7	483.6	0.791	468.4	735.9	1,204.3
580	594.7	485.4	0.777	470.6	733.6	1,204.2
590	604.7	487.2	0.764	472.7	731.3	1,204.0
600	614.7	488.9	0.751	474.7	729.1	1,203.8
610	624.7	490.7	0.739	476.7	726.9	1,203.6
620	634.7	492.4	0.727	478.7	724.7	1,203.4
630	644.7	494.1	0.715	480.7	722.5	1,203.2
640	654.7	495.8	0.704	482.7	720.3	1,203.0
650	664.7	497.5	0.693	484.7	718.1	1,202.8
660	674.7	499.2	0.682	486.7	715.9	1,202.6
670	684.7	500.8	0.671	488.6	713.8	1,202.4
680	694.7	502.4	0.661	490.5	711.6	1,202.1
690	704.7	504.0	0.651	492.4	709.5	1,201.9
700	714.7	505.5	0.642	494.3	707.3	1,201.6
710	724.7	507.1	0.632	496.2	705.2	1,201.4
720	734.7	508.7	0.623	498.0	703.1	1,201.1
730	744.7	510.2	0.614	499.8	701.0	1,200.8
740	754.7	511.7	0.606	501.6	698.9	1,200.5
750	764.7	513.2	0.597	503.4	696.8	1,200.2
760	774.7	514.7	0.589	505.2	694.8	1,200.0
770	784.7	516.1	0.581	507.0	692.7	1,199.7
780	794.7	517.6	0.573	508.8	690.7	1,199.5
790	804.7	519.0	0.566	510.5	688.6	1,199.1
800	814.7	520.5	0.558	512.3	686.5	1,198.8
810	824.7	521.9	0.551	514.0	684.6	1,198.6
820	834.7	523.3	0.544	515.7	682.6	1,198.3
830	844.7	524.7	0.537	517.4	680.6	1,198.0
840	854.7	526.0	0.530	519.0	678.6	1,197.6
850	864.7	527.4	0.523	520.7	676.6	1,197.3
860	874.7	528.7	0.517	522.4	674.6	1,197.0
870	884.7	530.1	0.511	524.1	672.6	1,196.7
880	894.7	531.4	0.504	525.7	670.6	1,196.3
890	904.7	532.7	0.498	527.4	668.6	1,196.0

Steam Tables

STEAM PRESSURE PSIG	STEAM PRESSURE PSIA	SATURATION TEMPERATURE °F	SPECIFIC VOLUME CU.FT./LB.	HEAT CONTENT (ABOVE 32°F) BTU/LB		
				SENSIBLE	LATENT	TOTAL
900	914.7	534.0	0.492	529.0	666.6	1,195.6
910	924.7	535.3	0.486	530.6	664.7	1,195.3
920	934.7	536.6	0.481	532.2	662.7	1,194.9
930	944.7	537.9	0.475	533.8	660.7	1,194.5
940	954.7	539.1	0.470	535.4	658.7	1,194.1
950	964.7	540.4	0.464	536.9	656.8	1,193.7
960	974.7	541.6	0.459	538.5	654.9	1,193.4
970	984.7	542.9	0.454	540.0	653.0	1,193.0
980	994.7	544.1	0.449	541.6	651.0	1,192.6
990	1,004.7	545.3	0.444	543.1	649.1	1,192.2
1,000	1,014.7	546.5	0.439	544.6	647.2	1,191.8
1,050	1,064.7	552.4	0.416	552.2	637.6	1,189.8
1,100	1,114.7	558.1	0.395	559.5	628.2	1,187.7
1,150	1,164.7	563.6	0.375	566.7	618.9	1,185.6
1,200	1,214.7	568.9	0.357	573.7	609.6	1,183.3
1,250	1,264.7	574.0	0.341	580.6	600.3	1,180.9
1,300	1,314.7	579.0	0.325	587.4	591.1	1,178.5
1,350	1,364.7	583.9	0.311	594.0	581.9	1,175.9
1,400	1,414.7	588.6	0.298	600.5	572.8	1,173.3
1,450	1,464.7	593.2	0.285	607.0	563.6	1,170.6
1,500	1,514.7	597.7	0.274	613.4	554.5	1,167.9
1,550	1,564.7	602.0	0.263	619.6	545.4	1,165.0
1,600	1,614.7	606.3	0.252	625.8	536.2	1,162.0
1,650	1,664.7	610.4	0.242	632.0	527.1	1,159.1
1,700	1,714.7	614.5	0.233	638.0	517.9	1,155.9
1,750	1,764.7	618.5	0.224	644.1	508.7	1,152.8
1,800	1,814.7	622.3	0.216	650.0	499.4	1,149.4
1,850	1,864.7	626.1	0.208	655.9	490.0	1,145.9
1,900	1,914.7	629.8	0.200	661.8	480.6	1,142.4
1,950	1,964.7	633.5	0.193	667.7	471.2	1,138.9
2,000	2,014.7	637.0	0.187	673.6	461.5	1,135.1
2,050	2,064.7	640.5	0.179	679.4	451.8	1,131.3
2,100	2,114.7	643.9	0.173	685.3	442.1	1,127.2
2,150	2,164.7	647.3	0.167	691.1	432.1	1,123.2
2,200	2,214.7	650.6	0.161	697.0	422.0	1,119.0
2,250	2,264.7	653.8	0.155	702.8	411.7	1,114.5
2,300	2,314.7	657.0	0.150	708.7	401.3	1,110.0
2,350	2,364.7	660.1	0.144	714.6	390.6	1,105.2
2,400	2,414.7	663.2	0.139	720.6	379.7	1,100.3
2,450	2,464.7	666.2	0.134	726.6	368.5	1,095.1
2,500	2,514.7	669.2	0.129	732.7	357.1	1,089.8

Steam Flow Through Orifices

ORIFICE DIA. INCHES	STEAM FLOW - LBS/HR.												
	STEAM PRESSURE - PSIG												
	2	5	10	15	25	50	75	100	125	150	200	250	300
1/32	0.3	0.5	0.6	0.7	0.9	1.5	2.1	2.7	3.3	3.9	5.1	6.3	7.4
1/16	1.3	1.9	2.3	2.8	3.8	6.1	8.5	10.8	13.2	15.6	20.3	25.1	29.8
3/32	2.8	4.2	5.3	6.3	8.5	13.8	19.1	24.4	29.7	35.1	45.7	56.4	67.0
1/8	4.5	7.5	9.4	11.2	15.0	24.5	34.0	43.4	52.9	62.4	81.3	100	119
5/32	7.8	11.7	14.6	17.6	23.5	38.3	53.1	67.9	82.7	97.4	127	156	186
3/16	11.2	16.7	21.0	25.3	33.8	55.1	76.4	97.7	119	140	183	226	268
7/32	15.3	22.9	28.7	34.4	46.0	75.0	104	133	162	191	249	307	365
1/4	20.0	29.8	37.4	45.0	60.1	98.0	136	173	212	250	325	401	477
9/32	25.2	37.8	47.4	56.9	76.1	124	172	220	268	316	412	507	603
5/16	31.2	46.6	58.5	70.3	94.0	153	212	272	331	390	508	627	745
11/32	37.7	56.4	70.7	85.1	114	185	257	329	400	472	615	758	901
3/8	44.9	67.1	84.2	101	135	221	306	391	476	561	732	902	1073
13/32	52.7	78.8	98.8	119	159	259	359	459	559	659	859	1059	1259
7/16	61.1	91.4	115	138	184	300	416	532	648	764	996	1228	1460
15/32	70.2	105	131	158	211	344	478	611	744	877	1144	1410	1676
1/2	79.8	119	150	180	241	392	544	695	847	998	1301	1604	1907

Notes:

1. Steam Leaks and Energy Wasted. A ⅛″ diameter hole in a steam pipe can discharge 62.4 Lb.Stm./Hr. at 150 psig, resulting in 30 tons of coal, 4,800 gallons of oil, or 7,500 therms of gas to be wasted each year (assuming 8,400 hour per year operation).

Flash Steam

FLASH STEAM FLOW
LBS. STEAM / HR. PER 100 LBS OF STEAM CONDENSATE / HR.

STEAM PRESS. PSIG	CONDENSATE PRESSURE PSIG																
	0	1	3	5	7	10	12	15	20	25	30	40	50	60	75	85	100
0	0.0																
1	0.3	0.0															
3	1.0	0.6	0.0														
5	1.6	1.2	0.6	0.0													
7	2.1	1.8	1.1	0.6	0.0												
10	2.8	2.5	1.9	1.3	0.7	0.0											
12	3.3	3.0	2.3	1.7	1.2	0.5	0.0										
15	3.9	3.6	3.0	2.4	1.8	1.1	0.6	0.0									
20	4.9	4.5	3.9	3.3	2.8	2.1	1.6	1.0	0.0								
25	5.7	5.4	4.8	4.2	3.7	2.9	2.5	1.8	0.9	0.0							
30	6.5	6.2	5.5	5.0	4.4	3.7	3.3	2.6	1.7	0.8	0.0						
40	7.8	7.5	6.9	6.3	5.8	5.1	4.6	4.0	3.0	2.2	1.4	0.0					
50	9.0	8.7	8.1	7.5	7.0	6.3	5.8	5.2	4.2	3.4	2.6	1.2	0.0				
60	10.0	9.7	9.1	8.5	8.0	7.3	6.9	6.2	5.3	4.5	3.7	2.3	1.1	0.0			
75	11.4	11.1	10.5	9.9	9.4	8.7	8.2	7.6	6.7	5.9	5.1	3.7	2.5	1.5	0.0		
85	12.2	11.9	11.3	10.7	10.2	9.5	9.1	8.5	7.5	6.7	6.0	4.6	3.4	2.3	0.9	0.0	
100	13.3	13.0	12.4	11.8	11.3	10.6	10.2	9.6	8.7	7.9	7.1	5.8	4.6	3.5	2.1	1.2	0.0
120	14.6	14.3	13.7	13.2	12.7	12.0	11.5	11.0	10.0	9.2	8.5	7.2	6.0	4.9	3.5	2.6	1.5
125	14.9	14.6	14.0	13.5	13.0	12.3	11.9	11.3	10.4	9.5	8.8	7.5	6.3	5.3	3.8	3.0	1.8
150	16.3	16.0	15.4	14.9	14.4	13.7	13.3	12.7	11.8	11.0	10.3	9.0	7.8	6.8	5.4	4.5	3.3
175	17.6	17.3	16.7	16.2	15.7	15.0	14.6	14.0	13.1	12.3	11.6	10.3	9.2	8.1	6.7	5.9	4.7
200	18.7	18.4	17.9	17.4	16.9	16.2	15.8	15.2	14.3	13.5	12.8	11.5	10.4	9.4	8.0	7.2	6.0
225	19.8	19.5	18.9	18.4	17.9	17.3	16.9	16.3	15.4	14.6	13.9	12.6	11.5	10.5	9.1	8.3	7.2
250	20.8	20.5	19.9	19.4	18.9	18.3	17.8	17.3	16.4	15.6	14.9	13.7	12.5	11.5	10.2	9.4	8.2
275	21.7	21.4	20.8	20.3	19.8	19.2	18.8	18.2	17.4	16.6	15.9	14.6	13.5	12.5	11.2	10.4	9.2
300	22.5	22.2	21.7	21.2	20.7	20.1	19.7	19.1	18.2	17.5	16.8	15.5	14.4	13.4	12.1	11.3	10.2

Low Pressure Steam Piping Warm-Up Loads

PIPE SIZE	POUNDS OF STEAM PER 100 FEET OF PIPE							
	STEAM PRESSURE PSIG							
	0	1	3	5	7	10	12	15
1/2"	1	1	2	2	2	2	2	2
3/4"	2	2	2	2	2	2	2	2
1"	3	3	3	3	3	3	4	4
1-1/4"	4	4	4	4	4	5	5	5
1-1/2"	5	5	5	5	5	6	6	6
2"	6	6	7	7	7	7	8	8
2-1/2"	10	10	10	11	11	12	12	13
3"	13	13	14	14	15	15	16	17
4"	18	19	19	20	21	22	23	24
5"	25	25	26	27	28	30	31	32
6"	32	33	34	36	37	39	40	42
8"	48	49	51	54	56	58	60	62
10"	68	70	73	76	79	83	85	89
12"	83	85	89	93	96	101	104	108
14"	92	94	98	103	106	111	115	119
16"	105	108	113	118	122	128	132	137
18"	119	122	127	133	137	144	149	154
20"	132	135	142	148	153	160	166	172
22"	146	150	157	164	169	177	183	190
24"	159	163	170	178	184	193	199	207
26"	173	177	185	194	200	210	217	225
28"	187	191	200	209	216	226	234	243
30"	200	205	214	224	232	243	251	260
32"	214	219	229	239	247	259	268	278
34"	227	233	243	254	263	275	284	295
36"	241	246	258	269	278	292	301	313
42"	281	288	301	314	325	341	352	366
48"	321	328	343	358	371	389	402	417
54"	361	370	387	404	418	438	453	470
60"	402	411	430	449	465	487	503	523
72"	483	494	517	539	558	585	604	628
84"	564	577	603	629	652	683	706	733
96"	645	660	690	720	745	781	807	838
CORR. FACTOR	1.50	1.49	1.46	1.44	1.43	1.41	1.40	1.39

Notes:

1. Table based on 70°F. ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F., multiply table values by correction factor.

Medium Pressure Steam Piping Warm-Up Loads

PIPE SIZE	POUNDS OF STEAM PER 100 FEET OF PIPE								
	STEAM PRESSURE PSIG								
	20	25	30	40	50	60	75	85	100
1/2"	2	2	2	2	2	3	3	3	3
3/4"	3	3	3	3	3	3	4	4	4
1"	4	4	4	5	5	5	5	6	6
1-1/4"	5	6	6	6	7	7	7	8	8
1-1/2"	6	7	7	7	8	8	9	9	10
2"	8	9	9	10	11	11	12	12	13
2-1/2"	13	14	15	16	17	17	19	19	20
3"	18	18	19	21	22	23	24	25	27
4"	25	26	27	29	31	32	35	36	38
5"	34	35	37	40	42	44	47	49	51
6"	44	46	48	51	55	57	61	63	66
8"	66	69	72	77	82	86	92	95	100
10"	94	98	102	110	116	122	130	135	142
12"	115	120	125	134	142	149	159	165	173
14"	126	132	138	148	157	164	175	182	191
16"	145	152	158	170	180	188	201	209	219
18"	163	171	178	191	203	213	227	235	247
20"	182	191	198	213	226	237	252	262	275
22"	201	211	220	236	250	262	279	290	304
24"	219	229	239	257	272	285	304	316	331
26"	238	250	260	279	296	310	331	344	360
28"	257	269	280	301	319	334	356	370	388
30"	275	289	300	323	342	358	382	397	416
32"	294	308	321	344	365	382	408	424	444
34"	312	327	341	366	388	407	434	450	472
36"	331	347	361	388	411	431	459	477	500
42"	386	405	422	453	480	503	536	557	584
48"	441	463	482	517	548	574	612	636	667
54"	497	521	542	583	617	647	690	717	751
60"	552	579	603	648	686	719	767	797	835
72"	664	696	724	778	825	864	921	957	1,003
84"	775	812	846	908	963	1,009	1,075	1,117	1,171
96"	886	929	967	1,039	1,101	1,153	1,230	1,278	1,340
CORR. FACTOR	1.37	1.36	1.35	1.32	1.31	1.29	1.28	1.27	1.26

Notes:

1. Table based on 70°F. ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F., multiply table values by correction factor.

High Pressure Steam Piping Warm-Up Loads

PIPE SIZE	POUNDS OF STEAM PER 100 FEET OF PIPE								
	STEAM PRESSURE PSIG								
	120	125	150	175	200	225	250	275	300
1/2"	3	3	3	4	4	4	4	4	5
3/4"	4	4	4	5	5	5	5	6	7
1"	6	6	7	7	7	8	8	8	11
1-1/4"	8	9	9	9	10	10	11	11	15
1-1/2"	10	10	11	11	12	12	13	13	18
2"	14	14	14	15	16	17	17	18	25
2-1/2"	21	22	23	24	25	26	27	28	39
3"	28	28	30	32	33	34	36	37	52
4"	40	40	43	45	47	49	51	53	75
5"	54	55	58	61	64	66	69	71	104
6"	70	71	75	79	83	86	89	92	144
8"	106	107	113	119	125	129	134	139	218
10"	150	152	161	169	177	184	191	197	275
12"	183	186	197	206	216	225	233	241	329
14"	202	204	217	227	238	247	257	266	362
16"	231	234	248	261	273	284	295	305	416
18"	261	264	280	294	308	320	332	343	470
20"	290	294	312	327	343	356	370	382	523
22"	322	326	345	362	380	394	409	423	578
24"	350	354	375	394	413	429	445	460	631
26"	381	386	409	429	449	467	485	501	384
28"	410	416	440	462	484	503	522	540	739
30"	440	446	472	496	519	540	560	579	794
32"	469	476	504	529	554	576	598	618	844
34"	499	506	536	562	589	612	635	657	900
36"	528	536	567	596	624	648	673	696	955
42"	617	626	663	696	729	757	786	813	1,116
48"	705	714	757	794	832	865	898	928	1,275
54"	794	805	852	895	937	974	1,011	1,045	1,436
60"	883	894	948	995	1,042	1,083	1,124	1,162	1,597
72"	1,060	1,075	1,139	1,195	1,252	1,301	1,350	1,396	1,946
84"	1,238	1,254	1,329	1,395	1,461	1,518	1,576	1,630	2,241
96"	1,415	1,435	1,520	1,595	1,671	1,737	1,803	1,864	2,510
CORR. FACTOR	1.25	1.25	1.24	1.23	1.22	1.22	1.21	1.21	1.20

Notes:

1. Table based on 70°F. ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F., multiply table values by correction factor.

Low Pressure Steam Piping Operating Loads

PIPE SIZE	POUNDS OF STEAM PER HOUR PER 100 FEET OF PIPE							
	STEAM PRESSURE PSIG							
	0	1	3	5	7	10	12	15
1/2"	2	2	2	2	3	3	3	3
3/4"	3	3	3	3	3	3	3	4
1"	3	3	3	4	4	4	4	4
1-1/4"	4	4	4	4	5	5	5	5
1-1/2"	4	4	5	5	5	6	6	6
2"	5	5	6	6	6	7	7	7
2-1/2"	6	6	7	7	7	8	8	9
3"	7	8	8	8	9	9	10	10
4"	9	9	10	10	11	12	12	13
5"	11	11	12	13	13	14	15	15
6"	13	13	14	15	15	16	17	18
8"	16	17	18	19	19	21	22	23
10"	20	20	21	23	24	25	26	28
12"	23	24	25	26	28	29	31	32
14"	25	26	27	29	30	32	33	35
16"	28	29	31	32	34	36	38	40
18"	31	32	34	36	38	40	42	44
20"	34	35	37	39	41	44	46	48
22"	37	38	41	43	45	48	50	53
24"	40	41	44	47	49	52	54	57
26"	47	48	51	54	57	60	63	66
28"	50	52	55	58	61	65	68	72
30"	54	56	59	62	65	70	73	77
32"	57	59	63	67	70	74	78	82
34"	61	63	67	71	74	79	83	87
36"	65	67	71	75	78	84	87	92
42"	75	78	83	87	92	98	102	107
48"	86	89	94	100	105	112	117	123
54"	97	100	106	112	118	125	131	138
60"	108	111	118	125	131	139	146	153
72"	129	133	141	150	157	167	175	184
84"	151	156	165	175	183	195	204	215
96"	172	178	189	200	209	223	233	245
CORR. FACTOR	1.70	1.68	1.66	1.64	1.60	1.58	1.57	1.55

Notes:

1. Table based on 70°F. ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F., multiply table values by correction factor.
3. Table values include convection and radiation loads with 80% efficient insulation.

Medium Pressure Steam Piping Operating Loads

PIPE SIZE	POUNDS OF STEAM PER HOUR PER 100 FEET OF PIPE								
	STEAM PRESSURE PSIG								
	20	25	30	40	50	60	75	85	100
1/2"	3	3	4	4	4	5	5	5	6
3/4"	4	4	4	5	5	6	6	6	7
1"	5	5	5	6	6	7	7	8	8
1-1/4"	6	6	6	7	8	8	9	9	10
1-1/2"	6	7	7	8	9	9	10	11	11
2"	8	8	9	10	11	11	12	13	14
2-1/2"	9	10	10	12	12	13	14	15	16
3"	11	12	12	14	15	16	17	18	19
4"	14	15	16	17	18	20	21	23	24
5"	17	18	19	21	22	24	26	27	29
6"	19	21	22	24	26	28	30	32	34
8"	25	26	28	30	33	35	38	40	43
10"	30	32	34	37	40	43	47	49	53
12"	35	37	39	43	47	50	54	57	61
14"	38	40	43	47	51	54	59	62	67
16"	43	45	48	53	57	61	67	70	75
18"	47	50	53	59	64	68	74	78	84
20"	52	56	59	65	70	75	82	86	92
22"	57	60	64	70	76	81	89	94	101
24"	61	65	69	76	83	88	96	102	109
26"	72	77	81	89	97	103	113	110	117
28"	77	82	87	96	104	111	122	129	138
30"	83	88	93	103	112	119	131	138	148
32"	88	94	100	110	119	127	139	147	157
34"	94	100	106	117	127	135	148	156	167
36"	99	106	112	124	134	143	157	166	177
42"	116	124	131	144	157	167	183	193	207
48"	132	141	149	165	179	191	209	221	236
54"	149	159	168	186	201	215	235	248	266
60"	165	177	187	206	224	239	261	276	295
72"	199	212	224	247	268	287	314	331	354
84"	232	247	261	289	313	334	366	386	413
96"	265	283	299	330	358	382	418	442	472
CORR. FACTOR	1.52	1.51	1.50	1.48	1.47	1.45	1.43	1.42	1.41

Notes:

1. Table based on 70°F. ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F., multiply table values by correction factor.
3. Table values include convection and radiation loads with 80% efficient insulation.

High Pressure Steam Piping Operating Loads

PIPE SIZE	POUNDS OF STEAM PER HOUR PER 100 FEET OF PIPE								
	STEAM PRESSURE PSIG								
	120	125	150	175	200	225	250	275	300
1/2"	6	6	7	7	8	8	8	9	9
3/4"	7	7	8	9	9	10	10	11	11
1"	9	9	10	10	11	12	12	13	14
1-1/4"	11	11	12	13	14	14	15	16	17
1-1/2"	12	12	13	14	15	16	17	18	19
2"	15	15	16	18	19	20	21	22	23
2-1/2"	18	18	19	21	22	23	25	26	27
3"	21	21	23	25	26	28	29	31	32
4"	26	27	29	31	33	35	37	38	40
5"	31	32	35	37	40	42	44	46	49
6"	37	38	41	44	46	49	52	54	57
8"	47	48	52	55	59	62	66	69	72
10"	57	58	63	67	72	76	80	84	88
12"	66	68	73	79	84	89	93	98	103
14"	72	74	80	85	91	96	102	107	112
16"	81	83	90	96	103	109	115	121	126
18"	91	92	100	107	115	121	128	134	141
20"	100	102	110	118	126	134	141	148	155
22"	109	111	120	129	138	146	154	161	169
24"	118	120	130	140	149	158	167	175	183
26"	127	129	140	150	161	170	179	188	197
28"	149	152	165	177	189	182	192	201	211
30"	160	163	177	190	203	214	226	237	249
32"	170	174	189	202	216	229	241	253	265
34"	181	185	200	215	230	243	256	269	282
36"	192	195	212	228	243	257	271	285	299
42"	224	228	248	265	284	300	317	332	348
48"	256	261	283	303	324	343	362	380	398
54"	287	293	318	341	365	386	407	427	448
60"	319	326	354	379	406	429	452	475	498
72"	383	391	425	455	487	514	543	570	597
84"	447	456	495	531	568	600	633	665	697
96"	511	521	566	607	649	686	724	760	796
CORR. FACTOR	1.39	1.39	1.39	1.38	1.37	1.37	1.36	1.36	1.35

Notes:

1. Table based on 70°F. ambient temperature, standard weight steel pipe to 250 psig, and extra-strong weight steel pipe above 250 psig.
2. For ambient temperatures of 0°F., multiply table values by correction factor.
3. Table values include convection and radiation loads with 80% efficient insulation.

Boiling Points of Water

PSIA	BOILING POINT °F.	PSIA	BOILING POINT °F.	PSIA	BOILING POINT °F.
0.5	79.6	44	273.1	150	358.5
1	101.7	46	275.8	175	371.8
2	126.0	48	278.5	200	381.9
3	141.4	50	281.0	225	391.9
4	152.9	52	283.5	250	401.0
5	162.2	54	285.9	275	409.5
6	170.0	56	288.3	300	417.4
7	176.8	58	290.5	325	424.8
8	182.8	60	292.7	350	431.8
9	188.3	62	294.9	375	438.4
10	193.2	64	297.0	400	444.7
11	197.7	66	299.0	425	450.7
12	201.9	68	301.0	450	456.4
13	205.9	70	303.0	475	461.9
14	209.6	72	304.9	500	467.1
14.69	212.0	74	306.7	525	472.2
15	213.0	76	308.5	550	477.1
16	216.3	78	310.3	575	481.8
17	219.4	80	312.1	600	486.3
18	222.4	82	313.8	625	490.7
19	225.2	84	315.5	650	495.0
20	228.0	86	317.1	675	499.2
22	233.0	88	318.7	700	503.2
24	237.8	90	320.3	725	507.2
26	242.3	92	321.9	750	511.0
28	246.4	94	323.4	775	514.7
30	250.3	96	324.9	800	518.4
32	254.1	98	326.4	825	521.9
34	257.6	100	327.9	850	525.4
36	261.0	105	331.4	875	528.8
38	264.2	110	334.8	900	532.1
40	267.3	115	338.1	950	538.6
42	270.2	120	341.3	1000	544.8

Comparison of Common Steam Heating Units of Measure

MBH (1000 BTUH)	STEAM LB./HR. (1)	EDR SQ.FT.	BOILER HP	CONDENSATE FLOW RATE GPM	COND. PUMP CAPACITY GPM (2)
10	10.6	42	0.3	0.02	0.06
25	26.4	104	0.7	0.05	0.15
50	52.9	208	1.5	0.10	0.30
75	79.3	313	2.2	0.16	0.48
100	105.8	417	2.9	0.21	0.63
200	211.5	833	5.8	0.41	1.23
300	317.3	1,250	8.7	0.62	1.86
400	423.0	1,667	11.6	0.83	2.49
500	528.8	2,083	14.5	1.03	3.09
750	793.1	3,125	21.7	1.55	4.65
1,000	1,058	4,167	29.0	2.07	6.21
1,250	1,322	5,208	36.2	2.58	7.74
1,500	1,418	6,250	43.5	3.10	9.30
1,750	1,851	7,292	50.7	3.62	10.8
2,000	2,115	8,333	58.0	4.13	12.4
2,500	2,644	10,417	72.5	5.17	15.5
3,000	3,173	12,500	87.0	6.20	18.6
4,000	4,230	16,667	115.9	8.27	24.8
5,000	5,288	20,833	144.9	10.3	30.9
7,500	7,931	31,250	217.4	15.5	46.5
10,000	10,575	41,667	289.9	20.7	62.1
15,000	15,862	62,500	434.8	31.0	93.0
20,000	21,150	83,333	579.7	41.3	124
25,000	26,438	104,167	724.6	51.7	155
30,000	31,725	125,000	869.6	62.0	186
35,000	37,014	145,833	1,015	72.3	217
40,000	42,301	166,667	1,159	82.7	248
50,000	52,876	208,333	1,449	103.3	310

Notes:

1. Steam flow rate is based on 15 psig steam with an enthalpy of 945.6 Btu/Lb.
2. Condensate pump capacity is equal to three times the condensate flow rate.

1 Psig Steam Piping Systems–Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.125	0.25	0.5	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	4	6	9						
3/4	10	14	20	18	Pressure	Drop	Governs	with	
1	20	28	40	29	these	Pipe	Sizes		
1-1/4	44	62	87	49					
1-1/2	68	96	135	67	135				
2	137	194	274	111	222				
2-1/2	226	320	452	158	317				
3	414	585	822	245	489	734			
4	874	1,236	1,748	421	842	1,263	1,685		
5	1,608	2,274	3,217	659	1,318	1,978	2,637		
6	2,654	3,753	5,308	956	1,912	2,867	3,823	4,779	
8	5,525	7,813		1,655	3,310	4,965	6,620	8,275	9,930
10	10,082	14,258		2,609	5,218	7,826	10,435	13,044	15,653
12	16,181			3,742	7,483	11,225	14,967	18,708	22,450
14	20,959			4,562	9,123	13,685	18,247	22,809	27,370
16	30,212			6,043	12,086	18,128	24,171	30,214	36,257
18	41,576			7,732	15,463	23,195	30,927	38,659	46,390
20	55,192			9,629	19,257	28,886	38,514	48,143	57,771
22				11,733	23,466	35,200	46,933	58,666	70,399
24				14,046	28,092	42,137	56,183	70,229	84,275
26				16,566	33,132	49,698	66,265	82,831	99,397
28				19,294	38,589	57,883	77,178	96,472	115,767
30				22,231	44,461	66,692	88,922	111,153	133,384
32				25,375	50,749	76,124	101,498	126,873	152,248
34				28,726	57,453	86,179	114,906	143,632	172,359
36				32,286	64,572	96,859	129,145	161,431	193,717
42				44,213	88,425	132,638	176,851	221,064	265,276
48				58,010	116,020	174,030	232,040	290,050	348,060
54				73,678	147,356	221,034	294,712	368,390	442,069
60	Velocity	Governs	with	91,217	182,434	273,651	364,868	456,085	547,302
72	these	Pipe	Sizes	131,907	263,815	395,722	527,629	659,537	791,444
84				180,081	360,162	540,243	720,324	900,404	1,080,485
96				235,738	471,475	707,213	942,951	1,178,689	1,414,426

Notes:

1. **Maximum recommended pressure drop / velocity: 0.125 Psig/100 Ft. / 4,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

3 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. PRESSURE DROP PSIG/100 FT. 0.125	0.25	0.5	VELOCITY FPM (MPH) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	5	6	9						
3/4	10	15	21	20	Pressure	Drop	Governs	with	
1	21	30	42	32	these	Pipe	Sizes		
1-1/4	46	65	92	55					
1-1/2	72	101	143	75					
2	145	205	290	124	248				
2-1/2	239	338	478	177	354				
3	437	619	870	274	547	821			
4	924	1,307	1,849	471	942	1,413			
5	1,701	2,405	3,402	737	1,475	2,212	2,949		
6	2,807	3,969	5,614	1,069	2,138	3,207	4,276	5,345	
8	5,843	8,263		1,851	3,702	5,553	7,404	9,255	11,106
10	10,662	15,078		2,918	5,835	8,753	11,670	14,588	17,506
12	17,112	24,200		4,185	8,369	12,554	16,738	20,923	25,108
14	22,165			5,102	10,204	15,305	20,407	25,509	30,611
16	31,951			6,758	13,516	20,275	27,033	33,791	40,549
18	43,968			8,647	17,294	25,941	34,588	43,235	51,883
20	58,368			10,768	21,537	32,305	43,074	53,842	64,611
22	75,290			13,122	26,245	39,367	52,489	65,611	78,734
24				15,709	31,417	47,126	62,834	78,543	94,252
26				18,527	37,055	55,582	74,110	92,637	111,164
28				21,579	43,157	64,736	86,315	107,893	129,472
30				24,862	49,725	74,587	99,450	124,312	149,175
32				28,379	56,757	85,136	113,515	141,893	170,272
34				32,127	64,255	96,382	128,509	160,637	192,764
36				36,109	72,217	108,326	144,434	180,543	216,651
42				49,447	98,894	148,341	197,788	247,235	296,682
48				64,878	129,755	194,633	259,511	324,388	389,266
54				82,401	164,801	247,202	329,603	412,003	494,404
60	Velocity	Governs	with	102,016	204,032	306,048	408,064	510,080	612,096
72	these	Pipe	Sizes	147,524	295,047	442,571	590,094	737,618	885,141
84				201,400	402,801	604,201	805,601	1,007,001	1,208,402
96				263,646	527,292	790,939	1,054,585	1,318,231	1,581,877

Notes:
1. **Maximum recommended pressure drop / velocity: 0.125 Psig/100 Ft. / 4,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

5 Psig Steam Piping Systems–Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.125	0.25	0.5	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	5	7	10						
3/4	11	15	22	22	Pressure	Drop	Governs	with	
1	22	31	44	35	these	Pipe	Sizes		
1-1/4	48	69	97	61					
1-1/2	75	106	150	83					
2	153	216	305	137	275				
2-1/2	251	355	503	196	392				
3	460	651	914	302	605	907			
4	972	1,375	1,944	521	1,042	1,563			
5	1,789	2,529	3,577	815	1,631	2,446	3,261		
6	2,952	4,174	5,903	1,182	2,364	3,546	4,728		
8	6,144	8,689		2,047	4,094	6,141	8,188	10,235	12,282
10	11,212	15,856		3,226	6,453	9,679	12,906	16,132	19,359
12	17,995	25,449		4,628	9,255	13,883	18,510	23,138	27,765
14	23,309	32,964		5,642	11,284	16,926	22,567	28,209	33,851
16	33,599			7,474	14,947	22,421	29,894	37,368	44,842
18	46,237			9,562	19,125	28,687	38,250	47,812	57,375
20	61,380			11,908	23,817	35,725	47,633	59,542	71,450
22	79,175			14,511	29,023	43,534	58,045	72,557	87,068
24	99,764			17,371	34,743	52,114	69,486	86,857	104,229
26				20,489	40,977	61,466	81,955	102,443	122,932
28				23,863	47,726	71,589	95,452	119,314	143,177
30				27,494	54,988	82,483	109,977	137,471	164,965
32				31,383	62,765	94,148	125,531	156,913	188,296
34				35,528	71,056	106,585	142,113	177,641	213,169
36				39,931	79,862	119,792	159,723	199,654	239,585
42				54,681	109,362	164,044	218,725	273,406	328,087
48				71,745	143,491	215,236	286,981	358,727	430,472
54				91,123	182,247	273,370	364,493	455,616	546,740
60	Velocity	Governs	with	112,815	225,630	338,445	451,260	564,075	676,890
72	these	Pipe	Sizes	163,140	326,280	489,419	652,559	815,699	978,839
84				222,720	445,439	668,159	890,879	1,113,598	1,336,318
96				291,555	583,109	874,664	1,166,219	1,457,774	1,749,328

Notes:

1. **Maximum recommended pressure drop / velocity: 0.25 Psig/100 Ft. / 6,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

7 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. PRESSURE DROP PSIG/100 FT. 0.125	0.25	0.5	VELOCITY FPM (MPH) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	5	7	10						
3/4	11	16	23		Pressure	Drop	Governs	with	
1	23	33	46	39	these	Pipe	Sizes		
1-1/4	51	72	101	67					
1-1/2	79	111	157	91					
2	160	226	319	150	300				
2-1/2	263	372	526	214	429				
3	481	680	956	331	662				
4	1,016	1,438	2,033	570	1,139	1,709			
5	1,870	2,645	3,741	892	1,783	2,675	3,567		
6	3,087	4,365	6,174	1,293	2,586	3,879	5,171		
8	6,426	9,087	12,851	2,239	4,477	6,716	8,955	11,194	
10	11,726	16,583		3,529	7,057	10,586	14,115	17,644	21,172
12	18,819	26,614		5,061	10,122	15,183	20,244	25,306	30,367
14	24,376	34,473		6,170	12,341	18,511	24,682	30,852	37,023
16	35,138			8,174	16,348	24,521	32,695	40,869	49,043
18	48,354			10,458	20,917	31,375	41,833	52,292	62,750
20	64,191			13,024	26,048	39,072	52,096	65,120	78,144
22	82,801			15,871	31,742	47,613	63,483	79,354	95,225
24	104,332			18,999	37,998	56,997	75,996	94,995	113,993
26	128,924			22,408	44,816	67,224	89,633	112,041	134,449
28				26,099	52,197	78,296	104,394	130,493	156,591
30				30,070	60,140	90,210	120,280	150,350	180,421
32				34,323	68,646	102,968	137,291	171,614	205,937
34				38,857	77,713	116,570	155,427	194,284	233,140
36				43,672	87,344	131,015	174,687	218,359	262,031
42				59,804	119,608	179,412	239,216	299,020	358,824
48				78,467	156,934	235,401	313,868	392,335	470,801
54				99,660	199,321	298,981	398,641	498,301	597,962
60	Velocity	Governs	with	123,384	246,768	370,153	493,537	616,921	740,305
72	these	Pipe	Sizes	178,424	356,847	535,271	713,695	892,119	1,070,542
84				243,585	487,171	730,756	974,342	1,217,927	1,461,513
96				318,869	637,739	956,608	1,275,478	1,594,347	1,913,217

Notes:

1. **Maximum recommended pressure drop / velocity: 0.25 Psig/100 Ft. / 6,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

10 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	8	11	15	15					
3/4	17	24	34	27	Pressure	Drop	Goverms	with	
1	35	49	69	44	these	Pipe	Sizes		
1-1/4	76	108	152	76	151				
1-1/2	118	167	236	103	206				
2	240	339	479	169	339				
2-1/2	395	558	790	242	484	725			
3	723	1,016	1,445	373	747	1,120			
4	1,527	2,160	3,054	643	1,286	1,929	2,572		
5	2,810	3,974	5,620	1,006	2,013	3,019	4,025	5,031	
6	4,637	6,558		1,459	2,918	4,377	5,836	7,295	8,754
8	9,654	13,652		2,526	5,053	7,579	10,105	12,632	15,158
10	17,616	24,912		3,982	7,964	11,946	15,929	19,911	23,893
12	28,273			5,711	11,423	17,134	22,846	28,557	34,268
14	36,621			6,963	13,927	20,890	27,853	34,816	41,780
16	52,789			9,224	18,448	27,672	36,896	46,120	55,344
18				11,802	23,604	35,406	47,208	59,011	70,813
20				14,697	29,395	44,092	58,790	73,487	88,185
22				17,910	35,820	53,730	71,641	89,551	107,461
24				21,440	42,880	64,320	85,760	107,201	128,641
26				25,287	50,575	75,862	101,150	126,437	151,724
28				29,452	58,904	88,356	117,808	147,260	176,712
30				33,934	67,868	101,802	135,735	169,669	203,603
32				38,733	77,466	116,199	154,932	193,665	232,398
34				43,849	87,699	131,548	175,398	219,247	263,097
36				49,283	98,567	147,850	197,133	246,416	295,700
42				67,488	134,977	202,465	269,954	337,442	404,930
48				88,549	177,098	265,648	354,197	442,746	531,295
54				112,466	224,932	337,397	449,863	562,329	674,795
60	Velocity	Governs	with	139,238	278,476	417,714	556,952	696,190	835,428
72	these	Pipe	Sizes	201,350	402,699	604,049	805,399	1,006,749	1,208,098
84				274,884	549,768	824,653	1,099,537	1,374,421	1,649,305
96				359,841	719,683	1,079,524	1,439,366	1,799,207	2,159,049

Notes:

1. **Maximum recommended pressure drop / velocity: 0.5 Psig/100 Ft. / 6,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

12 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. PRESSURE DROP PSIG/100 FT. 0.25	0.5	1	VELOCITY FPM (MPH) 2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	8	11	16						
3/4	18	25	36	29	Pressure	Drop	Governs	with	
1	36	51	72	47	these	Pipe	Sizes		
1-1/4	79	112	158	81					
1-1/2	123	173	245	111	221				
2	249	352	497	182	365				
2-1/2	410	579	819	260	520	780			
3	750	1,054	1,499	402	803	1,205			
4	1,584	2,240	3,168	692	1,383	2,075	2,767		
5	2,915	4,122	5,830	1,083	2,165	3,248	4,331	5,413	
6	4,810	6,803		1,570	3,139	4,709	6,279	7,849	9,418
8	10,013	14,161		2,718	5,436	8,154	10,873	13,591	16,309
10	18,272			4,284	8,569	12,853	17,138	21,422	25,706
12	29,326			6,145	12,290	18,435	24,580	30,725	36,870
14	37,986			7,492	14,984	22,475	29,967	37,459	44,951
16	54,755			9,924	19,848	29,773	39,697	49,621	59,545
18	75,351			12,698	25,396	38,094	50,792	63,490	76,188
20				15,813	31,626	47,439	63,252	79,066	94,879
22				19,270	38,539	57,809	77,079	96,348	115,618
24				23,068	46,135	69,203	92,270	115,338	138,406
26				27,207	54,414	81,621	108,828	136,034	163,241
28				31,688	63,375	95,063	126,750	158,438	190,126
30				36,510	73,019	109,529	146,039	182,548	219,058
32				41,673	83,346	125,019	166,693	208,366	250,039
34				47,178	94,356	141,534	188,712	235,890	283,068
36				53,024	103,048	159,073	212,097	265,121	318,145
42				72,611	145,223	217,834	290,445	363,056	435,668
48				95,271	190,542	285,812	381,093	476,354	571,625
54				121,003	242,006	363,008	484,011	605,014	726,017
60				149,807	299,615	449,422	599,229	749,036	898,844
72	Velocity	Governs	with	216,634	433,267	649,901	866,535	1,083,168	1,299,802
84	these	Pipe	Sizes	295,750	591,500	887,250	1,183,000	1,478,750	1,774,500
96				387,156	774,312	1,161,469	1,548,625	1,935,781	2,322,937

Notes:

1. **Maximum recommended pressure drop / velocity: 0.5 Psig/100 Ft. / 6,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

15 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.25	0.5	1	2,000 (23)	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)
1/2	8	12	16						
3/4	19	26	37	32	Pressure	Drop	Governs	with	
1	38	53	75	52	these	Pipe	Sizes		
1-1/4	83	117	166	90					
1-1/2	129	182	258	122	244				
2	261	370	523	201	403				
2-1/2	430	609	861	287	575	862			
3	788	1,107	1,575	444	887	1,331			
4	1,665	2,354	3,329	764	1,528	2,291	3,055		
5	3,063	4,332	6,126	1,196	2,391	3,587	4,782	5,978	
6	5,055	7,149	10,110	1,733	3,467	5,200	6,934	8,667	
8	10,522	14,881		3,002	6,003	9,005	12,006	15,008	18,010
10	19,201	27,155		4,731	9,463	14,194	18,925	23,656	28,388
12	30,817			6,786	13,572	20,358	27,143	33,929	40,715
14	39,918			8,273	16,546	24,820	33,093	41,366	49,639
16	57,540			10,959	21,918	32,878	43,837	54,796	65,755
18	79,183			14,022	28,045	42,067	56,089	70,112	84,134
20				17,462	34,925	52,387	69,849	87,312	104,774
22				21,279	42,559	63,838	85,118	106,397	127,676
24				25,473	50,947	76,420	101,894	127,367	152,840
26				30,044	60,089	90,133	120,178	150,222	180,267
28				34,992	69,985	104,977	139,970	174,962	209,955
30				40,317	80,635	120,952	161,270	201,587	241,905
32				46,019	92,039	138,058	184,078	230,097	276,117
34				52,098	104,197	156,295	208,394	260,492	312,590
36				58,554	117,109	175,663	234,218	292,772	351,326
42				80,184	160,368	240,553	320,737	400,921	481,105
48				105,207	210,414	315,621	420,828	526,035	631,242
54				133,623	267,245	400,868	534,491	668,114	801,736
60	Velocity	Governs	with	165,431	330,863	496,294	661,725	827,157	992,588
72	these	Pipe	Sizes	239,227	478,455	717,682	956,909	1,196,137	1,435,364
84				326,595	653,190	979,785	1,306,380	1,632,975	1,959,570
96				427,534	855,069	1,282,603	1,710,138	2,137,672	2,565,207

Notes:

1. **Maximum recommended pressure drop / velocity: 0.5 Psig/100 Ft. / 6,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

20 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	9	13	18		Pressure	Drop	Governs	with	
3/4	20	29	40		these	Pipe	Sizes		
1	41	57	81						
1-1/4	89	126	178						
1-1/2	139	196	277						
2	281	397	562	466					
2-1/2	463	655	926	665					
3	847	1,191	1,695	1,026	1,540				
4	1,790	2,532	3,581	1,767	2,651	3,535			
5	3,295	4,659	6,589	2,766	4,150	5,533			
6	5,437	7,689	10,874	4,011	6,016	8,022	10,027		
8	11,318	16,006	22,636	6,945	10,418	13,891	17,364	20,836	
10	20,653	29,208		10,948	16,421	21,895	27,369	32,843	41,054
12	33,148	46,878		15,702	23,553	31,403	39,254	47,105	58,881
14	42,936	60,720		19,143	28,715	38,286	47,858	57,430	71,787
16	61,891	87,527		25,358	38,038	50,717	63,396	76,075	95,094
18	85,170	120,449		32,446	48,669	64,892	81,115	97,338	121,673
20	113,063			40,406	60,609	80,812	101,015	121,218	151,522
22	145,843			49,238	73,857	98,476	123,095	147,714	184,643
24	183,768			58,943	88,414	117,885	147,357	176,828	221,035
26	227,082			69,519	104,279	139,039	173,799	208,558	260,698
28	276,022			80,969	121,453	161,937	202,422	242,906	303,632
30	330,813			93,290	139,935	186,580	233,225	279,870	349,838
32	397,670			106,484	159,726	212,968	266,210	319,451	399,314
34				120,550	180,825	241,100	301,375	361,650	452,062
36				135,488	203,232	270,977	338,721	406,465	508,081
42				185,537	278,306	371,075	463,844	556,612	695,765
48				243,437	365,156	486,875	608,593	730,312	912,890
54				309,188	463,782	618,376	772,970	927,564	1,159,456
60	Velocity	Governs	with	382,790	574,185	765,580	956,974	1,148,369	1,435,462
72	these	Pipe	Sizes	553,546	830,318	1,107,091	1,383,864	1,660,637	2,075,796
84				755,705	1,133,557	1,511,409	1,889,262	2,267,114	1,833,893
96				989,267	1,483,901	1,978,534	2,473,168	2,967,802	3,709,752

Notes:

1. **Maximum recommended pressure drop / velocity: 0.5 Psig/100 Ft. / 8,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

25 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.25	0.5	1	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	9	13	19						
3/4	21	30	43		Pressure	Drop	Governs	with	
1	43	61	86		these	Pipe	Sizes		
1-1/4	95	134	190						
1-1/2	148	209	295						
2	299	423	599	529					
2-1/2	493	697	986	754					
3	902	1,269	1,805	1,164	1,747				
4	1,907	2,697	3,814	2,005	3,008				
5	3,509	4,963	7,018	3,138	4,708	6,277			
6	5,791	8,190	11,582	4,550	6,825	9,100	11,376		
8	12,055	17,048	24,110	7,879	11,819	15,759	19,698	23,638	
10	21,998	31,110	43,996	12,420	18,629	24,839	31,049	37,259	
12	35,306	49,930		17,813	26,719	35,626	44,532	53,438	66,798
14	45,731	64,674		21,717	32,576	43,434	54,293	65,151	81,439
16	65,920	93,225		28,768	43,152	52,536	71,920	86,304	107,880
18	90,715	128,291		36,809	55,213	73,617	92,021	110,426	138,032
20	120,424	170,306		45,839	68,758	91,677	114,597	137,516	171,895
22	155,339			55,858	83,788	111,717	139,646	167,575	209,469
24	195,732			66,868	100,302	133,735	167,169	200,603	250,754
26	241,867			78,867	118,300	157,733	197,167	236,600	295,750
28	293,993			91,855	137,783	183,710	229,638	275,565	344,457
30	352,351			105,833	158,750	211,667	264,583	317,500	396,875
32	417,171			120,801	181,201	241,602	302,002	362,403	453,004
34	488,677			136,758	205,137	273,517	341,896	410,275	512,844
36	567,084			153,705	230,558	307,410	384,263	461,116	576,395
42				210,484	315,725	420,967	526,209	631,451	789,314
48				276,168	414,253	552,337	690,421	828,505	1,035,632
54				350,760	526,140	701,519	876,899	1,052,279	1,315,349
60	Velocity	Governs	with	434,257	651,386	868,515	1,085,643	1,302,772	1,628,465
72	these	Pipe	Sizes	627,972	941,958	1,255,944	1,569,930	1,882,916	2,354,984
84				857,312	1,285,968	1,714,624	2,143,280	2,571,936	3,214,920
96				1,122,278	1,683,417	2,244,556	2,805,695	3,366,834	4,208,542

Notes:

1. **Maximum recommended pressure drop / velocity: 0.5 Psig/100 Ft. / 8,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

30 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. — PRESSURE DROP PSIG/100 FT. 0.25	0.5	1	VELOCITY FPM (MPH) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	10	14	20						
3/4	23	32	45		Pressure these	Drop Pipe	Governs Sizes	with	
1	46	65	91						
1-1/4	101	142	201						
1-1/2	156	221	312						
2	317	448	633	591					
2-1/2	521	737	1,043	843					
3	954	1,342	1,909	1,302					
4	2,017	2,852	4,034	2,243	3,364				
5	3,711	5,249	7,423	3,510	5,266	7,021			
6	6,125	8,662	12,249	5,090	7,634	10,179			
8	12,749	18,030	25,499	8,813	13,220	17,626	22,033		
10	23,265	32,902	46,530	13,891	20,837	27,783	34,729	41,674	
12	37,340	52,806	74,679	19,924	29,886	39,848	49,810	59,772	
14	48,365	68,399		24,291	36,436	48,582	60,727	72,873	91,091
16	69,717	98,595		32,178	48,266	64,355	80,444	96,533	120,666
18	95,940	135,680		41,171	61,757	82,342	102,928	123,513	154,391
20	127,361	180,116		51,271	76,907	102,543	128,178	153,814	192,268
22	164,286	232,336		62,479	93,718	124,957	156,197	187,436	234,295
24	207,006			74,793	112,189	149,586	186,982	224,378	280,473
26	255,799			88,214	132,321	176,428	220,534	264,641	330,802
28	310,927			102,742	154,113	205,483	256,854	308,225	385,281
30	372,647			118,376	177,565	236,753	295,941	355,129	443,912
32	441,200			135,118	202,677	270,236	337,795	405,354	506,693
34	516,825			152,967	229,450	305,933	382,417	458,900	573,625
36	599,748			171,922	257,883	343,844	429,805	515,766	644,708
42				235,430	353,145	470,860	588,575	706,290	882,862
48				308,900	463,349	617,799	772,249	926,699	1,158,373
54				392,331	588,497	784,662	980,828	1,176,994	1,471,242
60				485,725	728,587	971,450	1,214,312	1,457,175	1,821,468
72	Velocity these	Governs Pipe	with Sizes	702,398	1,053,597	1,404,796	1,755,995	2,107,194	2,633,993
84				958,919	1,438,379	1,917,839	2,397,398	2,876,758	3,595,948
96				1,255,289	1,882,933	2,510,577	3,138,222	3,765,866	4,707,332

Notes:

1. **Maximum recommended pressure drop / velocity: 0.5 Psig/100 Ft. / 8,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

40 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	16	22	31						
3/4	35	50	71		Pressure	Drop	Governs	with	
1	71	100	142		these	Pipe	Sizes		
1-1/4	156	221	312						
1-1/2	242	343	485	433					
2	492	695	984	713					
2-1/2	810	1,145	1,620	1,017	1,526				
3	1,473	2,097	2,965	1,571	2,356				
4	3,133	4,430	6,265	2,705	4,058	5,410			
5	5,764	8,152	11,529	4,234	6,352	8,469	10,586		
6	9,513	13,453	19,026	6,139	9,209	12,278	15,348	18,418	
8	19,802	28,005	39,605	10,631	15,946	21,261	26,577	31,892	
10	36,136	51,103		16,757	25,135	33,513	41,891	50,270	62,837
12	57,996	82,019		24,033	36,050	48,066	60,083	72,100	90,124
14	75,122	106,239		29,301	43,951	58,602	73,252	87,903	109,878
16	108,286			38,814	58,221	77,628	97,035	116,442	145,553
18	149,016			49,662	74,493	99,325	124,156	148,987	186,234
20	197,819			61,846	92,769	123,692	154,615	185,537	231,922
22	255,172			75,364	113,047	150,729	188,411	226,093	282,617
24	321,526			90,218	135,327	180,437	225,546	270,655	338,319
26	397,311			106,407	159,611	212,815	266,018	319,222	399,028
28				123,932	185,897	247,863	309,829	371,795	464,743
30				142,791	214,186	285,582	356,977	428,373	535,466
32				162,985	244,478	325,971	407,464	488,956	611,195
34				184,515	276,773	369,030	461,288	553,546	691,932
36				207,380	311,070	414,760	518,450	622,140	777,675
42				283,986	425,979	567,972	709,965	851,958	1,064,947
48				372,608	558,912	745,216	931,521	1,117,825	1,397,281
54				473,247	709,871	946,494	1,183,118	1,419,742	1,774,677
60	Velocity	Governs	with	585,903	878,854	1,171,805	1,464,757	1,757,708	2,197,135
72	these	Pipe	Sizes	847,264	1,270,895	1,694,527	2,118,159	2,541,791	3,177,239
84				1,156,691	1,735,036	2,313,382	2,891,727	3,470,073	4,337,591
96				1,514,184	2,271,277	3,028,369	3,785,461	4,542,553	5,678,192

Notes:

1. **Maximum recommended pressure drop / velocity: 1.0 Psig/100 Ft. / 10,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

50 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. PRESSURE DROP PSIG/100 FT. 0.5	1	2	VELOCITY FPM (MPH) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	17	24	34						
3/4	38	54	76		Pressure	Drop	Governs	with	
1	77	109	154		these	Pipe	Sizes		
1-1/4	169	239	338						
1-1/2	263	371	525	508					
2	533	753	1,065	837					
2-1/2	877	1,241	1,755	1,194					
3	1,569	2,271	3,212	1,843	2,765				
4	3,393	4,799	6,786	3,174	4,761	6,348			
5	6,244	8,830	12,488	4,968	7,453	9,937	12,421		
6	10,304	14,573	20,609	7,203	10,805	14,407	18,008		
8	21,450	30,335	42,900	12,473	18,710	24,947	31,183	37,420	
10	39,142	55,355		19,661	29,492	39,322	49,153	58,983	73,729
12	62,822	88,844		28,199	42,298	56,398	70,497	84,597	105,746
14	81,373	115,078		34,380	51,570	68,759	85,949	103,139	128,924
16	117,296	165,882		45,542	68,313	91,084	113,854	136,625	170,782
18	161,415			58,270	87,406	116,541	145,676	174,811	218,514
20	214,279			72,566	108,849	145,132	181,414	217,697	272,122
22	276,404			88,428	132,641	176,855	221,069	265,283	331,604
24	348,279			105,856	158,784	211,712	264,640	317,568	396,961
26	430,370			124,851	187,277	249,703	312,128	374,554	468,192
28	523,121			145,413	218,120	290,826	363,533	436,239	545,299
30	626,961			167,541	251,312	335,083	418,853	502,624	628,280
32				191,236	286,854	382,473	478,091	573,709	717,136
34				216,498	324,747	432,996	541,245	649,493	811,867
36				243,326	364,989	486,652	608,315	729,978	912,472
42				333,210	499,815	666,420	833,025	999,630	1,249,538
48				437,194	655,790	874,387	1,092,984	1,311,581	1,639,476
54				555,277	832,915	1,110,553	1,388,192	1,665,830	2,082,288
60	Velocity	Governs	with	687,459	1,031,189	1,374,918	1,718,648	2,062,378	2,577,972
72	these	Pipe	Sizes	994,123	1,491,184	1,988,245	2,485,307	2,982,368	3,727,960
84				1,357,184	2,035,776	2,714,368	3,392,960	4,071,552	5,089,440
96				1,776,643	2,664,965	3,553,286	4,441,608	5,329,929	6,662,412

Notes:

1. **Maximum recommended pressure drop / velocity: 1.0 Psig/100 Ft. / 10,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

60 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	18	25	36						
3/4	41	58	82		Pressure	Drop	Governs	with	
1	82	116	164		these	Pipe	Sizes		
1-1/4	181	256	362						
1-1/2	281	397	562						
2	570	806	1,140	957					
2-1/2	938	1,327	1,877	1,366					
3	1,707	2,429	3,436	2,109	3,164				
4	3,630	5,133	7,260	3,632	5,449				
5	6,680	9,446	13,359	5,686	8,529	11,371			
6	11,023	15,589	22,046	8,243	12,365	16,487	20,608		
8	22,946	32,451	45,893	14,274	21,412	28,549	35,686	42,823	
10	41,873	59,217	83,745	22,500	33,750	45,000	56,249	67,499	
12	67,204	95,041		32,270	48,406	64,541	80,676	96,811	121,014
14	87,049	123,106		39,344	59,015	78,687	98,359	118,031	147,539
16	125,479	177,454		52,117	78,176	104,235	130,293	156,352	195,440
18	172,676	244,200		66,684	100,026	133,368	166,710	200,052	250,064
20	229,227	324,176		83,043	124,565	166,086	207,608	249,129	311,412
22	295,686			101,195	151,793	202,391	252,988	303,586	379,482
24	372,575			121,140	181,710	242,280	302,851	363,421	454,276
26	460,392			142,878	214,317	285,756	357,195	428,634	535,792
28	559,614			166,408	249,613	332,817	416,021	499,225	624,032
30	670,697			191,732	287,598	383,464	479,329	575,195	718,994
32	794,082			218,848	328,272	437,696	547,120	656,544	820,680
34				247,757	371,635	495,514	619,392	743,271	929,088
36				278,459	417,688	556,917	696,146	835,376	1,044,220
42				381,321	571,981	762,641	953,302	1,143,962	1,429,952
48				500,318	750,477	1,000,636	1,250,795	1,500,954	1,876,192
54				635,450	953,176	1,270,901	1,588,626	1,906,351	2,382,939
60	Velocity	Governs	with	786,718	1,180,077	1,573,436	1,966,795	2,360,154	2,950,193
72	these	Pipe	Sizes	1,137,659	1,706,489	2,275,318	2,844,148	3,412,977	4,266,221
84				1,553,141	2,329,711	3,106,282	3,882,852	4,659,423	5,824,279
96				2,033,164	3,049,746	4,066,328	5,082,909	6,099,491	7,624,364

Notes:

1. **Maximum recommended pressure drop / velocity: 1.0 Psig/100 Ft. / 12,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

75 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. PRESSURE DROP PSIG/100 FT. 0.5	1	2	VELOCITY FPM (MPH) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	20	28	39		Pressure	Drop	Governs	with	
3/4	45	63	89		these	Pipe	Sizes		
1	90	127	179						
1-1/4	197	279	394						
1-1/2	306	433	612						
2	621	879	1,243	1,138					
2-1/2	1,023	1,447	2,046	1,624					
3	1,862	2,649	3,746	2,507					
4	3,957	5,597	7,915	4,318	6,477				
5	7,283	10,299	14,565	6,758	10,138	13,517			
6	12,018	16,997	24,036	9,799	14,698	19,597			
8	25,018	35,380	50,035	16,967	25,451	33,935	42,419		
10	45,652	64,562	91,304	26,745	40,117	53,489	66,862	80,234	
12	73,270	103,620		38,359	57,538	76,718	95,897	115,077	143,846
14	94,906	134,218		46,766	70,150	93,533	116,916	140,299	175,374
16	136,805	193,471		61,950	92,925	123,900	154,876	185,851	232,313
18	188,261	266,242		79,265	118,897	158,530	198,162	237,795	297,244
20	249,917	353,436		98,711	148,066	197,422	246,777	296,132	370,165
22	322,374			120,288	180,431	240,575	300,719	360,863	451,079
24	406,203			143,996	215,993	287,991	359,989	431,987	539,983
26	501,947			169,834	254,752	339,669	424,586	509,503	636,879
28	610,125			197,804	296,707	395,609	494,511	593,413	741,767
30	731,235			227,905	341,858	455,811	569,764	683,716	854,646
32	865,756			260,138	390,206	520,275	650,344	780,413	975,516
34	1,014,152			294,501	441,751	589,001	736,252	883,502	1,104,378
36	1,176,871			330,995	496,492	661,990	827,487	992,985	1,241,231
42				453,264	679,896	906,527	1,133,159	1,359,791	1,699,739
48				594,712	892,068	1,189,424	1,486,780	1,784,136	2,230,170
54				755,340	1,133,009	1,510,679	1,888,349	2,266,019	2,832,524
60	Velocity	Governs	with	935,147	1,402,720	1,870,293	2,337,867	2,805,440	3,506,800
72	these	Pipe	Sizes	1,352,299	2,028,449	2,704,598	3,380,748	4,056,898	5,071,122
84				1,846,169	2,769,254	3,692,339	4,615,423	5,538,508	6,923,135
96				2,416,757	3,625,136	4,833,514	6,041,893	7,250,271	9,062,839

Notes:

1. **Maximum recommended pressure drop / velocity: 1.0 Psig/100 Ft. / 12,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

85 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	21	29	41		Pressure	Drop	Governs	with	
3/4	47	66	94		these	Pipe	Sizes		
1	94	133	188						
1-1/4	207	293	415						
1-1/2	322	455	644						
2	653	924	1,306	1,258					
2-1/2	1,076	1,521	2,151	1,794					
3	1,957	2,784	3,938	2,771					
4	4,160	5,883	8,320	4,771	7,157				
5	7,655	10,826	15,311	7,468	11,202	14,936			
6	12,633	17,866	25,267	10,828	16,241	21,655			
8	26,298	37,192	52,597	18,749	28,124	37,499	46,873		
10	47,989	67,867	95,979	29,553	44,330	59,107	73,883	88,660	
12	77,021	108,925	154,043	42,387	63,580	84,774	105,967	127,161	
14	99,765	141,089		51,678	77,516	103,355	129,194	155,033	193,791
16	143,808	203,376		68,456	102,684	136,911	171,139	205,367	256,709
18	197,899	279,872		87,589	131,383	175,178	218,972	262,766	328,458
20	262,712	371,531		109,077	163,615	218,153	272,692	327,230	409,037
22	338,879	479,247		132,919	199,379	265,839	332,298	398,758	498,447
24	426,999			159,117	238,675	318,234	397,792	477,350	596,688
26	527,645			187,669	281,504	375,338	469,173	563,007	703,759
28	641,361			218,576	327,865	437,153	546,441	655,729	819,661
30	768,671			251,838	377,758	503,677	629,596	755,515	944,394
32	910,079			287,455	431,183	574,910	718,638	862,366	1,077,957
34	1,066,072			325,427	488,140	650,854	813,567	976,281	1,220,351
36	1,237,121			365,753	548,630	731,507	914,384	1,097,260	1,371,575
42	1,845,105			500,862	751,293	1,001,724	1,252,155	1,502,586	1,878,232
48				657,164	985,746	1,314,328	1,642,910	1,971,492	2,464,365
54				834,660	1,251,989	1,669,319	2,086,649	2,503,979	3,129,973
60	Velocity	Governs	with	1,033,349	1,550,023	2,066,697	2,583,372	3,100,046	3,875,057
72	these	Pipe	Sizes	1,494,307	2,241,461	2,988,614	3,735,768	4,482,922	5,603,652
84				2,040,040	3,060,060	4,080,080	5,100,099	6,120,119	7,650,149
96				2,670,546	4,005,820	5,341,093	6,676,366	8,011,639	10,014,549

Notes:

1. **Maximum recommended pressure drop / velocity: 1.0 Psig/100 Ft. / 12,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

100 Psig Steam Piping Systems–Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	0.5	1	2	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	22	31	44						
3/4	50	71	100		Pressure	Drop	Governs	with	
1	101	142	201		these	Pipe	Sizes		
1-1/4	222	313	443						
1-1/2	344	486	688						
2	698	987	1,396						
2-1/2	1,149	1,625	2,299	2,049					
3	2,091	2,975	4,208	3,164					
4	4,446	6,287	8,891	5,449	8,173				
5	8,181	11,569	16,362	8,529	12,793				
6	13,501	19,093	27,001	12,365	18,548	24,730			
8	28,104	39,744	56,207	21,412	32,117	42,823	53,529		
10	51,283	72,526	102,567	33,750	50,624	67,499	84,374	101,249	
12	82,308	116,402	164,617	48,406	72,608	96,811	121,014	145,217	
14	106,613	150,773	213,226	59,015	88,523	118,031	147,539	177,046	
16	153,680	217,336		78,176	117,264	156,352	195,440	234,528	293,160
18	211,483	299,083		100,026	150,039	200,052	250,064	300,077	375,097
20	280,745	397,033		124,565	186,847	249,129	311,412	373,694	467,118
22	362,139	512,142		151,793	227,689	303,586	379,482	455,379	569,223
24	456,309	645,318		181,710	272,565	363,421	454,276	545,131	681,414
26	563,863	797,422		214,317	321,475	428,634	535,792	642,951	803,688
28	685,384			249,613	374,419	499,225	624,032	748,838	936,048
30	821,433			287,598	431,397	575,195	718,994	862,793	1,078,491
32	972,548			328,272	492,408	656,544	820,680	984,816	1,231,020
34	1,139,248			371,635	557,453	743,271	929,088	1,114,906	1,393,632
36	1,322,038			417,688	626,532	835,376	1,044,220	1,253,064	1,566,330
42	1,971,754			571,981	857,971	1,143,962	1,429,952	1,715,943	2,144,929
48	2,783,057			750,477	1,125,715	1,500,954	1,876,192	2,251,430	2,814,288
54				953,176	1,429,763	1,906,351	2,382,939	2,859,527	3,574,408
60				1,180,077	1,770,116	2,360,154	2,950,193	3,540,231	4,425,289
72	Velocity	Governs	with	1,706,489	2,559,733	3,412,977	4,266,221	5,119,466	6,399,332
84	these	Pipe	Sizes	2,329,711	3,494,567	4,659,423	5,824,279	6,989,134	8,736,418
96				3,049,746	4,574,618	6,099,491	7,624,364	9,149,237	11,436,546

Notes:

1. **Maximum recommended pressure drop / velocity: 1.0 Psig/100 Ft. / 12,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

120 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	34	48	75						
3/4	76	108	171		Pressure	Drop	Governs	with	
1	154	217	344		these	Pipe	Sizes		
1-1/4	338	478	756	746					
1-1/2	525	743	1,174	1,015					
2	1,065	1,507	2,382	1,673					
2-1/2	1,755	2,481	3,923	2,387	3,581				
3	3,212	4,542	7,181	3,686	5,530				
4	6,786	9,597	15,175	6,348	9,522	12,696			
5	12,488	17,661	27,924	9,937	14,905	19,873	24,842		
6	20,609	29,145	46,083	14,407	21,610	28,813	36,017	43,220	
8	42,900	60,670		24,947	37,420	49,894	62,367	74,840	93,550
10	78,284	110,711		39,322	58,983	78,644	98,305	117,966	147,458
12	125,644	177,688		56,398	84,597	112,796	140,995	169,194	211,492
14	162,745	230,156		68,759	103,139	137,519	171,898	206,278	257,848
16	234,593	331,764		91,084	136,625	182,167	227,709	273,251	341,563
18	322,831			116,541	174,811	233,082	291,352	349,623	437,028
20	428,558			145,132	217,697	290,263	362,829	435,395	544,243
22	552,808			176,855	265,283	353,711	442,138	530,566	663,207
24	696,558			211,712	317,568	423,425	529,281	635,137	793,921
26	860,739			249,703	374,554	499,405	624,256	749,108	936,385
28	1,046,243			290,826	436,239	581,652	727,065	872,478	1,090,598
30	1,253,922			335,083	502,624	670,165	837,707	1,005,248	1,256,560
32				382,473	573,709	764,945	956,181	1,147,418	1,434,272
34				432,996	649,493	865,991	1,082,181	1,298,987	1,623,734
36				486,652	729,978	973,304	1,216,630	1,459,956	1,824,945
42				666,420	999,630	1,332,840	1,666,050	1,999,260	2,499,076
48				874,387	1,311,581	1,748,775	2,185,968	2,623,162	3,278,952
54				1,110,553	1,665,830	2,221,107	2,776,383	3,331,660	4,164,575
60	Velocity	Governs	with	1,374,918	2,062,378	2,749,837	3,437,296	4,124,755	5,155,944
72	these	Pipe	Sizes	1,998,245	2,982,368	3,976,491	4,970,613	5,964,736	7,455,920
84				2,714,368	4,071,552	5,428,736	6,785,920	8,143,104	10,178,879
96				3,553,286	5,329,929	7,106,572	8,883,215	10,659,859	13,324,823

Notes:
1. **Maximum recommended pressure drop / velocity: 2.0 Psig/100 Ft. / 15,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

125 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	34	48	77						
3/4	78	110	174		Pressure	Drop	Governs	with	
1	156	221	350		these	Pipe	Sizes		
1-1/4	344	487	770						
1-1/2	534	756	1,195	1,051					
2	1,084	1,533	2,424	1,733					
2-1/2	1,785	2,525	3,992	2,472	3,708				
3	3,268	4,622	7,308	3,817	5,726				
4	6,905	9,766	15,441	6,573	9,860	13,146			
5	12,707	17,971	28,414	10,289	15,433	20,578	25,722		
6	20,971	29,657	46,892	14,917	22,376	29,834	37,293	44,751	
8	43,654	61,735		25,831	38,746	51,661	64,577	77,492	96,865
10	79,659	112,655		40,715	61,073	81,430	101,788	122,145	152,682
12	127,850	180,808		58,396	87,594	116,792	145,990	175,188	218,985
14	165,603	234,198		71,195	106,793	142,391	177,988	213,586	266,983
16	238,712	337,590		94,310	141,466	188,621	235,776	282,931	353,664
18	328,499			120,670	181,005	241,339	301,674	362,009	452,511
20	436,083			150,273	225,410	300,546	375,683	450,820	563,524
22	562,515			183,121	274,681	366,242	457,802	549,363	686,703
24	708,789			219,213	328,819	438,426	548,032	657,638	822,048
26	875,854			258,549	387,823	517,098	646,372	775,647	969,559
28	1,064,614			301,129	451,694	602,259	752,823	903,388	1,129,235
30	1,275,940			346,954	520,431	693,908	867,385	1,040,862	1,301,077
32				396,023	594,034	792,045	990,057	1,188,068	1,485,085
34				448,336	672,504	896,671	1,120,839	1,345,007	1,681,259
36				503,893	755,839	1,007,786	1,259,732	1,511,679	1,889,599
42				690,030	1,035,045	1,380,060	1,725,075	2,070,090	2,587,612
48				905,365	1,358,047	1,810,730	2,263,412	2,716,095	3,395,119
54				1,149,898	1,724,847	2,299,796	2,874,745	3,449,694	4,312,117
60	Velocity	Governs	with	1,423,629	2,135,443	2,847,258	3,559,072	4,270,886	5,338,608
72	these	Pipe	Sizes	2,058,684	3,088,027	4,117,369	5,146,711	6,176,053	7,720,067
84				2,810,532	4,215,798	5,621,064	7,026,330	8,431,596	10,539,495
96				3,679,171	5,518,757	7,358,343	9,197,928	11,037,514	13,796,893

Notes:

1. **Maximum recommended pressure drop / velocity: 2.0 Psig/100 Ft. / 15,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

150 Psig Steam Piping Systems–Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. PRESSURE DROP PSIG/100 FT. 1	2	5	VELOCITY FPM (MPH) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	37	52	83						
3/4	84	119	188		Pressure	Drop	Governs	with	
1	169	239	378		these	Pipe	Sizes		
1-1/4	372	526	832						
1-1/2	578	817	1,292	1,230					
2	1,173	1,658	2,622	2,027					
2-1/2	1,931	2,731	4,318	2,893					
3	3,535	4,999	7,905	4,466	6,700				
4	7,470	10,564	16,703	7,691	11,537	15,382			
5	13,746	19,439	30,736	12,039	18,059	24,078	30,098		
6	22,684	32,080	50,724	17,455	26,182	34,909	43,636		
8	47,221	66,780	105,589	30,225	45,337	60,449	75,562	90,674	
10	86,168	121,861		47,641	71,462	95,282	119,103	142,923	178,654
12	138,298	195,583		68,330	102,494	136,659	170,824	204,989	256,236
14	179,135	253,336		83,306	124,960	166,613	208,266	249,919	312,399
16	258,219	365,176		110,354	165,530	220,707	275,884	331,061	413,826
18	355,343	502,531		141,197	211,795	282,394	352,992	423,590	529,488
20	471,718			175,836	263,754	351,672	439,590	527,508	659,385
22	608,481			214,272	321,407	428,543	535,679	642,815	803,518
24	766,709			256,503	384,755	513,006	641,258	769,509	961,886
26	947,425			302,531	453,796	605,061	756,327	907,592	1,134,490
28	1,151,610			352,354	528,532	704,709	880,886	1,057,063	1,321,329
30	1,380,205			405,974	608,961	811,948	1,014,935	1,217,922	1,522,403
32	1,634,114			463,390	695,085	926,780	1,158,475	1,390,170	1,737,713
34	1,914,211			524,602	786,903	1,049,204	1,311,505	1,573,806	1,967,257
36				589,610	884,415	1,179,220	1,474,025	1,768,830	2,211,038
42				807,411	1,211,116	1,614,822	2,018,527	2,422,232	3,027,790
48				1,059,376	1,589,065	2,118,753	2,648,441	3,178,129	3,972,661
54				1,345,507	2,018,260	2,691,013	3,363,767	4,036,520	5,045,650
60	Velocity	Governs	with	1,665,802	2,498,703	3,331,604	4,164,505	4,997,406	6,246,757
72	these	Pipe	Sizes	2,408,887	3,613,330	4,817,773	6,022,217	7,226,660	9,033,325
84				3,288,631	4,932,946	6,577,262	8,221,577	9,865,893	12,332,366
96				4,305,034	6,457,551	8,610,068	10,762,586	12,915,103	16,143,878

Notes:

1. **Maximum recommended pressure drop / velocity: 2.0 Psig/100 Ft. / 15,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

175 Psig Steam Piping Systems–Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. — PRESSURE DROP PSIG/100 FT. 1	2	5	VELOCITY FPM (MPH) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	40	56	89						
3/4	90	127	201		Pressure these	Drop Pipe	Governs Sizes	with	
1	181	256	405						
1-1/4	398	563	891						
1-1/2	618	875	1,383						
2	1,255	1,775	2,806	2,322					
2-1/2	2,067	2,923	4,621	3,312					
3	3,783	5,350	8,459	5,114	7,672				
4	7,993	11,304	17,874	8,807	13,211	17,614			
5	14,709	20,802	32,891	13,786	20,679	27,572			
6	24,274	34,329	54,279	19,987	29,981	39,974	49,968		
8	50,531	71,461	112,990	34,610	51,916	69,221	86,526	103,831	
10	92,208	130,402		54,554	81,831	109,108	136,385	163,662	204,578
12	147,992	209,292		78,245	117,367	156,489	195,611	234,734	293,417
14	191,692	271,093		95,394	143,092	190,789	238,486	286,183	357,729
16	276,318	390,773		126,366	189,549	252,732	315,916	379,099	473,873
18	380,251	537,756		161,685	242,527	323,370	404,212	485,055	606,319
20	504,783	713,872		201,351	302,026	402,701	503,376	604,052	755,065
22	651,133			245,363	368,045	490,726	613,408	736,089	920,112
24	820,451			293,723	440,584	587,445	734,306	881,168	1,101,460
26	1,013,835			346,429	519,643	692,858	866,072	1,039,287	1,299,108
28	1,232,333			403,482	605,223	806,964	1,008,705	1,210,447	1,513,058
30	1,476,951			464,882	697,324	929,765	1,162,206	1,394,647	1,743,309
32	1,748,657			530,630	795,944	1,061,259	1,326,574	1,591,889	1,989,861
34	2,048,388			600,724	901,085	1,201,447	1,501,809	1,802,171	2,252,713
36	2,377,048			675,165	1,012,747	1,350,329	1,687,911	2,025,494	2,531,867
42				924,569	1,386,853	1,849,138	2,311,422	2,773,707	3,467,133
48				1,213,095	1,819,643	2,426,191	3,032,739	3,639,286	4,549,108
54				1,540,744	2,311,117	3,081,489	3,851,861	4,622,233	5,777,791
60				1,907,515	2,861,273	3,815,031	4,768,789	5,722,546	7,153,183
72	Velocity these	Governs Pipe	with Sizes	2,758,425	4,137,637	5,516,849	6,896,061	8,275,274	10,344,092
84				3,765,823	5,648,734	7,531,645	9,414,556	11,297,468	14,121,834
96				4,929,710	7,394,564	9,859,419	12,324,274	14,789,129	18,486,411

Notes:

1. **Maximum recommended pressure drop / velocity: 2.0 Psig/100 Ft. / 15,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

200 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	42	59	94		Pressure	Drop	Governs	with	
3/4	96	135	214		these	Pipe	Sizes		
1	192	272	430						
1-1/4	423	598	946						
1-1/2	656	928	1,468						
2	1,332	1,884	2,978	2,616					
2-1/2	2,194	3,102	4,905	3,732					
3	4,015	5,679	8,979	5,763	8,644				
4	8,485	11,999	18,972	9,923	14,885				
5	15,613	22,081	34,913	15,533	23,299	31,066			
6	25,766	36,439	57,616	22,520	33,780	45,040	56,300		
8	53,637	75,854	119,935	38,996	58,494	77,992	97,490	116,988	
10	97,876	138,418	218,858	61,467	92,200	122,934	153,667	184,401	
12	157,089	222,157		88,159	132,239	176,319	220,398	264,478	330,598
14	203,475	287,757		107,482	161,224	214,965	268,706	322,447	403,059
16	293,303	414,794		142,379	213,568	284,758	355,947	427,137	533,921
18	403,625	570,811		182,173	273,260	364,346	455,433	546,519	683,149
20	535,812	757,753		226,865	340,297	453,730	567,162	680,595	850,744
22	691,157	977,444		276,455	414,682	552,909	691,137	829,364	1,036,705
24	870,884	1,231,615		330,942	496,413	661,884	827,355	992,826	1,241,033
26	1,076,154			390,327	585,491	780,654	975,818	1,170,981	1,463,727
28	1,308,083			454,610	681,915	909,220	1,136,525	1,363,830	1,704,788
30	1,567,737			523,791	785,686	1,047,581	1,309,477	1,571,372	1,967,215
32	1,856,146			597,869	896,804	1,195,738	1,494,673	1,793,607	2,242,009
34	2,174,300			676,845	1,015,268	1,353,690	1,692,113	2,030,535	2,538,169
36	2,523,162			760,719	1,141,078	1,521,438	1,901,797	2,282,157	2,852,696
42	3,763,171			1,041,727	1,562,590	2,083,454	2,604,317	3,125,181	3,906,476
48				1,366,815	2,050,222	2,733,629	3,417,037	4,100,444	5,125,555
54				1,735,982	2,603,973	3,471,964	4,339,955	5,207,946	6,509,933
60	Velocity	Governs	with	2,149,229	3,223,844	4,298,458	5,373,073	6,447,687	8,059,609
72	these	Pipe	Sizes	3,107,962	4,661,943	6,215,925	7,769,906	9,323,887	11,654,859
84				4,243,014	6,364,521	8,486,028	10,607,536	12,729,043	15,911,303
96				5,554,385	8,331,577	11,108,770	13,885,962	16,663,155	20,828,943

Notes:
1. **Maximum recommended pressure drop / velocity: 2.0 Psig/100 Ft. / 15,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

225 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	44	63	99		Pressure	Drop	Governs	with	
3/4	101	143	225		these	Pipe	Sizes		
1	203	287	453						
1-1/4	446	631	998						
1-1/2	693	980	1,549						
2	1,405	1,987	3,142	2,912					
2-1/2	2,314	3,273	5,175	4,154					
3	4,236	5,991	9,473	6,414					
4	8,952	12,660	20,017	11,046	16,568				
5	16,473	23,296	36,834	17,290	25,935	34,579			
6	27,185	38,445	60,787	25,067	37,601	50,134			
8	56,589	80,029	126,536	43,407	65,110	86,814	108,517		
10	103,263	146,036	230,904	68,419	102,629	136,838	171,048	205,258	
12	165,735	234,384		98,131	147,196	196,262	245,327	294,392	367,990
14	214,674	303,595		119,639	179,459	239,279	299,099	358,918	448,648
16	309,447	437,623		158,483	237,724	316,966	396,207	475,449	594,311
18	425,840	602,228		202,778	304,167	405,556	506,945	608,334	760,418
20	565,302	799,458		252,525	378,787	505,050	631,312	757,575	946,968
22	729,198	1,031,241		307,724	461,585	615,447	769,309	923,171	1,153,963
24	918,816	1,299,402		368,374	552,561	736,748	920,934	1,105,121	1,381,402
26	1,135,385	1,605,676		434,476	651,714	868,952	1,086,189	1,303,427	1,629,284
28	1,380,078			506,029	759,044	1,012,059	1,265,074	1,518,088	1,897,611
30	1,654,023			583,035	874,552	1,166,070	1,457,587	1,749,105	2,186,381
32	1,958,305			665,492	998,238	1,330,984	1,663,730	1,996,476	2,495,595
34	2,293,971			753,401	1,130,101	1,506,802	1,883,502	2,260,202	2,825,253
36	2,662,034			846,761	1,270,142	1,693,523	2,116,903	2,540,284	3,175,355
42	3,970,291			1,159,553	1,739,330	2,319,107	2,898,883	3,478,660	4,348,325
48	5,603,917			1,521,411	2,282,116	3,042,821	3,803,526	4,564,232	5,705,290
54				1,932,333	2,898,500	3,864,666	4,830,833	5,797,000	7,246,250
60				2,392,321	3,588,482	4,784,643	5,980,803	7,176,964	8,971,205
72	Velocity	Governs	with	3,459,494	5,189,240	6,918,987	8,648,734	10,378,481	12,973,101
84	these	Pipe	Sizes	4,722,928	7,084,391	9,445,855	11,807,319	14,168,783	17,710,978
96				6,182,623	9,273,934	12,365,246	15,456,557	18,547,869	23,184,836

Notes:

1. **Maximum recommended pressure drop / velocity: 5.0 Psig/100 Ft. / 15,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

250 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	47	66	104		Pressure	Drop	Governs	with	
3/4	106	150	236		these	Pipe	Sizes		
1	213	301	476						
1-1/4	468	662	1,047						
1-1/2	727	1,028	1,625						
2	1,474	2,085	3,297	3,205					
2-1/2	2,428	3,434	5,430	4,573					
3	4,445	6,286	9,939	7,061					
4	9,392	13,283	21,002	12,160	18,239				
5	17,283	24,442	38,647	19,033	28,550	38,066			
6	28,522	40,337	63,778	27,595	41,393	55,190			
8	59,374	83,967	132,764	47,784	71,676	95,568	119,460		
10	108,345	153,223	242,267	75,319	112,978	150,638	188,297	225,957	
12	173,891	245,919	388,831	108,027	162,040	216,054	270,067	324,080	
14	225,238	318,535		131,705	197,557	263,409	329,261	395,114	493,892
16	324,675	459,160		174,465	261,698	348,930	436,163	523,395	654,244
18	446,796	631,865		223,227	334,841	446,455	558,068	669,682	837,102
20	593,122	838,801		277,991	416,986	555,982	694,977	833,973	1,042,466
22	765,083	1,081,991		338,756	508,134	677,512	846,890	1,016,268	1,270,335
24	964,032	1,363,348		405,522	608,284	811,045	1,013,806	1,216,567	1,520,709
26	1,191,259	1,684,694		478,291	717,436	956,581	1,195,726	1,434,872	1,793,590
28	1,447,994	2,047,773		557,060	835,590	1,114,120	1,392,650	1,671,180	2,088,975
30	1,735,421			641,831	962,747	1,283,662	1,604,578	1,925,493	2,406,867
32	2,054,677			732,604	1,098,905	1,465,207	1,831,509	2,197,811	2,747,264
34	2,406,861			829,378	1,244,067	1,658,755	2,073,444	2,488,133	3,110,166
36	2,793,037			932,153	1,398,230	1,864,306	2,330,383	2,796,460	3,495,574
42	4,165,676			1,276,489	1,914,733	2,552,977	3,191,222	3,829,466	4,786,832
48	5,879,695			1,674,837	2,512,256	3,349,675	4,187,094	5,024,512	6,280,640
54	7,959,549			2,127,200	3,190,800	4,254,399	5,317,999	6,381,599	7,976,999
60				2,633,575	3,950,363	5,267,151	6,583,938	7,900,726	9,875,908
72	Velocity	Governs	with	3,808,367	5,712,550	7,616,734	9,520,917	11,425,101	14,281,376
84	these	Pipe	Sizes	5,199,212	7,798,818	10,398,424	12,998,030	15,597,636	19,497,045
96				6,806,111	10,209,166	13,612,221	17,015,277	20,418,332	25,522,915

Notes:

1. **Maximum recommended pressure drop / velocity: 5.0 Psig/100 Ft. / 15,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

275 Psig Steam Piping Systems–Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR. PRESSURE DROP PSIG/100 FT. 1	2	5	VELOCITY FPM (MPH) 4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	49	69	109						
3/4	110	156	247		Pressure	Drop	Governs	with	
1	222	314	497		these	Pipe	Sizes		
1-1/4	489	692	1,094						
1-1/2	759	1,074	1,689						
2	1,541	2,179	3,445						
2-1/2	2,537	3,589	5,674	4,994					
3	4,645	6,569	10,386	7,711					
4	9,815	13,880	21,946	13,278	19,916				
5	18,061	25,542	40,385	20,783	31,175				
6	29,805	42,151	66,646	30,133	45,199	60,265			
8	62,044	87,743	138,734	52,178	78,267	104,356	130,445		
10	113,217	160,113	253,161	82,245	123,368	164,490	205,613	246,735	
12	181,710	256,977	406,316	117,961	176,941	235,921	294,901	353,882	
14	235,367	332,859	526,296	143,816	215,723	287,631	359,539	431,447	
16	339,275	479,807		190,508	285,762	381,017	476,271	571,525	714,406
18	466,887	660,278		243,754	365,632	487,509	609,386	731,263	914,079
20	619,793	876,519		303,554	455,331	607,108	758,884	910,661	1,138,327
22	799,486	1,130,644		369,907	554,860	739,813	924,766	1,109,720	1,387,150
24	1,007,382	1,424,653		442,813	664,219	885,625	1,107,032	1,328,438	1,660,548
26	1,244,826	1,760,450		522,272	783,408	1,044,545	1,305,681	1,566,817	1,958,521
28	1,513,106	2,139,855		608,285	912,428	1,216,570	1,520,713	1,824,855	2,281,069
30	1,813,457	2,564,616		700,851	1,051,277	1,401,703	1,752,128	2,102,554	2,628,193
32	2,147,070			799,971	1,199,956	1,599,942	1,999,927	2,399,913	2,999,891
34	2,515,091			905,644	1,358,466	1,811,288	2,264,110	2,716,932	3,396,165
36	2,918,632			1,017,870	1,526,805	2,035,741	2,544,676	3,053,611	3,817,014
42	4,352,994			1,393,869	2,090,804	2,787,739	3,484,674	4,181,608	5,227,010
48	6,144,088			1,828,849	2,743,273	3,657,698	4,572,122	5,486,547	6,858,183
54	8,317,466			2,322,809	3,484,213	4,645,617	5,807,021	6,968,426	8,710,532
60				2,875,748	4,313,623	5,751,497	7,189,371	8,627,245	10,784,057
72	Velocity	Governs	with	4,158,569	6,237,854	8,317,138	10,396,423	12,475,707	15,594,634
84	these	Pipe	Sizes	5,677,311	8,515,966	11,354,622	14,193,277	17,031,933	21,289,916
96				7,431,974	11,147,960	14,863,947	18,579,934	22,295,921	27,869,901

Notes:

1. **Maximum recommended pressure drop / velocity: 5.0 Psig/100 Ft. / 15,000 Fpm.**
2. **Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.**

300 Psig Steam Piping Systems—Steel Pipe

PIPE SIZE	STEAM FLOW LBS./HR.								
	PRESSURE DROP PSIG/100 FT.			VELOCITY FPM (MPH)					
	1	2	5	4,000 (45)	6,000 (68)	8,000 (91)	10,000 (114)	12,000 (136)	15,000 (170)
1/2	51	72	113						
3/4	115	163	257		Pressure	Drop	Governs	with	
1	232	327	518		these	Pipe	Sizes		
1-1/4	509	720	1,139						
1-1/2	791	1,118	1,768						
2	1,604	2,269	3,587						
2-1/2	2,642	3,736	5,908	5,413					
3	4,836	6,839	10,814	8,359					
4	10,219	14,451	22,850	14,394	21,591				
5	18,804	26,593	42,048	22,530	33,796				
6	31,032	43,886	69,390	32,665	48,998	65,331			
8	64,598	91,356	144,446	56,564	84,846	113,128	141,410		
10	117,879	166,706	263,586	89,158	133,737	178,316	222,895		
12	189,193	267,559	423,047	127,875	191,813	255,751	319,688	383,626	
14	245,059	346,565	547,968	155,904	233,855	311,807	389,759	467,711	
16	353,245	499,564		206,521	309,781	413,042	516,302	619,563	774,454
18	486,113	687,467		264,242	396,364	528,485	660,606	792,727	990,909
20	645,315	912,613		329,068	493,602	658,136	822,671	987,205	1,234,006
22	832,408	1,177,203		400,998	601,497	801,996	1,002,495	1,202,994	1,503,743
24	1,048,864	1,483,318		480,032	720,048	960,064	1,200,081	1,440,097	1,800,121
26	1,296,086	1,832,942		566,170	849,256	1,132,341	1,415,426	1,698,511	2,123,139
28	1,575,413	2,227,971		659,413	989,119	1,318,826	1,648,532	1,978,239	2,472,799
30	1,888,133	2,670,223		759,760	1,139,639	1,519,519	1,899,399	2,279,279	2,849,099
32	2,235,482	3,161,450		867,210	1,300,816	1,734,421	2,168,026	2,601,631	3,252,039
34	2,618,658			981,766	1,472,648	1,963,531	2,454,414	2,945,297	3,681,621
36	3,038,816			1,103,425	1,655,137	2,206,849	2,758,562	3,310,274	4,137,843
42	4,532,243			1,511,028	2,266,541	3,022,055	3,777,569	4,533,083	5,666,353
48	6,397,091			1,982,568	2,973,852	3,965,136	4,956,420	5,947,704	7,434,630
54	8,659,966			2,518,046	3,777,069	5,036,092	6,295,116	7,554,139	9,442,673
60	11,345,797			3,117,462	4,676,193	6,234,924	7,793,655	9,352,386	11,690,483
72	Velocity	Governs	with	4,508,107	6,762,160	9,016,214	11,270,267	13,524,321	16,905,401
84	these	Pipe	Sizes	6,154,503	9,231,754	12,309,005	15,386,256	18,463,508	23,079,384
96				8,056,649	12,084,973	16,113,298	20,141,622	24,169,947	30,212,433

Notes:

1. Maximum recommended pressure drop / velocity: 5.0 Psig/100 Ft. / 15,000 Fpm.
2. Table based on Standard Weight Steel Pipe using Steam Equations in Part 5.

PART 32

Appendix D: Pipe Materials, Expansion, and Support

32.01 Pipe Properties

A. Properties of Copper, Steel, and Stainless Steel Pipe Table Notes:

1. Un-Insulated Piping: Add 20% for hangers and supports.
2. Insulated Piping: Add 25% for hangers, supports, and insulation.
3. Readily Available Types K, L, and M Copper Pipe Sizes—½″, ¾″, 1″, 1¼″, 1½″, 2″, 2½″, 3″, 4″, 6″, 8″, 10″, 12″:
   a. Type L copper pipe is the most common copper pipe used in HVAC applications.
   b. Types K, L, and M copper may be hard drawn or annealed (soft) temper.
      1) Hard drawn copper pipe has higher allowable stress than annealed copper pipe.
   c. Types K, L, and M designate decreasing wall thicknesses.
   d. Type K is generally used for higher pressure/temperature applications and for direct burial.
   e. Type M copper pipe should not be used where subject to external damage.
   f. Copper pipe is manufactured in accordance with *ASTM Standard B88.*
4. Readily Available Steel Pipe Sizes—½″, ¾″, 1″, 1¼″, 1½″, 2″, 2½″, 3″, 4″, 6″, 8″, 10″, 12″, 14″, 16″, 18″, 20″, 24″, 30″, 36″, 42″, 48″, 54″, 60″, 72″, 84″, 96″:
   a. Standard steel pipe is the most common steel pipe used in HVAC applications.
   b. Standard and XS steel pipe are available in sizes through 96 inch.
   c. XXS steel pipe is available in sizes through 12 inch.
   d. Schedule 40 steel pipe is available in sizes through 96 inch.
   e. Schedule 80 and 160 steel pipe are available in sizes through 24 inch.
   f. Standard and Schedule 40 steel pipe have the same dimensions for 10 inch and smaller.
   g. XS and Schedule 80 steel pipe have the same dimensions for 8 inch and smaller.
   h. XXS and Schedule 160 have no dimensional relationship.
   i. Steel pipe is manufactured in accordance with ASTM Standards A53 and A106.
   j. The ASTM standards refer to steel pipe grades A and B. Grade A steel pipe has a lower tensile strength and is not generally used for HVAC applications.
   k. The ASTM standards refer to steel pipe Type E, S, and F:
      1) Type E (also referred to as ERW) steel pipe refers to electric resistance welded steel pipe.
      2) Type S steel pipe refers to seamless steel pipe.
      3) Type F steel pipe refers to furnace-butt welded steel pipe. This type is generally not used in HVAC applications and is only available in Grade A.
5. Readily Available Stainless Steel Pipe Sizes—½″, ¾″, 1″, 1¼″, 1½″, 2″, 2½″, 3″, 4″, 6″, 8″, 10″, 12″, 14″, 16″, 18″, 20″, 24″.
6. Pipe Sizes 5″, 22″, 26″, 28″, 32″, and 34″ are not standard sizes and not readily available in all locations.
7. Piping installations are generally governed by one of the following three codes (see also Part 19):
   a. *ASME B31.1-1998: Power Piping:*
      1) Applicable to Electric Generating Stations, Industrial and Institutional Plants, Central and District Heating/Cooling Plants, and Geothermal Heating.
   b. *ASME B31.3-1999: Process Piping:*
      1) Applicable to Petroleum Refineries, Chemical, Pharmaceutical, Textile, Paper, Semiconductor, and Cryogenic Plants.
   c. *ASME B31.9-1996: Building Services Piping:*
      1) Applicable to Industrial, Institutional, Commercial, and Public Buildings and Multi-Unit Residences.
      2) Most HVAC applications fall under *ASME B31.9* requirements.

Properties of Copper Pipe

PIPE SIZE In.	TYPE	INSIDE DIA. In.	WALL THICK In.	OUTSIDE DIA. In.	AREA Sq.In.	WEIGHT (1) PIPE Lb/Ft	WATER Lb/Ft	TOTAL Lb/Ft	WATER VOLUME Gal/Ft
1/2	K	0.527	0.049	0.625	0.218	0.301	0.095	0.396	0.011
	L	0.545	0.040	0.625	0.233	0.250	0.101	0.351	0.012
	M	0.569	0.028	0.625	0.254	0.179	0.110	0.289	0.013
3/4	K	0.745	0.065	0.875	0.436	0.562	0.189	0.751	0.023
	L	0.785	0.045	0.875	0.484	0.399	0.210	0.609	0.025
	M	0.811	0.032	0.875	0.517	0.288	0.224	0.512	0.027
1	K	0.995	0.065	1.125	0.778	0.736	0.337	1.073	0.040
	L	1.025	0.050	1.125	0.825	0.574	0.357	0.932	0.043
	M	1.055	0.035	1.125	0.874	0.407	0.379	0.786	0.045
1-1/4	K	1.245	0.065	1.375	1.217	0.909	0.527	1.437	0.063
	L	1.265	0.055	1.375	1.257	0.775	0.545	1.320	0.065
	M	1.291	0.042	1.375	1.309	0.598	0.567	1.165	0.068
1-1/2	K	1.481	0.072	1.625	1.723	1.194	0.746	1.941	0.089
	L	1.505	0.060	1.625	1.779	1.003	0.771	1.774	0.092
	M	1.527	0.049	1.625	1.831	0.825	0.793	1.618	0.095
2	K	1.959	0.083	2.125	3.014	1.810	1.306	3.116	0.157
	L	1.985	0.070	2.125	3.095	1.536	1.341	2.877	0.161
	M	2.009	0.058	2.125	3.170	1.280	1.373	2.654	0.165
2-1/2	K	2.435	0.095	2.625	4.657	2.567	2.018	4.585	0.242
	L	2.465	0.080	2.625	4.772	2.174	2.068	4.242	0.248
	M	2.495	0.065	2.625	4.889	1.777	2.118	3.895	0.254
3	K	2.907	0.109	3.125	6.637	3.511	2.876	6.387	0.345
	L	2.945	0.090	3.125	6.812	2.917	2.951	5.868	0.354
	M	2.981	0.072	3.125	6.979	2.348	3.024	5.371	0.363
4	K	3.857	0.134	4.125	11.684	5.712	5.062	10.774	0.607
	L	3.905	0.110	4.125	11.977	4.717	5.189	9.906	0.622
	M	3.935	0.095	4.125	12.161	4.089	5.269	9.358	0.632
5	K	4.805	0.160	5.125	18.133	8.484	7.856	16.341	0.942
	L	4.875	0.125	5.125	18.665	6.675	8.087	14.762	0.970
	M	4.907	0.109	5.125	18.911	5.839	8.193	14.033	0.982
6	K	5.741	0.192	6.125	25.886	12.166	11.215	23.381	1.345
	L	5.845	0.140	6.125	26.832	8.949	11.625	20.574	1.394
	M	5.881	0.122	6.125	27.164	7.822	11.769	19.590	1.411
8	K	7.583	0.271	8.125	45.162	22.732	19.566	42.298	2.346
	L	7.725	0.200	8.125	46.869	16.928	20.306	37.234	2.435
	M	7.785	0.170	8.125	47.600	14.443	20.623	35.066	2.473
10	K	9.449	0.338	10.125	70.123	35.330	30.381	65.711	3.643
	L	9.625	0.250	10.125	72.760	26.367	31.523	57.890	3.780
	M	9.701	0.212	10.125	73.913	22.445	32.023	54.468	3.840
12	K	11.315	0.405	12.125	100.554	50.695	43.565	94.259	5.224
	L	11.565	0.280	12.125	105.046	35.422	45.511	80.933	5.457
	M	11.617	0.254	12.125	105.993	32.203	45.921	78.124	5.506

Properties of Steel Pipe

PIPE SIZE In.	SCHEDULE		INSIDE DIA. In.	WALL THICK In.	OUTSIDE DIA. In.	AREA Sq.In.	WEIGHT (1) PIPE Lb/Ft	WATER Lb/Ft	TOTAL Lb/Ft	WATER VOLUME Gal/Ft
1/2	10	---	0.674	0.083	0.840	0.357	0.671	0.155	0.826	0.019
	40	STD	0.622	0.109	0.840	0.304	0.851	0.132	0.983	0.016
	80	XS	0.546	0.147	0.840	0.234	1.088	0.101	1.189	0.012
	160	---	0.466	0.187	0.840	0.171	1.304	0.074	1.378	0.009
	---	XXS	0.252	0.294	0.840	0.050	1.714	0.022	1.736	0.003
3/4	10	---	0.884	0.083	1.050	0.614	0.857	0.266	1.123	0.032
	40	STD	0.824	0.113	1.050	0.533	1.131	0.231	1.362	0.028
	80	XS	0.742	0.154	1.050	0.432	1.474	0.187	1.661	0.022
	160	---	0.614	0.218	1.050	0.296	1.937	0.128	2.065	0.015
	---	XXS	0.434	0.308	1.050	0.148	2.441	0.064	2.505	0.008
1	10	---	1.097	0.109	1.315	0.945	1.404	0.409	1.813	0.049
	40	STD	1.049	0.133	1.315	0.864	1.679	0.374	2.053	0.045
	80	XS	0.957	0.179	1.315	0.719	2.172	0.312	2.483	0.037
	160	---	0.815	0.250	1.315	0.522	2.844	0.226	3.070	0.027
	---	XXS	0.599	0.358	1.315	0.282	3.659	0.122	3.781	0.015
1-1/4	10	---	1.442	0.109	1.660	1.633	1.806	0.708	2.513	0.085
	40	STD	1.380	0.140	1.660	1.496	2.273	0.648	2.921	0.078
	80	XS	1.278	0.191	1.660	1.283	2.997	0.556	3.552	0.067
	160	---	1.160	0.250	1.660	1.057	3.765	0.458	4.223	0.055
	---	XXS	0.896	0.382	1.660	0.631	5.214	0.273	5.487	0.033
1-1/2	10	---	1.682	0.109	1.900	2.222	2.085	0.963	3.048	0.115
	40	STD	1.610	0.145	1.900	2.036	2.718	0.882	3.600	0.106
	80	XS	1.500	0.200	1.900	1.767	3.631	0.766	4.397	0.092
	160	---	1.338	0.281	1.900	1.406	4.859	0.609	5.468	0.073
	---	XXS	1.100	0.400	1.900	0.950	6.408	0.412	6.820	0.049
2	10	---	2.157	0.109	2.375	3.654	2.638	1.583	4.221	0.190
	40	STD	2.067	0.154	2.375	3.356	3.653	1.454	5.107	0.174
	80	XS	1.939	0.218	2.375	2.953	5.022	1.279	6.301	0.153
	160	---	1.689	0.343	2.375	2.241	7.444	0.971	8.415	0.116
	---	XXS	1.503	0.436	2.375	1.774	9.029	0.769	9.798	0.092
2-1/2	10	---	2.635	0.120	2.875	5.453	3.531	2.363	5.893	0.283
	40	STD	2.469	0.203	2.875	4.788	5.793	2.074	7.867	0.249
	80	XS	2.323	0.276	2.875	4.238	7.661	1.836	9.497	0.220
	160	---	2.125	0.375	2.875	3.547	10.013	1.537	11.549	0.184
	---	XXS	1.771	0.552	2.875	2.463	13.695	1.067	14.762	0.128
3	10	---	3.260	0.120	3.500	8.347	4.332	3.616	7.948	0.434
	40	STD	3.068	0.216	3.500	7.393	7.576	3.203	10.779	0.384
	80	XS	2.900	0.300	3.500	6.605	10.253	2.862	13.115	0.343
	160	---	2.626	0.437	3.500	5.416	14.296	2.346	16.642	0.281
	---	XXS	2.300	0.600	3.500	4.155	18.584	1.800	20.384	0.216
4	10	---	4.260	0.120	4.500	14.253	5.614	6.175	11.789	0.740
	40	STD	4.026	0.237	4.500	12.730	10.791	5.515	16.306	0.661
	80	XS	3.826	0.337	4.500	11.497	14.984	4.981	19.965	0.597
	160	---	3.438	0.531	4.500	9.283	22.509	4.022	26.531	0.482
	---	XXS	3.152	0.674	4.500	7.803	27.541	3.381	30.922	0.405

Properties of Steel Pipe

PIPE SIZE In.	SCHEDULE		INSIDE DIA. In.	WALL THICK In.	OUTSIDE DIA. In.	AREA Sq.In.	WEIGHT (1)			WATER VOLUME Gal/Ft
							PIPE Lb/Ft	WATER Lb/Ft	TOTAL Lb/Ft	
5	10	---	5.295	0.134	5.563	22.020	7.770	9.540	17.310	1.144
	40	STD	5.047	0.258	5.563	20.006	14.618	8.667	23.285	1.039
	80	XS	4.813	0.375	5.563	18.194	20.778	7.882	28.661	0.945
	160	---	4.313	0.625	5.563	14.610	32.962	6.330	39.291	0.759
	---	XXS	4.063	0.750	5.563	12.965	38.553	5.617	44.170	0.674
6	10	---	6.357	0.134	6.625	31.739	9.290	13.751	23.040	1.649
	40	STD	6.065	0.280	6.625	28.890	18.974	12.517	31.491	1.501
	80	XS	5.761	0.432	6.625	26.067	28.574	11.293	39.867	1.354
	160	---	5.189	0.718	6.625	21.147	45.297	9.162	54.459	1.099
	---	XXS	4.897	0.864	6.625	18.834	53.161	8.160	61.321	0.978
8	10	---	8.329	0.148	8.625	54.485	13.399	23.605	37.005	2.830
	20	---	8.125	0.250	8.625	51.849	22.362	22.463	44.825	2.693
	30	---	8.071	0.277	8.625	51.162	24.697	22.166	46.862	2.658
	40	STD	7.981	0.322	8.625	50.027	28.554	21.674	50.228	2.599
	80	XS	7.625	0.500	8.625	45.664	43.388	19.784	63.172	2.372
	---	XXS	6.875	0.875	8.625	37.122	72.425	16.083	88.508	1.928
	160	---	6.813	0.906	8.625	36.456	74.691	15.794	90.485	1.894
10	10	---	10.420	0.165	10.750	85.276	18.653	36.945	55.599	4.430
	20	---	10.250	0.250	10.750	82.516	28.036	35.750	63.785	4.287
	30	---	10.136	0.307	10.750	80.691	34.241	34.959	69.200	4.192
	40	STD	10.020	0.365	10.750	78.854	40.484	34.163	74.647	4.096
	60	XS	9.750	0.500	10.750	74.662	54.736	32.347	87.083	3.879
	80	---	9.564	0.593	10.750	71.840	64.328	31.125	95.453	3.732
	140	XXS	8.750	1.000	10.750	60.132	104.132	26.052	130.184	3.124
	160	---	8.500	1.125	10.750	56.745	115.647	24.585	140.231	2.948
12	10	---	12.390	0.180	12.750	120.568	24.165	52.236	76.401	6.263
	20	---	12.250	0.250	12.750	117.859	33.376	51.062	84.438	6.123
	30	---	12.090	0.330	12.750	114.800	43.774	49.737	93.511	5.964
	---	STD	12.000	0.375	12.750	113.097	49.563	48.999	98.562	5.875
	40	---	11.938	0.406	12.750	111.932	53.526	48.494	102.020	5.815
	---	XS	11.750	0.500	12.750	108.434	65.416	46.979	112.395	5.633
	80	---	11.376	0.687	12.750	101.641	88.510	44.036	132.545	5.280
	120	XXS	10.750	1.000	12.750	90.763	125.492	39.323	164.815	4.715
	160	---	10.126	1.312	12.750	80.531	160.274	34.890	195.164	4.183
14	10	---	13.500	0.250	14.000	143.139	36.713	62.014	98.728	7.436
	20	---	13.376	0.312	14.000	140.521	45.611	60.880	106.492	7.300
	30	STD	13.250	0.375	14.000	137.886	54.569	59.739	114.308	7.163
	40	---	13.126	0.437	14.000	135.318	63.302	58.626	121.928	7.029
	---	XS	13.000	0.500	14.000	132.732	72.091	57.506	129.597	6.895
	80	---	12.500	0.750	14.000	122.718	106.134	53.167	159.302	6.375
	160	---	11.188	1.406	14.000	98.309	189.116	42.592	231.708	5.107
16	10	---	15.500	0.250	16.000	188.692	42.053	81.750	123.803	9.802
	20	---	15.376	0.312	16.000	185.685	52.276	80.447	132.723	9.646
	30	STD	15.250	0.375	16.000	182.654	62.579	79.134	141.714	9.489
	40	XS	15.000	0.500	16.000	176.715	82.772	76.561	159.333	9.180
	80	---	14.314	0.843	16.000	160.921	136.465	69.718	206.183	8.360
	160	---	12.814	1.593	16.000	128.961	245.114	55.872	300.986	6.699

Properties of Steel Pipe

PIPE SIZE In.	SCHEDULE		INSIDE DIA. In.	WALL THICK In.	OUTSIDE DIA. In.	AREA Sq.In.	WEIGHT (1) PIPE Lb/Ft	WATER Lb/Ft	TOTAL Lb/Ft	WATER VOLUME Gal/Ft
18	10	---	17.500	0.250	18.000	240.528	47.393	104.208	151.601	12.495
	20	---	17.376	0.312	18.000	237.132	58.940	102.737	161.677	12.319
	---	STD	17.250	0.375	18.000	233.705	70.589	101.252	171.841	12.141
	30	---	17.126	0.437	18.000	230.357	81.971	99.802	181.772	11.967
	---	XS	17.000	0.500	18.000	226.980	93.452	98.338	191.790	11.791
	40	---	16.876	0.562	18.000	223.681	104.668	96.909	201.577	11.620
	80	---	16.126	0.937	18.000	204.241	170.755	88.487	259.242	10.610
	160	---	14.438	1.781	18.000	163.721	308.509	70.932	379.440	8.505
20	10	---	19.500	0.250	20.000	298.648	52.733	129.388	182.122	15.514
	20	STD	19.250	0.375	20.000	291.039	78.600	126.092	204.691	15.119
	30	XS	19.000	0.500	20.000	283.529	104.132	122.838	226.970	14.729
	40	---	18.814	0.593	20.000	278.005	122.911	120.445	243.356	14.442
	80	---	17.938	1.031	20.000	252.719	208.873	109.490	318.363	13.128
	160	---	16.064	1.968	20.000	202.674	379.008	87.808	466.816	10.529
22	10	---	21.500	0.250	22.000	363.050	58.074	157.290	215.364	18.860
	20	STD	21.250	0.375	22.000	354.656	86.610	153.654	240.263	18.424
	30	XS	21.000	0.500	22.000	346.361	114.812	150.060	264.872	17.993
	80	---	19.750	1.125	22.000	306.354	250.818	132.727	383.545	15.915
	160	---	17.750	2.125	22.000	247.450	451.072	107.207	558.278	12.855
24	10	---	23.500	0.250	24.000	433.736	63.414	187.915	251.328	22.532
	20	STD	23.250	0.375	24.000	424.557	94.620	183.938	278.558	22.055
	---	XS	23.000	0.500	24.000	415.476	125.492	180.003	305.496	21.583
	30	---	22.876	0.562	24.000	411.008	140.681	178.068	318.749	21.351
	40	---	22.626	0.687	24.000	402.073	171.054	174.197	345.251	20.887
	80	---	21.564	1.218	24.000	365.215	296.359	158.228	454.587	18.972
	160	---	19.314	2.343	24.000	292.978	541.938	126.932	668.870	15.220
26	10	---	25.376	0.312	26.000	505.750	85.598	219.115	304.713	26.273
	---	STD	25.250	0.375	26.000	500.740	102.630	216.944	319.574	26.012
	20	XS	25.000	0.500	26.000	490.874	136.173	212.670	348.842	25.500
28	10	---	27.376	0.312	28.000	588.613	92.263	255.015	347.277	30.577
	---	STD	27.250	0.375	28.000	583.207	110.640	252.673	363.313	30.296
	20	XS	27.000	0.500	28.000	572.555	146.853	248.058	394.910	29.743
	30	---	26.750	0.625	28.000	562.001	182.732	243.485	426.217	29.195
30	10	---	29.376	0.312	30.000	677.759	98.927	293.637	392.564	35.208
	---	STD	29.250	0.375	30.000	671.957	118.650	291.123	409.774	34.907
	20	XS	29.000	0.500	30.000	660.520	157.533	286.168	443.701	34.313
	30	---	28.750	0.625	30.000	649.181	196.082	281.255	477.337	33.724
	40	---	28.500	0.688	29.876	637.940	214.473	276.385	490.858	33.140
32	10	---	31.376	0.312	32.000	773.188	105.591	334.981	440.573	40.166
	---	STD	31.250	0.375	32.000	766.990	126.660	332.296	458.957	39.844
	20	XS	31.000	0.500	32.000	754.768	168.213	327.001	495.214	39.209
	30	---	30.750	0.625	32.000	742.643	209.432	321.748	531.180	38.579
	40	---	30.624	0.688	32.000	736.569	230.080	319.116	549.196	38.263

Properties of Steel Pipe

PIPE SIZE In.	SCHEDULE		INSIDE DIA. In.	WALL THICK In.	OUTSIDE DIA. In.	AREA Sq.In.	WEIGHT (1)			WATER VOLUME Gal/Ft
							PIPE Lb/Ft	WATER Lb/Ft	TOTAL Lb/Ft	
34	10	---	33.376	0.312	34.000	874.900	112.256	379.048	491.304	45.449
	---	STD	33.250	0.375	34.000	868.307	134.671	376.191	510.862	45.107
	20	XS	33.000	0.500	34.000	855.299	178.893	370.555	549.449	44.431
	30	---	32.750	0.625	34.000	842.389	222.782	364.962	587.744	43.760
	40	---	32.624	0.688	34.000	835.919	244.776	362.159	606.935	43.424
36	10	---	35.376	0.312	36.000	982.895	118.920	425.836	544.757	51.060
	---	STD	35.250	0.375	36.000	975.906	142.681	422.808	565.489	50.696
	20	XS	35.000	0.500	36.000	962.113	189.574	416.832	606.406	49.980
	30	---	34.750	0.625	36.000	948.417	236.133	410.899	647.031	49.268
	40	---	34.500	0.750	36.000	934.820	282.358	405.008	687.366	48.562
42	---	STD	41.250	0.375	42.000	1336.404	166.711	578.993	745.704	69.424
	20	XS	41.000	0.500	42.000	1320.254	221.614	571.996	793.610	68.585
	30	---	40.750	0.625	42.000	1304.203	276.183	565.042	841.225	67.751
	40	---	40.500	0.750	42.000	1288.249	330.419	558.130	888.549	66.922
48	---	STD	47.250	0.375	48.000	1753.450	190.742	759.677	950.418	91.088
	20	XS	47.000	0.500	48.000	1734.945	253.655	751.659	1005.314	90.127
	30	---	46.750	0.625	48.000	1716.537	316.234	743.684	1059.918	89.171
	40	---	46.500	0.750	48.000	1698.227	378.480	735.751	1114.231	88.220
54	---	STD	53.250	0.375	54.000	2227.046	214.772	964.860	1179.632	115.691
	20	XS	53.000	0.500	54.000	2206.183	285.695	955.822	1241.517	114.607
	30	---	52.750	0.625	54.000	2185.419	356.285	946.826	1303.111	113.528
	40	---	52.500	0.750	54.000	2164.754	426.540	937.873	1364.413	112.455
60	---	STD	59.250	0.375	60.000	2757.189	238.803	1194.543	1433.346	143.231
	20	XS	59.000	0.500	60.000	2733.971	317.736	1184.484	1502.220	142.024
	30	---	58.750	0.625	60.000	2710.851	396.336	1174.467	1570.803	140.823
	40	---	58.500	0.750	60.000	2687.829	474.601	1164.493	1639.095	139.627
72	---	STD	71.250	0.375	72.000	3987.123	286.863	1727.408	2014.272	207.123
	20	XS	71.000	0.500	72.000	3959.192	381.817	1715.307	2097.124	205.672
	30	---	70.750	0.625	72.000	3931.360	476.437	1703.249	2179.686	204.226
	40	---	70.500	0.750	72.000	3903.625	570.723	1691.233	2261.956	202.786
84	---	STD	83.250	0.375	84.000	5443.251	334.924	2358.271	2693.195	282.766
	20	XS	83.000	0.500	84.000	5410.608	445.898	2344.128	2790.027	281.071
	30	---	82.750	0.625	84.000	5378.063	556.539	2330.029	2886.567	279.380
	40	---	82.500	0.750	84.000	5345.616	666.845	2315.971	2982.816	277.694
96	---	STD	95.250	0.375	96.000	7125.574	382.985	3087.132	3470.117	370.160
	20	XS	95.000	0.500	96.000	7088.218	509.980	3070.948	3580.927	368.219
	30	---	94.750	0.625	96.000	7050.961	636.640	3054.806	3691.446	366.284
	40	---	94.500	0.750	96.000	7013.802	762.967	3038.707	3801.674	364.353

Properties of Stainless Steel Pipe

PIPE SIZE In.	SCHEDULE		INSIDE DIA. In.	WALL THICK In.	OUTSIDE DIA. In.	AREA Sq.In.	WEIGHT (1)			WATER VOLUME Gal/Ft
							PIPE Lb/Ft	WATER Lb/Ft	TOTAL Lb/Ft	
1/2	5	---	0.710	0.065	0.840	0.396	0.549	0.172	0.720	0.021
	10	---	0.674	0.083	0.840	0.357	0.684	0.155	0.839	0.019
3/4	5	---	0.920	0.065	1.050	0.665	0.697	0.288	0.985	0.035
	10	---	0.884	0.083	1.050	0.614	0.874	0.266	1.140	0.032
1	5	---	1.185	0.065	1.315	1.103	0.885	0.478	1.363	0.057
	10	---	1.097	0.109	1.315	0.945	1.432	0.409	1.842	0.049
1-1/4	5	---	1.530	0.065	1.660	1.839	1.129	0.797	1.926	0.096
	10	---	1.442	0.109	1.660	1.633	1.842	0.708	2.549	0.085
1-1/2	5	---	1.770	0.065	1.900	2.461	1.299	1.066	2.365	0.128
	10	---	1.682	0.109	1.900	2.222	2.127	0.963	3.089	0.115
2	5	---	2.245	0.065	2.375	3.958	1.636	1.715	3.351	0.206
	10	---	2.157	0.109	2.375	3.654	2.691	1.583	4.274	0.190
2-1/2	5	---	2.709	0.083	2.875	5.764	2.524	2.497	5.022	0.299
	10	---	2.635	0.120	2.875	5.453	3.601	2.363	5.964	0.283
3	5	---	3.334	0.083	3.500	8.730	3.090	3.782	6.872	0.454
	10	---	3.260	0.120	3.500	8.347	4.419	3.616	8.035	0.434
4	5	---	4.334	0.083	4.500	14.753	3.994	6.392	10.385	0.766
	10	---	4.260	0.120	4.500	14.253	5.726	6.175	11.901	0.740
5	5	---	5.345	0.109	5.563	22.438	6.476	9.721	16.197	1.166
	10	---	5.295	0.134	5.563	22.020	7.925	9.540	17.465	1.144
6	5	---	6.407	0.109	6.625	32.240	7.737	13.968	21.705	1.675
	10	---	6.357	0.134	6.625	31.739	9.475	13.751	23.226	1.649
8	5	---	8.407	0.109	8.625	55.510	10.112	24.050	34.162	2.884
	10	---	8.329	0.148	8.625	54.485	13.667	23.605	37.273	2.830
10	5	---	10.482	0.134	10.750	86.294	15.497	37.386	52.883	4.483
	10	---	10.420	0.165	10.750	85.276	19.026	36.945	55.972	4.430
12	5	---	12.438	0.156	12.750	121.504	21.403	52.641	74.044	6.312
	10	---	12.390	0.180	12.750	120.568	24.648	52.236	76.884	6.263
14	5	---	13.688	0.156	14.000	147.153	23.527	63.754	87.281	7.644
	10	---	13.624	0.188	14.000	145.780	28.287	63.159	91.446	7.573
16	5	---	15.670	0.165	16.000	192.854	28.463	83.553	112.016	10.018
	10	---	15.624	0.188	16.000	191.723	32.384	83.063	115.447	9.960
18	5	---	17.670	0.165	18.000	245.224	32.058	106.243	138.301	12.739
	10	---	17.624	0.188	18.000	243.949	36.480	105.690	142.170	12.673
20	5	---	19.624	0.188	20.000	302.458	40.576	131.039	171.615	15.712
	10	---	19.564	0.218	20.000	300.611	46.979	130.239	177.218	15.616
22	5	---	21.624	0.188	22.000	367.250	44.672	159.110	203.782	19.078
	10	---	21.564	0.218	22.000	365.215	51.729	158.228	209.957	18.972
24	5	---	23.564	0.218	24.000	436.102	56.479	188.940	245.418	22.655
	10	---	23.500	0.250	24.000	433.736	64.682	187.915	252.597	22.532

32.02 Pipe Expansion

Thermal Expansion of Metal Pipe

SATURATED STEAM PRESSURE PSIG	TEMPERATURE °F	LINEAR THERMAL EXPANSION INCHES/100 FEET		
		CARBON STEEL	STAINLESS STEEL	COPPER
--	-30	-0.19	-0.30	-0.32
--	-20	-0.12	-0.20	-0.21
--	-10	-0.06	-0.10	-0.11
--	0	0	0	0
--	10	0.08	0.11	0.12
--	20	0.15	0.22	0.24
-14.6	32	0.24	0.36	0.37
-14.6	40	0.30	0.45	0.45
-14.5	50	0.38	0.56	0.57
-14.4	60	0.46	0.67	0.68
-14.3	70	0.53	0.78	0.79
-14.2	80	0.61	0.90	0.90
-14.0	90	0.68	1.01	1.02
-13.7	100	0.76	1.12	1.13
-13.0	120	0.91	1.35	1.37
-11.8	140	1.06	1.57	1.59
-10.0	160	1.22	1.79	1.80
-7.2	180	1.37	2.02	2.05
-3.2	200	1.52	2.24	2.30
0	212	1.62	2.38	2.43
2.5	220	1.69	2.48	2.52
10.3	240	1.85	2.71	2.76
20.7	260	2.02	2.94	2.99
34.6	280	2.18	3.17	3.22
52.3	300	2.35	3.40	3.46
75.0	320	2.53	3.64	3.70
103.3	340	2.70	3.88	3.94
138.3	360	2.88	4.11	4.18
181.1	380	3.05	4.35	4.42
232.6	400	3.23	4.59	4.87
294.1	420	3.41	4.83	4.91
366.9	440	3.60	5.07	5.15

Thermal Expansion of Metal Pipe

SATURATED STEAM PRESSURE PSIG	TEMPERATURE °F	LINEAR THERMAL EXPANSION INCHES/100 FEET		
		CARBON STEEL	STAINLESS STEEL	COPPER
452.2	460	3.78	5.32	5.41
551.4	480	3.97	5.56	5.65
666.1	500	4.15	5.80	5.91
797.7	520	4.35	6.05	6.15
947.8	540	4.54	6.29	6.41
1118	560	4.74	6.54	6.64
1311	580	4.93	6.78	6.92
1528	600	5.13	7.03	7.18
1772	620	5.34	7.28	7.43
2045	640	5.54	7.53	7.69
2351	660	5.75	7.79	7.95
2693	680	5.95	8.04	8.20
3079	700	6.16	8.29	8.47
---	720	6.37	8.55	8.71
---	740	6.59	8.81	9.00
---	760	6.80	9.07	9.26
---	780	7.02	9.33	9.53
---	800	7.23	9.59	9.79
---	820	7.45	9.85	10.07
---	840	7.67	10.12	10.31
---	860	7.90	10.38	10.61
---	880	8.12	10.65	10.97
---	900	8.34	10.91	11.16
---	920	8.56	11.18	11.42
---	940	8.77	11.45	11.71
---	960	8.99	11.73	11.98
---	980	9.20	12.00	12.27
---	1000	9.42	12.27	12.54

L-Bend, Z-Bend and U-Bend or Loop Table Notes:

1. Table based on *ASTM A53,* Grade B, Steel Pipe.
2. Temperature range applicable through 400°F.
3. Table also applicable to copper tube.
4. For equations and diagrams relating to pipe expansion see Part 5, Equations.
5. L-Bend, Z-Bend, and U-Bend or Loop dimensions are minimum dimensions, recommend rounding up to nearest ½ foot (H = 2W).

Pipe Expansion L-Bends

PIPE SIZE	EXPANSION OF LONGEST LEG							
	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
1/2	5'-9"	7'-0"	8'-2"	9'-2"	10'-0"	11'-6"	12'-9"	14'-0"
3/4	6'-6"	8'-4"	9'-3"	10'-4"	11'-3"	13'-0"	14'-8"	16'-0"
1	7'-2"	8'-9"	10'-2"	11'-4"	12'-6"	14'-4"	16'-0"	17'-6"
1-1/4	8'-0"	9'-10"	11'-4"	12'-8"	14'-0"	16'-2"	18'-0"	19'-8"
1-1/2	8'-8"	10'-6"	12'-2"	13'-8"	15'-0"	17'-2"	19'-3"	21'-0"
2	9'-8"	11'-9"	13'-8"	15'-2"	16'-8"	19'-3"	21'-6"	23'-6"
2-1/2	10'-8"	13'-0"	15'-0"	16'-9"	18'-4"	21'-2"	23'-8"	26'-0"
3	11'-8"	14'-4"	16'-6"	18'-6"	20'-2"	23'-4"	26'-2"	28'-8"
4	13'-3"	16'-2"	18'-8"	21'-0"	23'-0"	26'-6"	29'-8"	32'-6"
5	14'-8"	18'-0"	20'-9"	23'-3"	25'-6"	29'-6"	32'-10"	36'-0"
6	16'-2"	19'-8"	22'-8"	25'-4"	27'-9"	32'-2"	35'-10"	39'-3"
8	18'-4"	22'-6"	26'-0"	29'-0"	31'-8"	36'-8"	41'-0"	44'-10"
10	20'-6"	25'-0"	29'-9"	32'-4"	35'-6"	40'-10"	45'-8"	50'-0"
12	22'-3"	27'-3"	31'-6"	35'-2"	38'-6"	44'-6"	49'-9"	54'-6"
14	23'-4"	28'-8"	33'-0"	36'-10"	40'-4"	46'-8"	52'-2"	57'-2"
16	25'-0"	30'-6"	35'-3"	39'-6"	43'-2"	50'-0"	55'-8"	61'-0"
18	26'-6"	32'-4"	37'-6"	41'-9"	45'-9"	52'-10"	59'-2"	64'-10"
20	27'-10"	34'-2"	39'-6"	44'-0"	48'-3"	55'-8"	62'-3"	68'-3"
22	29'-3"	35'-9"	41'-4"	46'-2"	50'-8"	58'-6"	65'-4"	71'-8"
24	30'-6"	37'-6"	43'-2"	48'-3"	52'-10"	61'-0"	68'-3"	74'-9"
26	31'-9"	39'-0"	45'-0"	50'-3"	55'-0"	63'-6"	71'-0"	77'-9"
28	33'-0"	40'-4"	46'-8"	52'-2"	57'-2"	66'-0"	73'-8"	80'-9"
30	34'-2"	41'-9"	48'-3"	54'-0"	59'-2"	68'-3"	76'-3"	83'-8"
32	35'-3"	43'-2"	50'-0"	55'-8"	61'-0"	70'-6"	78'-9"	86'-4"
34	36'-4"	44'-6"	51'-4"	57'-6"	63'-0"	72'-8"	81'-2"	89'-0"
36	37'-6"	45'-9"	52'-10"	59'-2"	64'-9"	74'-9"	83'-8"	91'-6"
42	40'-6"	49'-6"	57'-2"	63'-10"	70'-0"	80'-9"	90'-3"	99'-10"
48	43'-2"	52'-10"	61'-0"	68'-3"	74'-9"	86'-4"	96'-5"	105'-8"
54	45'-9"	56'-1"	64'-9"	72'-4"	79'-3"	91'-6"	102'-4"	112'-1"
60	48'-3"	59'-1"	68'-3"	76'-3"	83'-7"	96'-6"	107'-10"	118'-2"
72	52'-10"	64'-9"	74'-9"	83'-7"	91'-6"	105'-8"	118'-2"	129'-5"
84	57'-1"	69'-11"	80'-9"	90'-3"	98'-10"	114'-2"	127'-7"	140'-0"
96	61'-0"	74'-9"	86'-4"	96'-6"	105'-8"	122'-0"	136'-5"	149'-6"

Pipe Expansion Z-Bends

PIPE SIZE	ANCHOR TO ANCHOR EXPANSION							
	1"	1-1/2"	2"	2-1/2"	3"	4"	5"	6"
1/2	3'-8"	4'-6"	5'-2"	5'-10"	6'-5"	7'-4"	8'-2"	9'-0"
3/4	4'-2"	5'-2"	6'-2"	6'-8"	7'-3"	8'-6"	9'-4"	10'-3"
1	4'-8"	5'-8"	6'-6"	7'-4"	8'-0"	9'-2"	10'-4"	11'-3"
1-1/4	5'-2"	6'-4"	7'-4"	8'-2"	9'-0"	10'-4"	11'-8"	12'-8"
1-1/2	5'-6"	6'-10"	7'-10"	8'-9"	9'-7"	11'-0"	12'-4"	13'-6"
2	6'-2"	7'-8"	8'-9"	9'-9"	10'-8"	12'-4"	13'-10"	15'-2"
2-1/2	6'-10"	8'-4"	9'-8"	10'-9"	11'-9"	13'-8"	15'-2"	16'-8"
3	7'-6"	9'-2"	10'-8"	12'-0"	13'-0"	15'-0"	16'-9"	18'-4"
4	8'-6"	10'-6"	12'-0"	13'-6"	14'-9"	17'-0"	19'-0"	20'-10"
5	9'-6"	11'-8"	13'-4"	15'-0"	16'-6"	19'-0"	21'-2"	23'-2"
6	10'-4"	12'-8"	14'-6"	16'-4"	18'-0"	20'-8"	23'-0"	25'-3"
8	11'-9"	14'-6"	16'-8"	18'-8"	20'-4"	23'-6"	26'-4"	28'-10"
10	13'-2"	16'-2"	18'-6"	20'-9"	22'-9"	26'-3"	29'-4"	32'-2"
12	14'-4"	17'-6"	20'-3"	22'-8"	24'-9"	28'-8"	32'-0"	35'-0"
14	15'-0"	18'-4"	21'-2"	23'-8"	26'-0"	30'-0"	33'-6"	36'-8"
16	16'-0"	19'-8"	22'-8"	25'-4"	27'-9"	32'-0"	35'-9"	39'-3"
18	17'-0"	20'-10"	24'-0"	26'-10"	29'-6"	34'-0"	38'-0"	41'-8"
20	18'-0"	22'-0"	25'-3"	28'-4"	31'-0"	35'-9"	40'-0"	43'-10"
22	18'-10"	23'-0"	26'-8"	29'-8"	32'-6"	37'-8"	42'-0"	46'-0"
24	19'-8"	24'-0"	27'-9"	31'-0"	34'-0"	39'-2"	43'-10"	48'-0"
26	20'-6"	25'-0"	28'-10"	32'-4"	35'-4"	40'-10"	45'-8"	50'-0"
28	21'-2"	26'-0"	30'-0"	33'-6"	36'-8"	42'-4"	47'-4"	52'-0"
30	22'-0"	26'-10"	31'-0"	34'-8"	38'-0"	43'-10"	49'-0"	53'-8"
32	22'-8"	27'-9"	32'-0"	35'-10"	39'-3"	45'-4"	50'-8"	55'-6"
34	23'-4"	28'-8"	33'-0"	37'-0"	40'-6"	46'-8"	52'-2"	57'-2"
36	24'-0"	29'-6"	34'-0"	38'-0"	41'-8"	48'-0"	53'-8"	58'-10"
42	26'-0"	31'-9"	36'-8"	41'-0"	45'-0"	52'-0"	58'-0"	63'-6"
48	27'-9"	34'-0"	39'-3"	43'-10"	48'-0"	55'-6"	62'-0"	67'-11"
54	29'-5"	36'-0"	41'-7"	46'-6"	50'-11"	58'-10"	65'-9"	72'-0"
60	31'-0"	38'-0"	43'-10"	49'-0"	53'-8"	62'-0"	69'-4"	75'-11"
72	34'-0"	41'-7"	48'-0"	53'-8"	58'-10"	67'-11"	75'-11"	83'-2"
84	36'-8"	44'-11"	51'-11"	58'-0"	63'-6"	73'-4"	82'-0"	89'-10"
96	39'-3"	48'-0"	55'-6"	62'-0"	67'-11"	78'-5"	87'-8"	96'-0"

Pipe Expansion U-Bends or Loops

PIPE SIZE	ANCHOR TO ANCHOR EXPANSION							
	1"		1-1/2"		2"		2-1/2"	
	W	H	W	H	W	H	W	H
1/2	1'-2"	2'-4"	1'-6"	3'-0"	1'-8"	3'-4"	1'-10"	3'-8"
3/4	1'-4"	2'-8"	1'-8"	3'-4"	1'-10"	3'-8"	2'-2"	4'-4"
1	1'-6"	3'-0"	1'-9"	3'-6"	2'-0"	4'-0"	2'-4"	4'-8"
1-1/4	1'-8"	3'-4"	2'-0"	4'-0"	2'-4"	4'-8"	2'-8"	5'-4"
1-1/2	1'-9"	3'-6"	2'-2"	4'-4"	2'-6"	5'-0"	2'-9"	5'-6"
2	1'-11"	3'-10"	2'-4"	4'-8"	2'-9"	5'-6"	3'-2"	6'-4"
2-1/2	2'-2"	4'-4"	2'-8"	5'-4"	3'-0"	6'-0"	3'-3"	6'-6"
3	2'-4"	4'-8"	3'-0"	6'-0"	3'-4"	6'-8"	3'-9"	7'-6"
4	2'-8"	5'-4"	3'-3"	6'-6"	3'-9"	7'-6"	4'-2"	8'-4"
5	3'-0"	6'-0"	3'-8"	7'-4"	4'-2"	8'-4"	4'-8"	9'-4"
6	3'-3"	6'-6"	4'-0"	8'-0"	4'-7"	9'-2"	5'-2"	10'-4"
8	3'-8"	7'-4"	4'-6"	9'-0"	5'-2"	10'-4"	5'-10"	11'-8"
10	4'-2"	8'-4"	5'-0"	10'-0"	5'-10"	11'-8"	6'-6"	13'-0"
12	4'-6"	9'-0"	5'-6"	11'-0"	6'-4"	12'-8"	7'-2"	14'-4"
14	4'-8"	9'-4"	5'-9"	11'-6"	6'-8"	13'-4"	7'-6"	15'-0"
16	5'-0"	10'-0"	6'-2"	12'-4"	7'-1"	14'-2"	8'-0"	16'-0"
18	5'-4"	10'-8"	6'-6"	13'-0"	7'-6"	15'-0"	8'-6"	17'-0"
20	5'-8"	11'-4"	7'-0"	14'-0"	7'-11"	15'-9"	8'-10"	17'-8"
22	5'-10"	11'-8"	7'-3"	14'-6"	8'-3"	16'-6"	9'-3"	18'-6"
24	6'-1"	12'-2"	7'-6"	15'-0"	8'-8"	17'-4"	9'-8"	19'-4"
26	6'-5"	13'-0"	7'-10"	15'-8"	9'-0"	18'-0"	10'-2"	20'-4"
28	6'-8"	13'-4"	8'-2"	16'-4"	9'-4"	18'-8"	10'-6"	21'-0"
30	6'-10"	13'-8"	8'-6"	17'-0"	9'-8"	19'-4"	11'-0"	21'-8"
32	7'-1"	14'-2"	8'-8"	17'-4"	10'-0"	20'-0"	11'-2"	22'-4"
34	7'-4"	14'-8"	9'-0"	18'-0"	10'-4"	20'-8"	11'-6"	23'-0"
36	7'-6"	15'-0"	9'-2"	18'-4"	10'-8"	21'-4"	12'-0"	23'-8"
42	8'-1"	16'-2"	10'-0"	20'-0"	11'-6"	13'-0"	12'-9"	25'-6"
48	8'-8"	17'-4"	10'-7"	21'-2"	12'-3"	24'-6"	13'-8"	27'-4"
54	9'-2"	18'-4"	11'-3"	22'-6"	13'-0"	26'-0"	14'-6"	29'-0"
60	9'-8"	19'-4"	11'-10"	23'-8"	13'-8"	27'-4"	15'-3"	30'-6"
72	10'-7"	21'-2"	13'-0"	26'-0"	15'-0"	30'-0"	16'-9"	33'-6"
84	11'-5"	22'-10"	14'-0"	28'-0"	16'-2"	32'-4"	18'-1"	36'-2"
96	12'-3"	24'-6"	15'-0"	30'-0"	17'-3"	34'-6"	19'-4"	38'-8"

Pipe Expansion U-Bends or Loops

PIPE SIZE	ANCHOR TO ANCHOR EXPANSION							
	3"		4"		5"		6"	
	W	H	W	H	W	H	W	H
1/2	2'-0"	4'-0"	2'-4"	4'-8"	2'-8"	5'-4"	2'-10"	5'-8"
3/4	2'-4"	4'-8"	2'-8"	5'-4"	3'-0"	6'-0"	3'-3"	6'-6"
1	2'-6"	5'-0"	3'-0"	6'-0"	3'-4"	6'-8"	3'-6"	7'-0"
1-1/4	2'-10"	5'-8"	3'-3"	6'-6"	3'-8"	7'-4"	4'-0"	8'-0"
1-1/2	3'-0"	6'-0"	3'-6"	7'-0"	3'-10"	7'-8"	4'-3"	8'-6"
2	3'-4"	6'-8"	4'-0"	8'-0"	4'-4"	8'-8"	4'-9"	9'-6"
2-1/2	3'-8"	7'-4"	4'-3"	8'-6"	4'-10"	9'-10"	5'-2"	10'-4"
3	4'-1"	8'-2"	4'-8"	9'-4"	5'-4"	10'-8"	5'-9"	11'-8"
4	4'-7"	9'-2"	5'-4"	10'-8"	5'-10"	11'-8"	6'-6"	13'-0"
5	5'-2"	10'-4"	6'-0"	12'-0"	6'-8"	13'-4"	7'-3"	14'-6"
6	5'-7"	11'-2"	6'-6"	13'-0"	7'-2"	14'-4"	8'-0"	16'-0"
8	6'-4"	12'-8"	7'-4"	14'-8"	8'-4"	16'-8"	9'-0"	18'-0"
10	7'-1"	14'-2"	8'-2"	16'-4"	9'-2"	18'-4"	10'-0"	20'-0"
12	7'-9"	15'-6"	9'-0"	18'-0"	10'-0"	20'-0"	11'-0"	22'-0"
14	8'-1"	16'-2"	9'-4"	18'-8"	10'-6"	21'-0"	11'-6"	23'-0"
16	8'-8"	17'-4"	10'-0"	20'-0"	11'-2"	22'-4"	12'-3"	24'-6"
18	9'-2"	18'-4"	10'-8"	21'-4"	11'-10"	23'-8"	13'-0"	26'-0"
20	9'-8"	19'-4"	11'-2"	22'-4"	12'-6"	25'-0"	13'-8"	27'-4"
22	10'-2"	20'-4"	11'-8"	23'-4"	13'-2"	26'-4"	14'-4"	28'-8"
24	10'-8"	21'-4"	12'-3"	24'-6"	13'-8"	27'-4"	15'-0"	30'-0"
26	11'-0"	22'-0"	12'-9"	25'-6"	14'-4"	28'-8"	15'-7"	31'-2"
28	11'-6"	23'-0"	13'-2"	26'-4"	14'-10"	29'-8"	16'-2"	32'-4"
30	12'-0"	23'-8"	13'-8"	27'-4"	15'-4"	30'-8"	16'-9"	33'-6"
32	12'-3"	24'-6"	14'-2"	28'-4"	15'-10"	31'-8"	17'-3"	34'-6"
34	12'-8"	25'-4"	14'-6"	29'-0"	16'-4"	32'-8"	18'-0"	36'-0"
36	13'-0"	26'-0"	15'-0"	30'-0"	16'-10"	33'-8"	18'-4"	36'-8"
42	14'-0"	28'-0"	16'-2"	32'-4"	18'-2"	36'-4"	20'-0"	40'-0"
48	15'-0"	30'-0"	17'-4"	34'-8"	19'-4"	38'-8"	21'-2"	42'-4"
54	15'-11"	31'-10"	18'-4"	36'-8"	20'-6"	41'-0"	22'-5"	44'-10"
60	16'-9"	33'-6"	19'-4"	38'-8"	21'-7"	43'-2"	23'-8"	47'-4"
72	18'-4"	36'-8"	21'-2"	42'-4"	23'-8"	47'-4"	25'-11"	51'-10"
84	19'-10"	39'-8"	22'-10"	45'-8"	25'-7"	51'-2"	28'-0"	56'-0"
96	21'-2"	42'-4"	24'-5"	48'-10"	27'-4"	54'-8"	29'-11"	59'-10

Pipe Expansion U-Bends or Loops

PIPE SIZE	ANCHOR TO ANCHOR EXPANSION							
	7"		8"		10"		12"	
	W	H	W	H	W	H	W	H
1/2	3'-2"	6'-4"	3'-3"	6'-6"	3'-8"	7'-4"	4'-0"	8'-0"
3/4	3'-6"	7'-0"	3'-8"	7'-4"	4'-2"	8'-4"	4'-6"	9'-0"
1	3'-10"	7'-8"	4'-0"	8'-0"	4'-7"	9'-2"	5'-0"	10'-0"
1-1/4	4'-4"	8'-8"	4'-7"	9'-2"	5'-1"	10'-2"	5'-7"	11'-2"
1-1/2	4'-8"	9'-4"	5'-0"	10'-0"	5'-6"	11'-0"	6'-0"	12'-0"
2	5'-2"	10'-4"	5'-6"	11'-0"	6'-1"	12'-2"	6'-8"	13'-4"
2-1/2	5'-8"	11'-4"	6'-0"	12'-0"	6'-8"	13'-4"	7'-4"	14'-8"
3	6'-2"	12'-4"	6'-8"	13'-4"	7'-6"	15'-0"	8'-1"	16'-2"
4	7'-0"	14'-0"	7'-6"	15'-0"	8'-6"	17'-0"	9'-2"	18'-4"
5	7'-10"	15'-8"	8'-4"	16'-8"	9'-4"	18'-8"	10'-2"	20'-4"
6	8'-6"	17'-0"	9'-2"	18'-4"	10'-2"	20'-4"	11'-2"	22'-4"
8	9'-8"	19'-4"	10'-4"	20'-8"	11'-7"	23'-2"	12'-8"	25'-4"
10	10'-10"	21'-8"	11'-7"	23'-2"	13'-0"	26'-0"	14'-2"	28'-4"
12	11'-10"	23'-8"	12'-7"	25'-2"	14'-0"	28'-0"	15'-6"	31'-0"
14	12'-4"	24'-8"	13'-3"	26'-6"	14'-9"	29'-6"	16'-2"	32'-4"
16	13'-2"	26'-4"	14'-2"	28'-4"	15'-9"	31'-6"	17'-3"	34'-6"
18	14'-0"	28'-0"	15'-0"	30'-0"	16'-9"	33'-6"	18'-4"	36'-8"
20	14'-10"	29'-8"	15'-9"	31'-6"	17'-8"	35'-4"	19'-4"	38'-8"
22	15'-6"	31'-0"	16'-7"	33'-2"	18'-6"	37'-0"	20'-3"	40'-6"
24	16'-2"	32'-4"	17'-4"	34'-8"	19'-4"	38'-8"	21'-2"	42'-4"
26	16'-10"	33'-8"	18'-0"	36'-0"	20'-0"	40'-0"	22'-0"	44'-0"
28	17'-6"	35'-0"	18'-8"	37'-4"	21'-0"	42'-0"	23'-0"	46'-0"
30	18'-2"	36'-4"	19'-4"	38'-8"	21'-7"	43'-2"	23'-8"	47'-4"
32	18'-8"	37'-4"	20'-0"	40'-0"	22'-4"	44'-8"	24'-6"	49'-0"
34	19'-4"	38'-8"	20'-8"	41'-4"	23'-0"	46'-0"	25'-2"	50'-4"
36	19'-10"	39'-8"	21'-2"	42'-4"	23'-8"	47'-4"	26'-0"	52'-0"
42	21'-6"	43'-0"	23'-0"	46'-0"	25'-6"	51'-0"	28'-0"	56'-0"
48	22'-10"	45'-8"	24'-5"	48'-10"	27'-4"	54'-8"	30'-0"	60'-0"
54	24'-3"	48'-6"	25'-11"	51'-10"	29'-0"	58'-0"	31'-9"	63'-6"
60	25'-7"	51'-2"	27'-4"	54'-8"	30'-6"	61'-0"	33'-6"	67'-0"
72	23'-8"	47'-4"	29'-11"	59'-10"	33'-5"	66'-10"	36'-8"	73'-4"
84	30'-3"	60'-6"	32'-4"	64'-8"	36'-1"	72'-2"	39'-7"	69'-2"
96	32'-4"	64'-8"	34'-7"	69'-2"	38'-8"	77'-4"	42'-4"	84'-8"

32.03 Pipe Support

Horizontal Pipe Support Spacing

PIPE SIZE	MAXIMUM HORIZONTAL HANGER SPACING FEET						MINIMUM ROD SIZE INCHES
	STEEL			COPPER			
	RECOMMEND	WATER SYSTEMS	VAPOR SYSTEMS	RECOMMEND	WATER SYSTEMS	VAPOR SYSTEMS	
1/2	6	7	8	5	5	6	3/8
3/4	6	7	9	5	5	7	3/8
1	6	7	9	6	6	8	3/8
1-1/4	6	7	9	6	7	9	3/8
1-1/2	6	9	12	6	8	10	3/8
2	7	10	13	7	8	11	3/8
2-1/2	10	11	14	8	9	13	1/2
3	10	12	15	10	10	14	1/2
4	10	14	17	10	12	16	5/8
5	10	16	19	10	13	18	5/8
6	10	17	21	10	14	20	3/4
8	12	19	24	10	16	23	7/8
10	12	22	26	10	18	25	7/8
12	12	23	30	10	19	28	7/8
14	12	25	32	--	--	--	1
16	12	27	35	--	--	--	1
18	12	28	37	--	--	--	1-1/4
20	12	30	39	--	--	--	1-1/4
22	12	30	39	--	--	--	1-1/2
24	12	32	42	--	--	--	1-1/2
26	12	32	42	--	--	--	1-1/2
28	12	32	42	--	--	--	1-1/2
30	12	33	44	--	--	--	1-1/2
32	12	33	44	--	--	--	1-1/2
34	12	33	44	--	--	--	1-1/2
36	12	33	44	--	--	--	1-1/2
42	12	33	44	--	--	--	1-1/2
48	12	32	42	--	--	--	1-3/4
54	12	33	44	--	--	--	1-3/4
60	12	33	44	--	--	--	2
72	12	33	44	--	--	--	2
84	12	33	44	--	--	--	2-1/2
96	12	33	44	--	--	--	2-1/2

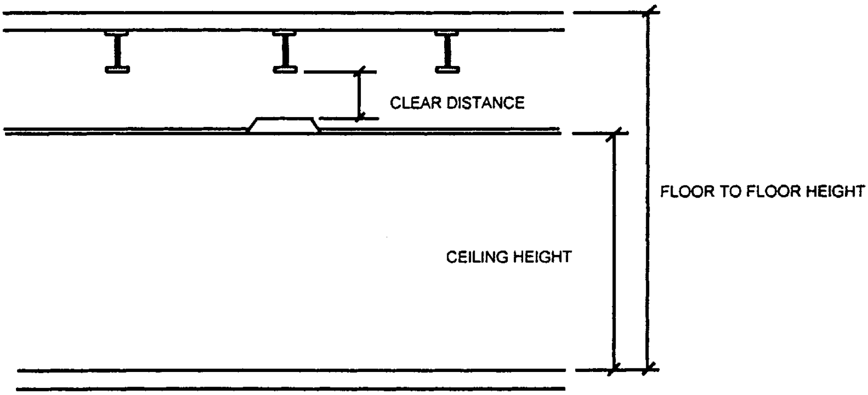
Vertical Pipe Support Spacing

PIPE SIZE	MAXIMUM VERTICAL SUPPORT SPACING FEET		SUPPORT
	STEEL	COPPER	
8" AND SMALLER	EVERY OTHER FLOOR AND BASE OF TALL PIPE RISERS	EVERY FLOOR AND BASE OF TALL PIPE RISERS	STEEL EXTENSION PIPE CLAMPS
10" - 12"	EVERY OTHER FLOOR AND BASE OF ALL PIPE RISERS	EVERY FLOOR AND BASE OF ALL PIPE RISERS	STEEL EXTENSION PIPE CLAMPS
14" - 24"	EVERY OTHER FLOOR AND BASE OF ALL PIPE RISERS	NOT APPLICABLE	STEEL EXTENSION PIPE CLAMPS
26" - 96"	EVERY FLOOR AND BASE OF ALL PIPE RISERS	NOT APPLICABLE	STEEL EXTENSION PIPE CLAMPS

PART 33

Appendix E: Space Requirements

33.01 Space Requirements



Ceiling Plenum Space

CLEAR DISTANCE - LIGHT TO BEAM IN INCHES											
FLOOR TO FLOOR	CLG. HEIGHT	BEAM DEPTH									
		12"	14"	16"	18"	21"	24"	27"	30"	33"	36"
9'-0"	7"-0"	*	*	*	*	*	*	*	*	*	*
	7'-6"	*	*	*	*	*	*	*	*	*	*
	8"-0"	*	*	*	*	*	*	*	*	*	*
	8'-6"	*	*	*	*	*	*	*	*	*	*
	9'-0"	*	*	*	*	*	*	*	*	*	*
10"-0"	7"-0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	*
	7'-6"	4.5	2.5	*	*	*	*	*	*	*	*
	8"-0"	*	*	*	*	*	*	*	*	*	*
	8'-6"	*	*	*	*	*	*	*	*	*	*
	9'-0"	*	*	*	*	*	*	*	*	*	*
11'-0"	8'-0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	*
	8'-6"	4.5	2.5	*	*	*	*	*	*	*	*
	9'-0"	*	*	*	*	*	*	*	*	*	*
	9'-6"	*	*	*	*	*	*	*	*	*	*
	10'-0"	*	*	*	*	*	*	*	*	*	*
	10'-6"	*	*	*	*	*	*	*	*	*	*
12'-0"	8'-0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5	*
	8'-6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*	*
	9'-0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	*
	9'-6"	4.5	2.5	0.5	*	*	*	*	*	*	*
	10'-0"	*	*	*	*	*	*	*	*	*	*
	10'-6"	*	*	*	*	*	*	*	*	*	*

Ceiling Plenum Space

CLEAR DISTANCE - LIGHT TO BEAM IN INCHES											
FLOOR TO FLOOR	CLG. HEIGHT	BEAM DEPTH									
		12"	14"	16"	18"	21"	24"	27"	30"	33"	36"
13'-0"	8'-0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5	10.5
	8'-6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5	4.5
	9'-0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5	*
	9'-6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*	*
	10'-0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	*
	10'-6"	4.5	2.5	0.5	*	*	*	*	*	*	*
14'-0"	8'-0"	46.5	44.5	42.5	40.5	37.5	34.5	31.5	28.5	25.5	22.5
	8'-6"	40.5	38.5	36.5	34.5	31.5	28.5	25.5	22.5	19.5	16.5
	9'-0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5	10.5
	9'-6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5	4.5
	10'-0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5	*
	10'-6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*	*
	11'-0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	*
	11'-6"	4.5	2.5	0.5	*	*	*	*	*	*	*
15'-0"	8'-0"	58.5	56.5	54.5	52.5	49.5	46.5	43.5	40.5	37.5	34.5
	8'-6"	52.5	50.5	48.5	46.5	43.5	40.5	37.5	34.5	31.5	28.5
	9'-0"	46.5	44.5	42.5	40.5	37.5	34.5	31.5	28.5	25.5	22.5
	9'-6"	40.5	38.5	36.5	34.5	31.5	28.5	25.5	22.5	19.5	16.5
	10'-0"	34.5	32.5	30.5	28.5	25.5	22.5	19.5	16.5	13.5	10.5
	10'-6"	28.5	26.5	24.5	22.5	19.5	16.5	13.5	10.5	7.5	4.5
	11'-0"	22.5	20.5	18.5	16.5	13.5	10.5	7.5	4.5	1.5	*
	11'-6"	16.5	14.5	12.5	10.5	7.5	4.5	1.5	*	*	*
	12'-0"	10.5	8.5	6.5	4.5	1.5	*	*	*	*	*
20'-0"	9'-0"	106	104	102	100	97.5	94.5	91.5	88.5	85.5	82.5
	9'-6"	100	98.5	96.5	94.5	91.5	88.5	85.5	82.5	79.5	76.5
	10'-0"	94.5	92.5	90.5	88.5	85.5	62.5	79.5	76.5	73.5	70.5
	10'-6"	88.5	86.5	84.5	82.5	79.5	76.5	73.5	70.5	67.5	64.5
	11'-0"	82.5	80.5	78.5	76.5	73.5	70.5	67.5	64.5	61.5	58.5
	11'-6"	76.5	74.5	72.5	70.5	67.5	64.5	61.5	58.5	55.5	52.5
	12'-0"	70.5	68.5	66.5	64.5	61.5	58.5	55.5	52.5	49.5	46.5

Notes for Ceiling Plenum Space Tables:

1. Assumptions: 2″ fire proofing on beam, 6″ fluorescent light depth, 5½″ floor slab thickness, 2″ suspended ceiling thickness.
2. For depth from beam to ceiling, add 4″ to above figures.
3. For depth from underside of slab to light, add depth of beam plus 2″.
4. * indicates beam protruding through ceiling.

Pipe Spacing on Racks

MINIMUM CENTERLINE-TO-CENTERLINE DIMENSIONS, INCHES											
PIPE SIZE	PIPE SIZE										
	1/2	3/4	1	1-1/4	1-1/2	2	2-1/2	3	4	5	6
1/2	7.5	---	---	---	---	---	---	---	---	---	---
3/4	8.0	8.0	---	---	---	---	---	---	---	---	---
1	8.0	8.5	8.5	---	---	---	---	---	---	---	---
1-1/4	8.5	8.5	8.5	9.0	---	---	---	---	---	---	---
1-1/2	8.5	8.5	9.0	9.0	9.0	---	---	---	---	---	---
2	9.0	9.0	9.5	9.5	9.5	10.0	---	---	---	---	---
2-1/2	10.0	10.0	10.5	10.5	10.5	11.0	12.0	---	---	---	---
3	10.0	10.5	10.5	11.0	11.0	11.5	12.5	12.5	---	---	---
4	11.5	11.5	12.0	12.0	12.0	12.5	13.5	14.0	15.0	---	---
5	12.0	12.0	12.5	12.5	12.5	13.0	14.0	14.5	15.5	16.0	---
6	12.5	12.5	13.0	13.0	13.0	13.5	14.5	14.5	16.0	16.5	17.0
8	13.5	14.0	14.0	14.5	14.5	15.0	16.0	16.0	17.5	18.0	18.5
10	15.0	15.0	15.5	15.5	15.5	16.0	17.0	17.5	18.5	19.0	19.5
12	16.5	16.5	17.0	17.5	17.0	17.5	18.5	19.0	20.0	20.5	21.0
14	17.5	17.5	18.0	18.0	18.0	18.5	19.5	20.0	21.0	21.5	22.0
16	18.5	19.0	19.0	19.0	19.5	20.0	21.0	21.0	22.5	23.0	23.5
18	19.5	19.5	20.0	20.0	20.0	20.5	21.5	22.0	23.0	23.5	24.0
20	20.5	21.0	21.0	21.0	21.5	22.0	23.0	23.0	24.5	25.0	25.5
22	22.0	22.0	22.0	22.0	22.5	23.0	24.0	24.0	25.5	26.0	26.5
24	23.0	23.5	23.5	23.5	23.5	24.0	25.0	25.5	26.5	27.0	27.5
26	24.0	24.5	24.5	24.5	25.0	25.0	26.0	26.5	28.0	28.0	29.0
28	25.0	25.5	25.5	25.5	26.0	26.5	27.5	27.5	29.0	29.5	30.0
30	26.5	27.0	27.0	27.0	27.0	27.5	28.5	29.0	30.0	30.5	31.0
32	28.0	28.0	28.0	28.0	28.5	29.0	29.5	30.0	31.5	32.0	32.5
34	29.0	29.0	29.0	29.0	29.5	30.0	31.0	31.0	32.5	33.0	33.5
36	30.0	30.5	30.5	30.5	30.5	31.0	32.0	32.5	33.5	34.0	34.5
42	33.5	34.0	34.0	34.0	34.0	34.5	35.5	36.0	37.0	37.5	38.0
48	36.5	37.0	37.0	37.5	37.5	38.0	39.0	39.0	40.5	41.0	41.5
54	40.0	40.0	40.5	40.5	41.0	41.5	42.5	42.5	44.0	44.5	45.0
60	43.5	43.5	44.0	44.0	44.0	44.5	45.5	46.0	47.0	47.5	48.0
72	50.0	50.5	50.5	51.0	51.0	51.5	52.5	52.5	54.0	54.5	55.0
84	57.0	57.0	57.5	57.5	57.5	58.0	59.0	59.5	60.5	61.0	61.5
96	63.5	64.0	64.0	64.5	64.5	65.0	66.0	66.0	67.5	68.0	68.5

Notes for Pipe Spacing on Racks Tables:

1. Table based on Schedule 40 pipe and includes the outside dimensions for flanges, fittings, etc.; insulation over flanges, fittings, etc.; and space between fittings as follows:
   a. Pipe sizes: 2″ and smaller: 1½″ Insulation.
      Pipe sizes: 2½″ and larger: 2″ Insulation.
   b. Space between two pipes 3″ and smaller: 1″.
   c. Space between one pipe 3″ and smaller and one pipe 4″ and larger: 1½″.
   d. Space between two pipes 4″ and larger: 2″.
2. For Schedule 80 and 160 pipe and 300 lb. fittings add the following:
   a. Pipe sizes 4″ and smaller: 1″.
   b. Pipe sizes 5″ to 12″: 1½″.
   c. Pipe sizes 14″ and larger: 2″.
3. Tables do not include space for valve handles and stems, expansion joints, expansion loops, and pipe guides.

Pipe Spacing on Racks

MINIMUM CENTERLINE-TO-CENTERLINE DIMENSIONS, INCHES											
PIPE SIZE	PIPE SIZE										
	8	10	12	14	16	18	20	22	24	26	28
1/2	---	---	--	--	--	--	--	---	---	---	---
3/4	---	---	--	--	--	--	--	---	---	---	---
1	---	---	--	--	--	--	--	---	---	---	---
1-1/4	---	---	--	--	--	--	--	---	---	---	---
1-1/2	---	---	--	--	--	--	--	---	---	---	---
2	---	---	--	--	--	--	--	---	---	---	---
2-1/2	---	---	--	--	--	--	--	---	---	---	---
3	---	---	--	--	--	--	--	---	---	---	---
4	---	---	--	--	--	--	--	---	---	---	---
5	---	---	--	--	--	--	--	---	---	---	---
6	---	---	--	--	--	--	--	---	---	---	---
8	19.5	---	--	--	--	--	--	---	---	---	---
10	21.0	22.0	--	--	--	--	--	---	---	---	---
12	22.5	23.5	25.0	--	--	--	--	---	---	---	---
14	23.5	24.5	26.0	27.0	---	---	---	---	---	---	---
16	24.5	26.0	27.5	28.5	30.0	---	---	---	---	---	---
18	25.5	26.5	28.0	29.0	30.5	31.0	---	---	---	---	---
20	26.5	28.0	29.5	30.5	31.5	32.5	33.5	---	---	---	---
22	27.5	29.0	30.5	31.5	32.5	33.5	34.5	35.5	---	---	---
24	29.0	30.0	31.5	32.5	34.0	34.5	36.0	37.0	38.0	---	---
26	30.0	31.0	33.0	34.0	35.0	36.0	37.0	38.0	39.5	40.5	---
28	31.0	32.5	34.0	35.0	36.0	37.0	38.0	39.0	40.5	41.5	42.5
30	32.5	33.5	35.0	36.0	37.5	38.0	39.5	40.5	41.5	42.5	44.0
32	34.0	35.0	36.5	37.4	39.0	39.5	41.0	42.0	43.0	44.0	45.5
34	35.0	36.0	37.5	38.5	40.0	40.5	42.0	43.0	44.0	45.0	46.5
36	36.0	37.0	38.5	39.5	41.0	41.5	43.0	44.0	45.0	46.5	47.5
42	39.5	40.5	42.0	41.0	44.5	45.0	46.5	47.5	48.5	50.0	51.0
48	42.5	44.0	45.5	46.5	47.5	48.5	49.5	51.0	52.0	53.0	54.0
54	46.0	47.5	49.0	50.0	51.0	52.0	53.0	54.0	55.5	56.5	57.5
60	49.5	50.5	52.0	53.0	54.5	55.0	56.5	57.5	58.5	60.0	61.0
72	56.0	57.5	59.0	60.0	61.0	62.0	63.0	64.5	65.5	66.5	67.5
84	63.0	64.0	65.5	66.5	68.0	68.5	70.0	71.0	72.0	73.5	74.5
96	69.5	71.0	72.5	73.5	74.5	75.5	76.5	78.0	79.0	80.0	81.0

Notes for Pipe Spacing on Racks Tables:

1. Table based on Schedule 40 pipe and includes the outside dimensions for flanges, fittings, etc.; insulation over flanges, fittings, etc.; and space between fittings as follows:
   a. Pipe sizes: 2″ and smaller: 1½″ Insulation.
      Pipe sizes: 2½″ and larger: 2″ Insulation.
   b. Space between two pipes 3″ and smaller: 1″.
   c. Space between one pipe 3″ and smaller and one pipe 4″ and larger: 1½″.
   d. Space between two pipes 4″ and larger: 2″.
2. For Schedule 80 and 160 pipe and 300 lb. fittings add the following:
   a. Pipe sizes 4″ and smaller: 1″.
   b. Pipe sizes 5″ to 12″: 1½″.
   c. Pipe sizes 14″ and larger: 2″.
3. Tables do not include space for valve handles and stems, expansion joints, expansion loops, and pipe guides.

Pipe Spacing on Racks

MINIMUM CENTERLINE-TO-CENTERLINE DIMENSIONS, INCHES											
PIPE SIZE	PIPE SIZE										
	30	32	34	36	42	48	54	60	72	84	96
1/2	---	---	---	---	---	---	---	---	---	---	---
3/4	---	---	---	---	---	---	---	---	---	---	---
1	---	---	---	---	---	---	---	---	---	---	---
1-1/4	---	---	---	---	---	---	---	---	---	---	---
1-1/2	---	---	---	---	---	---	---	---	---	---	---
2	---	---	---	---	---	---	---	---	---	---	---
2-1/2	---	---	---	---	---	---	---	---	---	---	---
3	---	---	---	---	---	---	---	---	---	---	---
4	---	---	---	---	---	---	---	---	---	---	---
5	---	---	---	---	---	---	---	---	---	---	---
6	---	---	---	---	---	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---	---	---	---
10	---	---	---	---	---	---	---	---	---	---	---
12	---	---	---	---	---	---	---	---	---	---	---
14	---	---	---	---	---	---	---	---	---	---	---
16	---	---	---	---	--	---	---	---	---	---	---
18	---	---	---	---	--	---	---	---	---	---	---
20	---	---	---	---	--	---	---	---	---	---	---
22	---	---	---	---	--	---	---	---	---	---	---
24	---	---	---	---	--	---	---	---	---	---	---
26	---	---	---	---	--	---	---	---	---	---	---
28	---	---	---	---	--	---	---	---	---	---	---
30	45.0	---	---	---	--	---	---	---	---	---	---
32	46.5	48.0	---	---	--	---	---	---	---	---	---
34	47.5	49.0	50.0	---	--	---	---	---	---	---	---
36	48.5	50.0	51.0	52.0	--	---	---	---	---	---	---
42	52.0	53.5	54.5	55.5	59.0	---	---	---	---	---	---
48	55.5	57.0	58.0	59.0	62.5	65.5	--	---	---	---	---
54	58.5	60.0	61.0	62.5	66.0	69.0	72.5	---	---	---	---
60	62.0	63.5	64.5	65.5	69.0	72.5	76.0	79.0	---	---	---
72	69.0	70.5	71.5	72.5	76.0	79.0	82.5	86.0	92.5	---	---
84	75.4	77.0	78.0	79.0	82.5	86.0	89.5	92.5	99.5	106.0	---
96	82.5	84.0	85.0	86.0	89.5	92.5	96.0	99.5	106.0	113.0	119.5

Notes for Pipe Spacing on Racks Tables:

1. Table based on Schedule 40 pipe and includes the outside dimensions for flanges, fittings, etc.; insulation over flanges, fittings, etc.; and space between fittings as follows:
   a. Pipe sizes: 2″ and smaller: 1½″ Insulation.
      Pipe sizes: 2½″ and larger: 2″ Insulation.
   b. Space between two pipes 3″ and smaller: 1″.
   c. Space between one pipe 3″ and smaller and one pipe 4″ and larger: 1½″.
   d. Space between two pipes 4″ and larger: 2″.
2. For Schedule 80 and 160 pipe and 300 lb. fittings add the following:
   a. Pipe sizes 4″ and smaller: 1″.
   b. Pipe sizes 5″ to 12″: 1½″.
   c. Pipe sizes 14″ and larger: 2″.
3. Tables do not include space for valve handles and stems, expansion joints, expansion loops, and pipe guides.

PART 34

Appendix F: Miscellaneous

34.01 Airborne Contaminants

A. Particle Classifications:

1. Fine <2.5 microns
2. Course ≥2.5 microns
3. Respirable <10.0 microns
4. Nonrespirable ≥10.0 microns

B. Relative Sizes:

1. Micron = 1 millionth of a meter (0.000001 meter) = 39 millionths of an inch (0.000039 inch)
2. Visible to the Naked Eye 25 microns
3. Human Hair 100 microns
4. Dust 25 microns
5. Optical Microscope 0.25 micron
6. Scanning Electron Microscope 0.002 micron
7. Macro Particle Range 25 microns and larger
8. Micro Particle Range 1.0 to 25 microns
9. Molecular Macro Range 0.085 to 1.0 micron
10. Molecular Range 0.002 to 0.085 micron
11. Ionic Range 0.002 microns and smaller

C. Airborne Particle Sizes are given in the following table:

PARTICLE	PARTICLE SIZE MICRONS	PARTICLE	PARTICLE SIZE MICRONS
PLANT			
POLLEN SPANISH MOSS POLLEN MOLD	10 - 100 150 - 750 3 - 12	TEA DUST GRAIN DUSTS SAW DUST	8 - 300 5 - 1000+ 30 - 600
SPORES STARCHES MILLED FLOUR	3 - 40 3 - 100 1 - 100	CORN STARCH PUDDING MIX CAYENNE PEPPER	0.09 - 0.75 3 - 160 15 - 1000
MILLED CORN MUSTARD GINGER	1 - 100 6 - 10 25 - 40	SNUFF TEXTILE FIBERS CORN COBB CHAFF	3 - 30 8 - 1000+ 30 - 100
COFFEE COFFEE ROAST SOOT	5 - 400 0.6 - 3.5	CARBON BLACK CHANNEL BLACK	0.2 - 10 0.2 - 100
ANIMAL			
BACTERIA VIRUSES DUST MITES	0.3 - 60 0.005 - 0.1 100 - 300	HUMAN HAIR HAIR RED BLOOD CELLS	60 - 600 5 - 200 5 - 10
SPIDER WEB DISINTEGRATED FECES FECES	2.5 0.8 - 1.5 10 - 45	LIQUID DROPLETS, SNEEZED BONE DUST	0.5 - 5 --- 3 - 350

PARTICLE	PARTICLE SIZE MICRONS	PARTICLE	PARTICLE SIZE MICRONS
COMBUSTION			
COMBUSTION TOBACCO SMOKE BURNING WOOD	0.01 - 0.1 0.01 - 4.5 0.2 - 3	SMOKE PARTICLES: NATURAL MATLS. SYNTHETIC MATLS.	--- 0.01 - 0.1 1 - 50
ROSIN SMOKE COAL FLUE GAS OIL SMOKE	0.01 - 1 0.08 - 0.2 0.03 - 1	SMOLDERING COOKING OIL FLAMING COOKING OIL AUTO EMISSIONS	0.3 - 0.9 0.3 - 0.9 1 - 150
FLY ASH	0.9 - 1000		
MINERAL			
ASBESTOS CEMENT DUST COAL DUST	0.7 - 90 3 - 100 1 - 100	CARBON DUST CARBON DUST-GRAPHITE FERTILIZER	0.25 - 5 0.02 - 2 10 - 1000
SEA SALT TEXTILES CLAY	0.035 - 0.5 6 - 20 0.1 - 50	GROUND LIMESTONE LEAD BROMINE	10 - 1000 0.1 - 0.7 0.1 - 0.7
CALCIUM, ZINC IRON LEAD DUST	0.7 - 20 4 - 20 2	GLASS WOOL FIBERGLASS INSULATION	1000 8 1 - 1000
TALC NH_4CL FUMES	0.5 - 50 0.1 - 3	METALLURGICAL DUST METALLURGICAL FUMES	0.1 - 1000 0.1 - 1000
OTHER			
ATMOSPHERIC DUST LUNG DAMAGING DUST MIST	0.001 - 40 0.6 - 7 70 - 350	YEAST CELLS SUGARS GELATIN	2 - 75 0.0008 - 0.005 5 - 90
OXYGEN CARBON DIOXIDE ATOMIC RADII	0.00050 0.00065 0.0001 - 0.001	BEACH SAND COPIER TONER FABRIC PROTECTOR	100 - 10,000 0.5 - 15 2.5 - 5
AIR FRESHENER HAIR SPRAY SPRAY PAINT	0.2 - 2 3 - 7 8 - 10	FACE POWDER LINT HUMIDIFIER	0.1 - 30 10 - 90 0.9 - 3
ANTIPERSPIRANT DUSTING AID PAINT PIGMENTS	6 - 10 6 - 15 0.1 - 5	ARTIFICIAL TEXTILE FIBERS INSECTICIDE DUSTS	--- 10 - 30 0.5 - 10

D. Airborne Particulate Cleanliness Classes: *FED-STD-209E-1992:*

1. A Clean Zone is a defined space in which the concentration of airborne particles is controlled to meet a specified airborne particulate cleanliness class.
2. A Cleanroom is a room in which the concentration of airborne particles is controlled and which contains one or more clean zones:
   a. As-built Cleanroom is a cleanroom complete and ready for operation, certifiable, with all services connected and functional, but without equipment or operating personnel in the facility.
   b. At-rest Cleanroom is a cleanroom that is complete, with all services functioning and with equipment installed and operable or operating, as specified, but without operating personnel in the facility.

c. Operational Cleanroom is a cleanroom in normal operation, with all services functioning and with equipment and personnel, if applicable, present and performing their normal work functions in the facility.

CLASS NAME		CLASS LIMITS									
		0.1 MICRON		0.2 MICRON		0.3 MICRON		0.5 MICRON		5 MICRON	
		VOLUME UNITS		VOLUME UNITS		VOLUME UNITS		VOLUME UNITS		VOLUME UNITS	
SI	ENGLISH	M^3	FT^3	M^3	FT^3	M^3	FT^3	M^3	FT^3	M^3	FT^3
M1		350	9.91	75.7	2.14	30.9	0.875	10.0	0.283	—	—
M1.5	1	1,240	35.0	265	7.50	106	3.00	35.3	1.00	—	—
M2		3,500	99.1	757	21.4	309	8.75	100	2.83	—	—
M2.5	10	12,400	350	2,650	75.0	1,060	30.0	353	10.0	—	—
M3		35,000	991	7,570	214	3,090	87.5	1,000	28.3	—	—
M3.5	100	—	—	26,500	750	10,600	300	3,530	100	—	—
M4		—	—	75,700	2,140	30,900	875	10,000	283	—	—
M4.5	1,000	—	—	—	—	—	—	35,300	1,000	247	7.00
M5		—	—	—	—	—	—	100,000	2,830	618	17.5
M5.5	10,000	—	—	—	—	—	—	353,000	10,000	2,470	70.0
M6		—	—	—	—	—	—	1,000,000	28,300	6,180	175
M6.5	100,000	—	—	—	—	—	—	3,530,000	100,000	24,700	700
M7		—	—	—	—	—	—	10,000,000	283,000	61,800	1,750

Cleanroom Design Criteria

CLEANROOM DESIGN CRITERIA	FEDERAL STANDARD 209E CLASSIFICATIONS ENGLISH / METRIC					
	1	10	100	1,000	10,000	100,000
	M1.5	M2.5	M3.5	M4.5	M5.5	M6.5
CIRCULATION RATE AC/HR (8)	360 - 540	360 - 540	210 - 540	120 - 300	30 - 120	12 - 60
ROOM AIR VELOCITY FT./MIN.	60 - 90	60 - 90	35 - 90 (1)	20 - 50	5 - 20	2 - 10
% FILTER COVERAGE	100	100	50 - 100 (1)	25 - 60	10 - 40	5 - 20
ROOM CHARACTERISTICS	LAMINAR	LAMINAR	LAMINAR / NON-LAMINAR	NON-LAMINAR	NON-LAMINAR	NON-LAMINAR
UNIDIRECTIONAL FLOW	YES	YES	YES / NO	NO	NO	NO
PARALLELISM DEGREES (2)	10 - 35	10 - 35	10 - 35 N/A	N/A	N/A	N/A

Notes:

1. Velocity and filter coverage could be reduced possibly as low as 35 fpm and 50% coverage if parallelism requirements are relaxed by the client.
2. Parallelism requirements are often driven by a client's standard facility criteria.
3. Makeup Air: 1–6 CFM/SQ.FT.
4. Pressurization Requirement: ¼–½ CFM/SQ.FT.
5. Temperature:
   a. Range: 68–74°F.
   b. Tolerance: ±0.1–±2.0°F.
   c. Change Rate: 0.75–2.0°F./Hour
   d. Example: 72°F., ±2.0°F.
6. Relative Humidity:
   a. Range: 30–50%RH
   b. Tolerance: ±1.0–±5.0%RH
   c. Change Rate: 1.0–5.0%RH/Hour
   d. Example: 45% RH, ±5.0%RH
7. Fire Protection/Smoke Purge Exhaust: 3–5 CFM/SQ.FT.
8. Air change rate is based on 10′-0″ ceiling height.

34.02 Miscellaneous

Wind Chill Index

°F DRY BULB	WIND VELOCITY (mph)										
	0 Calm	5	10	15	20	25	30	35	40	45	50
35	35	33	21	16	12	7	5	3	1	1	0
30	30	27	16	11	3	0	-2	-4	-5	-6	-7
25	25	21	9	1	-4	-7	-11	-13	-15	-17	-17
20	20	16	2	-6	-9	-15	-18	-20	-22	-24	-24
15	15	12	-2	-11	-17	-22	-26	-27	-29	-31	-31
10	10	7	-9	-18	-24	-29	-33	-35	-37	-38	-39
5	5	0	-15	-25	-32	-37	-41	-43	-45	-46	-47
0	0	-6	-22	-33	-40	-45	-49	-52	-53	-54	-56
-5	-5	-11	-27	-40	-46	-52	-56	-60	-62	-63	-63
-10	-10	-15	-31	-45	-52	-58	-63	-67	-69	-70	-70
-15	-15	-20	-38	-51	-60	-67	-70	-72	-76	-78	-79
-20	-20	-25	-45	-60	-68	-75	-78	-83	-87	-87	-88
-25	-25	-31	-52	-65	-76	-83	-87	-90	-94	-94	-96
-30	-30	-35	-58	-70	-81	-89	-94	-98	-101	-101	-103
-35	-35	-41	-64	-78	-88	-96	-101	-105	-107	-108	-110
-40	-40	-47	-70	-85	-96	-104	-109	-113	-116	-118	-120
-45	-45	-54	-77	-90	-103	-112	-117	-123	-128	-129	-130

Notes:

1. **Table provides equivalent wind chill temperatures at various outside dry bulb temperatures and corresponding wind velocities.**
2. **Wind speed greater than 40 mph have little additional chilling effect.**
3. **$WCF \cong T_{DB} - (1.5 \times W_S)$**
   WCF = Wind Chill Factor
   T_{DB} = Dry Bulb Air Temperature
   W_S = Wind Speed

Heat Index

APPARENT TEMPERATURE, ^{o}F.															
%RH	TEMPERATURE, ^{o}F.														
	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140
0	64	69	73	78	83	87	91	95	99	103	107	111	117	120	125
5	64	69	74	79	84	88	83	97	102	107	111	115	122	128	
10	65	70	75	80	85	90	95	100	105	111	116	123	131		
15	65	71	76	81	85	91	97	102	106	115	123	131			
20	66	72	77	82	87	93	99	105	112	120	130	141			
25	66	72	77	83	88	94	101	109	117	127	139				
30	67	73	78	84	90	96	104	113	123	135	148				
35	67	73	79	85	91	98	107	118	130	143					
40	68	74	79	86	93	101	110	123	137	151					
45	68	74	80	87	95	104	115	129	143						
50	69	75	81	88	96	107	120	135	150						
55	69	75	81	89	96	110	126	142							
60	70	76	82	90	100	114	132	149							
65	70	76	83	91	102	119	138								
70	70	77	85	93	106	124	144								
75	70	77	86	95	109	130									
80	71	77	86	97	113	136									
85	71	78	87	99	117										
90	71	79	88	102	122										
95	71	79	89	105											
100	72	80	91	106											

Notes:

1. Table provides equivalent heat index temperatures at various temperatures and corresponding relative humidities.
2. The heat index is a measure of how the average person perceives temperature and humidity and how it affects the body's ability to cool itself.
3. Sunstroke and heat exhaustion are likely when the heat index is 105 or greater.

Areas and Circumferences of Circles

DIAMETER IN INCHES	AREA		CIRCUMFERENCE	
	SQUARE INCHES	SQUARE FEET	INCHES	FEET
0.5	0.20	0.0014	1.57	0.1309
0.75	0.44	0.0031	2.36	0.1963
1	0.79	0.0055	3.14	0.2618
1.25	1.23	0.0085	3.93	0.3272
1.5	1.77	0.0123	4.17	0.3927
2	3.14	0.0218	6.28	0.5236
2.5	4.91	0.0341	7.85	0.6545
3	7.07	0.0491	9.42	0.7854
3.5	9.62	0.0668	11.00	0.9163
4	12.57	0.0873	12.57	1.0472
4.5	15.90	0.1104	14.14	1.1781
5.0	19.63	0.1364	15.71	1.3090
5.5	23.76	0.1650	17.28	1.4399
6	28.27	0.1963	18.85	1.5708
6.5	33.18	0.2304	20.42	1.7017
7	38.48	0.2673	21.99	1.8326
7.5	44.18	0.3068	23.56	1.9635
8	50.27	0.3491	25.13	2.0944
8.5	56.75	0.3941	26.70	2.2253
9	63.62	0.4418	28.27	2.3562
9.5	70.88	0.4922	29.85	2.4871
10	78.54	0.5454	31.42	2.6180
10.5	86.59	0.6013	32.99	2.7489
11	95.03	0.6600	34.56	2.8798
11.5	103.87	0.7213	36.13	3.0107
12	113.10	0.7854	37.70	3.1416
13	132.73	0.9218	40.84	3.4034
14	153.94	1.0690	43.98	3.6652
15	176.71	1.2272	47.12	3.9270
16	201.06	1.3963	50.27	4.1888
17	226.98	1.5763	53.41	4.4506
18	254.47	1.7671	56.55	4.7124
19	283.53	1.9689	59.69	4.9742
20	314.16	2.1817	62.83	5.2360
21	346.36	2.4053	65.97	5.4978
22	380.13	2.6398	69.12	5.7596
23	415.48	2.8852	72.26	6.0214
24	452.39	3.1416	75.40	6.2832
25	490.87	3.4088	78.54	6.5450
26	530.93	3.6870	81.68	6.8068
27	572.56	3.9761	84.82	7.0686
28	615.75	4.2761	87.96	7.3304

Areas and Circumferences of Circles

DIAMETER IN INCHES	AREA		CIRCUMFERENCE	
	SQUARE INCHES	SQUARE FEET	INCHES	FEET
29	660.52	4.5869	91.11	7.5922
30	706.86	4.9087	94.25	7.8540
31	754.77	5.2414	97.39	8.1158
32	804.25	5.5851	100.53	8.3776
33	855.30	5.9396	103.67	8.6394
34	907.92	6.3050	106.81	8.9012
35	962.11	6.6813	109.96	9.1630
36	1017.88	7.0686	113.10	9.4248
37	1075.21	7.4667	116.24	9.6866
38	1134.11	7.8758	119.38	9.9484
39	1194.59	8.2958	122.52	10.2102
40	1256.64	8.7266	125.66	10.4720
41	1320.25	9.1684	128.81	10.7338
42	1385.44	9.6211	131.95	10.9956
43	1452.20	10.0847	135.09	11.2574
44	1520.53	10.5592	138.23	11.5192
45	1590.43	11.0447	141.37	11.7810
46	1661.90	11.5410	144.51	12.0428
47	1734.94	12.0482	147.65	12.3046
48	1809.55	12.5663	150.80	12.5663
49	1885.74	13.0954	153.94	12.8282
50	1963.50	13.6354	157.08	13.0900
52	2123.72	14.7480	163.36	13.6136
54	2290.22	15.9043	169.65	14.1372
56	2463.01	17.1042	175.93	14.6608
58	2642.08	18.3478	182.21	15.1844
60	2827.43	19.6350	188.50	15.7080
62	3019.07	20.9658	194.78	16.2316
64	3216.99	22.3402	201.06	16.7552
66	3421.19	23.7583	207.35	17.2788
68	3631.68	25.2200	213.63	17.8024
70	3848.45	26.7254	219.91	18.3260
72	4071.50	28.2743	226.19	18.8496
74	4300.84	29.8669	232.48	19.3732
76	4536.46	31.5032	238.76	19.8968
78	4778.36	33.1831	245.04	20.4204
80	5026.55	34.9066	251.33	20.9440
82	5281.02	36.6737	257.61	21.4675
84	5541.77	38.4845	263.89	21.9911
86	5808.80	40.3389	270.18	22.5147
88	6082.12	42.2370	276.46	23.0383
90	6361.73	44.1786	282.74	23.5619

Fraction-Decimal Equivalents

64THS	32NDS	16THS	8THS	4THS	HALF	WHOLE	DECIMAL
1/64	-	-	-	-	-	-	0.0156
2/64	1/32	-	-	-	-	-	0.0313
3/64	-	-	-	-	-	-	0.0469
4/64	2/32	1/16	-	-	-	-	0.0625
5/64	-	-	-	-	-	-	0.0781
6/64	3/32	-	-	-	-	-	0.0938
7/64	-	-	-	-	-	-	0.1094
8/64	4/32	2/16	1/8	-	-	-	0.1250
9/64	-	-	-	-	-	-	0.1406
10/64	5/32	-	-	-	-	-	0.1563
11/64	-	-	-	-	-	-	0.1719
12/64	6/32	3/16	-	-	-	-	0.1875
13/64	-	-	-	-	-	-	0.2031
14/64	7/32	-	-	-	-	-	0.2188
15/64	-	-	-	-	-	-	0.2344
16/64	8/32	4/16	2/8	1/4	-	-	0.2500
17/64	-	-	-	-	-	-	0.2656
18/64	9/32	-	-	-	-	-	0.2813
19/64	-	-	-	-	-	-	0.2969
20/64	10/32	5/16	-	-	-	-	0.3125
21/64	-	-	-	-	-	-	0.3281
22/64	11/32	-	-	-	-	-	0.3438
23/64	-	-	-	-	-	-	0.3594
24/64	12/32	6/16	3/8	-	-	-	0.3750
25/64	-	-	-	-	-	-	0.3906
26/64	13/32	-	-	-	-	-	0.4063
27/64	-	-	-	-	-	-	0.4219
28/64	14/32	7/16	-	-	-	-	0.4375
29/64	-	-	-	-	-	-	0.4531
30/64	15/32	-	-	-	-	-	0.4688
31/64	-	-	-	-	-	-	0.4844
32/64	16/32	8/16	4/8	2/4	1/2	-	0.5000

Fraction-Decimal Equivalents

64THS	32NDS	16THS	8THS	4THS	HALF	WHOLE	DECIMAL
33/64	-	-	-	-	-	-	0.5156
34/64	17/32	-	-	-	-	-	0.5312
35/64	-	-	-	-	-	-	0.5469
36/64	18/32	9/16	-	-	-	-	0.5625
37/64	-	-	-	-	-	-	0.5781
38/64	19/32	-	-	-	-	-	0.5938
39/64	-	-	-	-	-	-	0.6094
40/64	20/32	10/16	5/8	-	-	-	0.6250
41/64	-	-	-	-	-	-	0.6406
42/64	21/32	-	-	-	-	-	0.6563
43/64	-	-	-	-	-	-	0.6719
44/64	22/32	11/16	-	-	-	-	0.6875
45/64	-	-	-	-	-	-	0.7031
46/64	23/32	-	-	-	-	-	0.7188
47/64	-	-	-	-	-	-	0.7343
48/64	24/32	12/16	6/8	3/4	-	-	0.7500
49/64	-	-	-	-	-	-	0.7656
50/64	25/32	-	-	-	-	-	0.7813
51/64	-	-	-	-	-	-	0.7969
52/64	26/32	13/16	-	-	-	-	0.8125
53/64	-	-	-	-	-	-	0.8281
54/64	27/32	-	-	-	-	-	0.8438
55/64	-	-	-	-	-	-	0.8594
56/64	28/32	14/16	7/8	-	-	-	0.8750
57/64	-	-	-	-	-	-	0.8906
58/64	29/32	-	-	-	-	-	0.9063
59/64	-	-	-	-	-	-	0.9219
60/64	30/32	15/16	-	-	-	-	0.9375
61/64	-	-	-	-	-	-	0.9531
62/64	31/32	-	-	-	-	-	0.9688
63/64	-	-	-	-	-	-	0.9844
64/64	32/32	16/16	8/8	4/4	2/2	1	1.0000

Physical Properties of Fuels and Oils

SUBSTANCE	FORMULA	MOLECULAR WEIGHT	PHASE	SPECIFIC VOLUME Cu.Ft./Lbm	DENSITY Lbm/Cu.Ft.	SPECIFIC GRAVITY
FUELS						
GASOLINE	—	113.0	LIQ.	0.0223	44.9	0.72
KEROSINE	—	154.0	LIQ.	0.0200	49.9	0.80
DIESEL FUEL (1-D)	—	170.0	LIQ.	0.0183	54.6	0.875
DIESEL FUEL (2-D)	—	184.0	LIQ.	0.0174	57.4	0.920
DIESEL FUEL (4-D)	—	198.0	LIQ.	0.0167	59.9	0.960
FUEL OIL No.1	—	—	LIQ.	0.0183	54.6	0.875
FUEL OIL No.2	—	—	LIQ.	0.0174	57.4	0.920
FUEL OIL No.4	—	198.0	LIQ.	0.0167	59.8	0.959
FUEL OIL No.5 Lt	—	—	LIQ.	0.0167	59.9	0.960
FUEL OIL No.5 Hv	—	—	LIQ.	0.0167	59.9	0.960
FUEL OIL No.6	—	—	LIQ.	0.0167	59.9	0.960
PARAFIN OR ALKANE SERIES						
METHANE (NAT.GAS)	CH_4	16.041	GAS	24.0963	0.0415	0.553
ETHANE	C_2H_6	30.067	GAS	12.9032	0.0775	1.033
PROPANE	C_3H_8	44.092	GAS	8.7719	0.114	1.520
n-BUTANE	C_4H_{10}	58.118	GAS	0.0276	36.14	481.9
ISOBUTANE	C_4H_{10}	58.118	GAS	0.0288	34.77	463.6
n-PENTANE	C_5H_{12}	72.144	LIQ.	0.0256	39.08	0.626
ISOPENTANE	C_5H_{12}	72.144	LIQ.	0.0258	38.77	0.621
NEOPENTANE	C_5H_{12}	72.144	GAS	0.0261	38.27	510.3
n-HEXANE	C_6H_{14}	86.178	LIQ	0.0243	41.14	0.659
NEOHEXANE	C_6H_{14}	86.178	LIQ.	0.0247	40.51	0.649
n-HEPTANE	C_7H_{16}	100.206	LIQ.	0.0239	41.70	0.668
TRIPTANE	C_7H_{16}	100.206	LIQ.	0.0232	43.07	0.690
n-OCTANE	C_8H_{18}	114.223	LIQ.	0.0227	44.14	0.707
ISO-OCTANE	C_8H_{18}	114.223	LIQ.	0.0228	43.82	0.702

Physical Properties of Fuels and Oils

SUBSTANCE	FORMULA	MOLECULA R WEIGHT	PHASE	SPECIFIC VOLUME Cu.Ft./Lbm	DENSITY Lbm/Cu.Ft.	SPECIFIC GRAVITY
OLEFIN OR ALKENE SERIES						
ETHYLENE	C_2H_4	28.054	GAS	13.6426	0.0733	0.977
PROPYLENE	C_3H_6	42.081	GAS	7.5187	0.113	1.507
BUTYLENE	C_4H_8	56.108	GAS	0.0269	37.12	494.9
ISOBUTENE	C_4H_8	56.108	GAS	0.0272	36.83	491.1
n-PENTENE	C_5H_{10}	70.135	LIQ.	0.0250	40.02	0.641
AROMATIC SERIES						
BENZENE	C_6H_6	78.114	LIQ.	0.0172	58.18	0.932
TOLULENE	C_7H_8	92.141	LIQ.	0.0181	55.31	0.886
XYLENE	C_8H_{10}	106.169	LIQ.	0.0186	53.75	0.861
OTHER HYDROCARBONS						
ACETYLENE	C_2H_2	26.038	GAS	14.8148	0.0675	0.900
NAPHTHALENE	$C_{10}H_8$	128.175	SOLID	—	71.48	—
METHYL ALCOHOL	CH_3OH	32.041	LIQ.	0.0204	49.10	0.789
EHTYL ALCOHOL	C_2H_5OH	46.067	LIQ.	0.0204	49.01	0.787
MOTOR OILS						
5W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
10W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
20W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
30W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
40W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
50W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
GEAR OILS						
75W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
80W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
85W	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
90	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
120	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
140	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94
150	—	—	LIQ.	0.0176	54.9-58.7	0.88-0.94

Physical Properties of Fuels and Oils

SUBSTANCE	BOILING PT. F.	IGNITION TEMP. F.	FLASH POINT	FLAMMABILITY LIMITS (IN AIR) % BY VOLUME
FUELS				
GASOLINE	100 - 400	536	-45	1.4 - 7.6
KEROSINE	304 - 574	410	100 - 162	0.7 - 5.0
DIESEL FUEL (1-D)	—	—	100	—
DIESEL FUEL (2-D)	—	—	125	—
DIESEL FUEL (4-D)	—	—	130	—
FUEL OILS No.1	304 - 574	410	100 - 162	0.7 - 5.0
FUEL OILS No.2	—	494	126 - 204	—
FUEL OILS No.4	—	505	142 - 240	—
FUEL OILS No.5 Lt	—	—	156 - 336	—
FUEL OILS No.5 Hv	—	—	160 - 250	—
FUEL OILS No.6	—	—	150	—
PARAFIN OR ALKANE SERIES				
METHANE (NAT.GAS)	-258.7	900 - 1170	GAS	5.0 - 15.0
ETHANE	-127.5	959	GAS	3.0 - 12.5
PROPANE	-43.8	842	GAS	2.1 - 10.1
n-BUTANE	31.1	761	-76	1.86 - 8.41
ISOBUTANE	10.9	864	-117	1.80 - 8.44
n-PENTANE	97.0	500	<-40	1.40 - 7.80
ISOPENTANE	82.2	788	<-60	1.32 - 9.16
NEOPENTANE	49.1	842	GAS	1.38 - 7.22
n-HEXANE	155.7	437	-7	1.25 - 7.0
NEOHEXANE	121.5	797	-54	1.19 - 7.58
n-HEPTANE	209.1	419	25	1.00 - 6.00
TRIPTANE	177.6	849	—	1.08 - 6.69
n-OCTANE	258.3	428	56	0.95 - 3.20
ISO-OCTANE	243.9	837	10	0.79 - 5.94

Physical Properties of Fuels and Oils

SUBSTANCE	BOILING PT. F.	IGNITION TEMP. F.	FLASH POINT	FLAMMABILITY LIMITS (IN AIR) % BY VOLUME
OLEFIN OR ALKENE SERIES				
ETHYLENE	-154.7	914	GAS	2.75 - 28.6
PROPYLENE	-53.9	856	GAS	2.00 - 11.1
BUTYLENE	21.2	829	GAS	1.98 - 9.65
n-BUTENE	—	—	—	—
ISOBUTENE	19.6	869	GAS	1.8 - 9.0
n-PENTENE	86.0	569	—	1.65 - 7.70
AROMATIC SERIES				
BENZENE	176.2	1040	12	1.35 - 6.65
TOLULENE	321.1	992	40	1.27 - 6.75
XYLENE	281.1	867	63	1.00 - 6.00
OTHER HYDROCARBONS				
ACETYLENE	-119.2	581	GAS	2.50 - 100
NAPHTHALENE	424.4	959	174	0.90 - 5.90
METHYL ALCOHOL	151	725	—	6.7 - 36.0
EHTYL ALCOHOL	172	689	—	3.3 - 19.0
MOTOR OILS				
5W	—	—	420	—
10W	—	—	425	—
20W	—	—	465	—
30W	—	—	450	—
40W	--	—	475	—
50W	—	—	485	—
GEAR OILS				
75W	—	—	375	—
80W	—	—	425	—
85W	—	—	435	—
90	—	—	425	—
120	—	—	425	—
140	—	—	580	—
150	—	—	580	—

Velocity of Sound in Various Media

MEDIUM	VELOCITY	
	FEET PER SECOND	MILES PER HOUR
RUBBER	310	211
AIR	1,130	770
WATER VAPOR	1,328	905
CORK	1,640	1,118
LEAD	4,026	2,745
WATER	4,625	3,153
WOOD	10,825	7,380
BRASS	11,480	7,827
COPPER	11,670	7,957
BRICK	11,800	8,045
CONCRETE	12,100	8,250
WOOD	12,500	8,523
STEEL & IRON	16,000	10,909
GLASS	16,400	11,181
ALUMINUM	19,000	12,955

Voice Level Comparison at Various Distances

DISTANCE FEET	NORMAL VOICE LEVEL dB	RAISED VOICE LEVEL dB	VERY LOUD VOICE dB	SHOUTING VOICE dB
1	70	76	82	88
3	60	66	72	78
6	54	60	66	72
12	48	54	60	66
24	42	48	54	60

Directional Effect on Sound

DIRECTION OF SOUND SOURCE WITH RESPECT TO LISTENER	DECREASE IN SPEACH ENERGY
FACE TO FACE	0 dB
30 DEGREE ROTATION AWAY	1.5
60 DEGREE ROTATION AWAY	3.0
90 DEGREE ROTATION AWAY	4.5
120 DEGREE ROTATION AWAY	6.0
150 DEGREE ROTATION AWAY	7.5
180 DEGREE ROTATION AWAY SOURCE TURNED AWAY FROM LISTENER	9.0

Typical Sound Levels

PRESSURE LEVEL dB	TYPICAL SOUND	SUBJECTIVE IMPRESSION
150	Jet Plane Take-off Military Jet Takeoff at 100 Ft.	Short exposure can cause hearing loss.
140		
130	Artillery Fire at 10 Ft. Machine Gun	Deafening (Threshold of Pain)
120	Siren at 100 Feet Jet Plane (Passenger Ramp) Thunder Sonic Boom	
110	Wood Working Shop Accelerating Motorcycle Hard Rock Band 75 Piece Orchestra	Threshold of Discomfort
100	Subway (Steel Wheels) Propeller Plane, Outboard Motor Loud Street Noise Power Lawn Mower	Very Loud
90	Truck Unmuffled Train Whistle Kitchen Blender Pneumatic Jackhammer Shouting at 5 Feet	
80	Printing Press Subway (Rubber Wheels) Noisy Office Computer Printout Room Average Factory	Loud Intolerable for Phone Use
70	Average Street Noise Quiet Typewriter Freight Train at 100 Feet Average Radio Speech at 3 Feet	Loud
60	Noisy Home Average Office Normal Conversation at 3 Ft.	Loud Unusual Background
50	General Office Quiet Office Quiet Radio, Window AC Unit Average Home Quiet Street	Moderate
40	Private Office Quiet Home/Residential Area	Moderate
30	Quiet Conversation Broadcast Studio	Noticeably Quiet
20	Empty Auditorium Whisper Watch Ticking Buzzing Inset at 3 Ft. Rural Ambient	Very Quiet
10	Rustling Leaves Soundproof Room Human Breathing	Very Faint Threshod of Good Hearing
0		Intolerbly Quiet Threshold of Audibility (Youthful Hearing)

Typical Noise Levels

EQUIPMENT	dBA
Saturn Rocket	200
Turbo Jet Engine	170
Jet Plane/Aircraft at Take-off, Inside Jet Engine Test Cell	150
Turbo Popeller Plane at Takeoff, Military Jet Takeoff at 100 Ft.	140
Large Pipe Organ, Artillery Fire at 10 Ft., Machine Gun	130
Jolt Squeeze Hammer	122
Small Aircraft Engine, Siren at 100 Feet, Jet Plane (Passenger Ramp), Thunder, Sonic Boom, Threshold of Feeling (Pain)	120
Blaring Radio, Wood Working Shop, Accelerating Motorcycle, Hard Rock Band, 75 Piece Orchestra, Chain Saw	110
Vacuum Pump, Large Air Compressor	108
Positive Displacement Blower, Air Hammer	107
Magnetic Drill Press, Air Chisel, High Pressure Gas Leak	106
Banging of Steel Plate, Wood Planer	104
Air Compressor, Automobile at Highway Speed, Subway (Steel Wheels), Propeller Plane, Outboard Motor, Loud Street Noise, Power Lawn Mower, Helicopter	100
Turbine Condenser, Welder, Punch Press, Riveter, Power Saws, Plastic Chipper	98
Small Air Compressor, Airplane Cabin Normal Flight	94
Heavy Duty Grinder	93
Heavy Diesel Powered Vehicle, Spinning Machines - Looms, Noisy Street	92
Voice, Shouting, Truck Unmuffled, Train Whistle, Kitchen Blender, Pneumatic Jackhammer, Shouting at 5 Feet, Noisy Factory, Blender	90
Printing Press, Inside Average Rail Road Car, Toilet Flushing	86
Garbage Disposal, Printing Press, Subway (Rubber Wheels), Noisy Office, Computer Printout Room, Average Factory, Lathe, Police Whistle, Telephone Ring, Clothes Washer, Dish Washer, TV - Loud	80
Voice - Conversational Level, Average Street Noise, Quiet Typewriter, Freight Train at 100 Feet, Average Radio, Speech at 3 Feet, Inside Average Automobile, Clothes Dryer, Vacuum Cleaner, TV - Soft	70
Electronic Equipment Ventilation Fan, Noisy Home, Average Office, Normal Conversation at 3 Ft., Hair Dryer	60
Office Air Diffuser, General Office, Quiet Office, Quiet Radio, Window AC Unit, Average Home, Quiet Street	50
Small Electric Clock, Private Office, Quiet Home/Residential Area, Refrigerator, Bird Singing, Wilderness Ambient, Agricultural Land	40
Voice, Soft Whisper, Quiet Conversation, Broadcast Studio	30
Rustling Leaves, Empty Auditorium, Whisper, Watch Ticking, Buzzing Inset at 3 Ft., Rural Ambient	20
Human Breath, Sound Proof Room, Rustling Leaves	10
Threshold of Hearing	0

Subjective Effect of Changes in Sound Characteristics

CHANGE IN SOUND PRESSURE LEVEL	CHANGE IN APPARENT LOUDNESS
1 dB	Insignificant
3 dB	Just Perceptible
5 dB	Clearly Noticeable
10 dB	Twice or Half as Loud
15 dB	Significant Change
20 dB	Much Louder or Quieter

Decibel Addition

DIFFERENCE BETWEEN TWO LEVELS dB	ADD TO HIGHER LEVEL dB
0	3
1	2.5
2	2
3	2
4	1.5
5	1
6	1
7	1
8	0.5
9	0.5
10	0.5
More than 10	0

Acceptable HVAC Noise Levels

SPACE TYPE	RECOMMENDED NC LEVEL	RECOMMENDED RC LEVEL	EQUIVALENT SOUND LEVEL METER READINGS (A SCALE) dB
Apartments	NC 25-35	RC 25-35	35-45
Assembly Halls	NC 25-30	RC 25-30	35-40
Churches	NC 30-35	RC 30-35	40-45
Concert and Recital Halls	NC 15-20	RC 15-20	25-30
Courtrooms	NC 30-40	RC 30-40	40-50
Factories	NC 40-65	RC 40-65	50-75
Hospitals and Clinics			
Private Rooms	NC 25-30	RC 25-30	35-40
Wards	NC 30-35	RC 30-35	40-45
Operating Rooms	NC 25-30	RC 25-30	35-40
Laboratories	NC 35-40	RC 35-40	45-50
Corridors	NC 30-35	RC 30-35	40-45
Public Areas	NC 35-40	RC 35-40	45-50
Hotels/Motels			
Individual Rooms/Suites	NC 25-35	RC 25-35	35-45
Meeting/Banquet Rooms	NC 25-35	RC 25-35	35-45
Halls,Corridors,Lobbies	NC 35-40	RC 35-40	45-50
Service/Support Areas	NC 40-45	RC 40-45	50-55
Ligitimate Theaters	NC 20-25	RC 20-25	30-35
Libraries	NC 30-40	RC 30-40	40-50
Music Rooms	NC 20-25	RC 20-25	30-35
Movie/Motion Picture Theaters	NC 30-35	RC 30-35	40-45
Offices			
Executive	NC 25-30	RC 25-30	35-40
Conference Rooms	NC 25-30	RC 25-30	35-40
Private	NC 30-35	RC 30-35	40-45
Open-Plan Offices/Areas	NC 35-40	RC 35-40	45-50
Business Mach/Computers	NC 40-45	RC 40-45	50-55
Public Circulation	NC 40-45	RC 40-45	50-55
Private Residences	NC 25-35	RC 25-35	35-45
Recording Studios	NC 15-20	RC 15-20	25-30
Restaurants	NC 40-45	RC 40-45	50-55
Retail Stores	NC 40-45	RC 40-45	50-55
Schools			
Lecture and Classrooms	NC 25-30	RC 25-30	35-40
Open-Plan Classrooms	NC 35-40	RC 35-40	45-50
Sports Coliseums	NC 45-55	RC 45-55	55-65
TV/Broadcast Studios	NC 15-25	RC 15-25	25-35

U.S. Postal Service Abbreviations

UNITED STATES POSTAL SERVICE STANDARD ABBREVIATIONS			
STATE	ABBREV.	STATE	ABBREV.
ALABAMA	AL	MONTANA	MT
ALASKA	AK	NEBRASKA	NE
ARIZONA	AZ	NEVADA	NV
ARKANSAS	AR	NEW HAMPSHIRE	NH
CALIFORNIA	CA	NEW JERSEY	NJ
COLORADO	CO	NEW MEXICO	NM
CONNECTICUT	CT	NEW YORK	NY
DELAWARE	DE	NORTH CAROLINA	NC
DISTRICT OF COLUMBIA	DC	NORTH DAKOTA	ND
FLORIDA	FL	OHIO	OH
GEORGIA	GA	OKLAHOMA	OK
HAWAII	HI	OREGON	OR
IDAHO	ID	PENNSYLVANIA	PA
ILLINOIS	IL	PUERTO RICO	PR
INDIANA	IN	RHODE ISLAND	RI
IOWA	IA	SOUTH CAROLINA	SC
KANSAS	KS	SOUTH DAKOTA	SD
KENTUCKY	KY	TENNESSEE	TN
LOUISIANA	LA	TEXAS	TX
MAINE	ME	UTAH	UT
MARYLAND	MD	VERMONT	VT
MASSACHUSETTS	MA	VIRGINIA	VA
MICHIGAN	MI	WASHINGTON	WA
MINNESOTA	MN	WEST VIRGINIA	WV
MISSISSIPPI	MS	WISCONSIN	WI
MISSOURI	MO	WYOMING	WY

PART 35

Appendix G: Designer's Checklist

35.01 Boilers, Chillers, Cooling Towers, Heat Exchangers, and Other Central Plant Equipment

A. Have Owner redundancy requirements been met? Has future equipment space been clearly indicated on the drawings? Has move-in route and replacement access been determined?

B. Have multiple pieces of central plant equipment been provided to prevent system shutdown in the event of equipment failure? Has low load been evaluated and is equipment selected capable of operating at this low load condition?

C. Has proper service access been provided? Has tube pull or clean space been provided?

D. Have final loads been calculated and final equipment selection been made? Has equipment been specified and capacity scheduled?

E. Has chemical treatment of hydronic and steam systems been properly addressed? Have flushing and passivation of hydronic and steam systems been adequately covered, in particular waste treatment handling of spent flushing water and chemicals?

F. Does central plant equipment need to be on emergency power?

G. When multiple pieces of equipment are headered together, have adequate provisions for expansion and contraction been provided, especially boiler systems? Recommendation: Multiple boiler connections to header, from boiler nozzles to header main, should be U-shaped (first traveling away from header, then traveling parallel to header, and finally traveling back toward header) to accommodate expansion and contraction of piping to prevent excess stress on the boiler nozzles.

H. When specifying boiler control and oxygen trim systems, chillers with remote starters and remote control panels, cooling tower basin heaters, and other electrical or control systems associated with central plant equipment, has field wiring required for these systems been coordinated with the electrical and I&C engineers? This includes panel installation, interconnecting power and control wiring, instrument air, and mounting of devices.

I. Have starter, disconnect switch, adjustable frequency drive, and/or motor control center space been coordinated and/or located?

J. When specifying dual fuel boilers, does the Owner want a dual fuel pilot (natural gas and fuel oil) or is a tee connection preferred for connection to portable propane bottle?

35.02 Air Handling Equipment—Makeup, Recirculation, and General Air Handling Equipment

A. Have Owner redundancy requirements been met? Has future equipment space been clearly indicated on the drawings? Has move-in route and replacement access been determined?

B. Have multiple pieces of air handling equipment been provided to prevent system shutdown in the event of equipment failure?

C. Has adequate coil pull space and service space been provided? Recommendation: The service access space should be a minimum of the unit width plus 2 feet on at least one side and a minimum of 2 feet on the other side.

D. Have unit components and capacities been properly specified, detailed, and scheduled–coils, filters, fans, motors, humidifiers, outside air and return air dampers, smoke detectors, smoke dampers, access section, service vestibules, access doors, interior lighting (incandescent, fluorescent), etc? Have coil and filter air pressure drops been scheduled? Have coil water pressure drops been scheduled?

E. Have outside air and return air been mixed prior to entering any air handling unit filters or coils?

F. Has proper length downstream of humidifiers been provided to absorb humidification vapor trail? The first air handling unit section downstream of the humidifier should be stainless steel, including coil frames, especially with DI, RO, or UPW water.

G. Have cooling coils been locked out during the air handling unit preheat and humidification operation?

H. Has piping in service vestibules been checked for adequate space? Recommendation: A minimum of 6′-0″ wide and minimum of 9′-0″ high clearance should be maintained to allow for pipe installation for full length of unit.

I. Are access doors of adequate size to remove fans, motors, filters, dampers, actuators, inlet guide vanes or other variable flow device, and other devices requiring service and/or replacement?

J. Do all air handling unit preheat coils with a design mixed air temperature below 40°F. have preheat pumps? To reduce the risk of freezing, preheat pumps are recommended for all preheat coils with a design mixed air temperature below 40°F.

K. Have coil selections been made so that low water flows, in direct response to low loads, do not fall into laminar flow region?

L. Have air conditioning condensate drains been piped to appropriate drainage system? Have drains been provided for storm water and sanitary?

M. Have receptacles been provided for roof mounted equipment in accordance with the NEC?

N. Have starter, disconnect switch, adjustable frequency drive, and/or motor control center space been coordinated and/or located?

O. Does air handling equipment need to be on emergency power?

35.03 Piping Systems—General

A. Expansion Tank: Has size, location, adequate space, support, makeup water pressure and makeup water location with been coordinated with Plumbing Engineer?

B. Are there provisions for piping expansion and contraction, anchors, guides, loops vs. joints? Have anchor locations and forces been coordinated with Structural Engi-

neer? Locate anchors at steel beams and avoid joists if possible. Is piping coordinated with building expansion joints?

C. Do the drawings clearly indicate where ASME code piping and valves are required at the boilers in accordance with ASME Code requirements for high temperature (over 250°F.) and high pressure boilers (over 15 psig)?

D. Does the boiler layout and design have enough expansion and flexibility in the boiler connection piping to prevent overstressing the boiler nozzle? It is best to use U-shaped layout to header.

E. Have flexible connections been clearly shown on the drawings and have they been properly detailed? Have the appropriate flexible connections been specified for the application?

F. Is there structural support for large water risers?

G. Are there drains and air vents on water systems and adequate space for service?

H. Are balancing valves required on parallel piping loops?

I. Is adequate space available for pitching of pipes?

J. Is there space for coil and tube removal or cleaning (i.e., AHUs, Chillers, Boilers, etc.) and is it clearly shown on the drawings where it is required?

K. Is coil piped for counterflow or parallel flow as indicated by detail (parallel flow for preheat coils only; all others counter flow)?

L. Condensate drains from room terminals with chilled, dual temperature water and packaged cooling units: Do local authorities require condensate drains to be piped to sanitary or to storm? Can condensate drains be discharged onto roof? onto grade?

M. Are relief valve settings noted on drawings or schedules?

N. Is there adequate straight pipe up- and downstream of flow meter orifices?

O. Have all required equipment valves not covered by standard details been indicated? Avoid duplications.

P. Do not run horizontal piping in solid masonry walls or in narrow stud partitions.

Q. Has all piping been eliminated from electrical switchgear, transformer, motor control center, and emergency generator rooms? If not, have drain troughs or enclosures been provided?

R. Are shutoff valves provided at base of all risers?

S. Are all systems compatible with flow requirements established by control diagrams?

T. Is cathodic protection required for buried piping?

U. Has required heat tracing been included, coordinated, and insulated?

V. Will large mains or risers transmit noise to occupied spaces? Are isolators required in supply and return at pump?

W. Is present and future duty for pumps, boilers, chillers, cooling towers, heat exchangers, terminal units, coils, AHUs, etc. specified? Scheduled?

X. Are air conditioning and steam condensate (when wasted) piped to storm water or sanitary? Is steam condensate cooled?

35.04 Steam and Condensate Piping

A. See Piping Systems–General for additional requirements.

B. Are end of main drips shown, detailed, and specified?

C. Will condensate drain? Are pipes oversized for opposing flow?

D. Will humidifier arms add excessive sensible heat to air stream (likely on small flat ducts and some AHUs)? Insulate where needed. Provide motor operated shutoff valve if steam is live during mechanical cooling season.

E. Are riser drips shown, detailed, and specified?

F. Flash tank for medium and high pressure condensate. Vent flash tanks either to low pressure steam or outdoors.

G. Are relief valves piped to outside? Have they been sized?

H. Has steam consumption for humidification been considered in establishing water makeup quantity for boiler?

I. Has adequate space been allowed for pressure reducing stations? Have standard details been edited?

J. Are water sampling connections provided?

K. Are steam injectors piped to floor drains?

L. Avoid cross-connections between gravity condensate returns and pumped condensate return lines.

M. Is there adequate height between condensate receiver and/or feedwater heater and pump to prevent flashing at pump, particularly with condensate above 200°F.?

N. Has bypass around boiler feedwater heater been provided for maintenance?

O. Are there drip runouts to equipment such as sterilizers and glassware washers?

P. Are end of main drips piped?

Q. Are condensate return systems compatible?

R. Have noise suppressors been provided on reduced pressure side of PRVs? Will radiated noise be a problem? Are there adequate numbers of stages of pressure reduction for quiet operation and an adequate number of valves for capacity control?

S. Are steam and/or condensate flow meters and recorders required?

T. Is there adequate access to components requiring service on boilers? Is catwalk required?

U. Are boilers piped in accordance with ASME code? Is there nonreturn plus shutoff valve on HP boiler?

V. Is condensate tank vented to outside?

W. Are chemicals used in treatment system suitable for humidification? Are chemical feed systems shown, detailed, and specified?

X. Is feedwater heater required or is deaerator required?

Y. Are water softeners required on makeup? Are they shown, detailed, and specified?

Z. Are bottom blowdown and continuous blowdown shown, detailed, and specified?

AA. Avoid lifting steam condensate, if possible.

BB. Are proper traps being used? Have they been specified and scheduled?

CC. Are air conditioning and steam condensate (when wasted) piped to storm water or to sanitary? Is steam condensate cooled?

35.05 Low Temperature Hot Water and Dual Temperature Systems

A. See Piping Systems–General for additional requirements.

B. Are balancing valves indicated? Are flow measuring stations needed and indicated?

C. Is pressure regulation needed?

D. Is a bypass filter required? Is GPM included in pump capacity?

E. Is standby pump needed?

F. Converter support: Are details needed? Is elevation indicated?

G. Are service valves shown?

H. Will branch piping and ducts fit in allotted space or enclosure?

I. Are riser shutoff valves shown?

J. Are riser drains and vents shown?

K. Is there adequate space for installation and use of riser valves?

L. Will minimum allowable circulation be maintained through hot water boiler?

M. Is distribution system reverse return? If not, will balancing problems result?

35.06 Chilled Water and Condenser Water Systems

A. See Piping Systems–General for additional requirements.

B. Are balancing valves indicated? Are flow measuring stations needed? Have they been indicated?

C. Is pressure regulation needed?

D. Is bypass filter required? Is GPM included in pump capacity?

E. Is standby pump needed?

F. Are service valves shown?

G. Will branch piping and ducts fit in allotted space or enclosure?

H. Are riser shutoff valves shown?

I. Are riser drains and vents shown?

J. Is there adequate space for installation and use of riser valves?

K. Will minimum allowable circulation be maintained through chiller?

L. Is distribution system reverse return? If not, will balancing problems result?

M. Condenser water piping: Loop traps to avoid excessive drainage, submerged impeller. Has available NPSH been calculated? Is NPSH indicated in pump schedule?

N. For cooling tower makeup, overflow, and drain splash blocks, are there balancing valves in branch lines to tower cells? Coordinate makeup with Plumbing Engineer.

35.07 Air Systems

A. Are adequate balancing dampers provided to prevent noise at outlets due to excessive pressure, or to avoid complicated balancing procedures on extensive low pressure systems or exhaust systems (i.e., each zone of a multizone system; to limit flow variation due to stack effect in vertical low pressure and exhaust systems)?

B. Are fire damper locations, type, and flow restrictions indicated? Is there adequate height for damper recess pocket at shaft wall? Is breakaway ductwork at fire damper wall sleeve detailed or specified?

C. Are smoke damper locations, type, and flow restrictions indicated? Is there adequate height for damper at shaft wall? Is breakaway ductwork at smoke damper wall sleeve detailed or specified? Is smoke damper operator located on supported duct and not on breakaway duct?

D. Are access doors at fire dampers, smoke dampers, turning vanes, humidifiers, coils, etc., properly specified and included in general notes?

E. Are proper relief air provisions provided?

F. Is return air fan needed? Is outside air fan needed?

G. Are condensate drains provided? Are outside air intake drains provided?

H. Are flexible connections shown and specified?

I. Is sound lining required? Is it properly located and specified?

J. Will duct arrangement permit transfer of excessive noise between offices, toilet rooms and rooms of a different function?

K. Are there objectionable fan noise from intakes or exhaust points to nearby buildings?

L. Are outlets located in supply mains? Are there noisy conditions?

M. Do trunk ducts pass above quiet rooms? Will noise be a problem?

N. Have fan class, bearing arrangement, motor location, etc., been shown, scheduled, or specified?

O. Are air intakes on party walls?

P. Will outlets blow at lights, beams, sprinkler heads, smoke detectors? Sprinkler head and smoke detector locations must meet code requirements. Locate in accordance with code.

Q. Have outlet and return grille elevations been coordinated with architect and indicated?

R. Adjust outlet air quantities for duct heat gain and duct leakage.

S. Are isotope and chemical exhaust ducts accessible?

T. Is there interference between sill grille discharge and drapes or blinds? Beware of annoying movement of vertical blinds or light drapes caused by sill air discharge nearby.

U. Are present and future duty for air terminal units, AHUs, fans, etc., specified and scheduled?

V. Is exhaust or relief discharge or plumbing stack effluent near intakes. Maintain a minimum of 10 feet clear.

W. Is there anti-stratification provision at intakes, large mixing box outlets, downstream of steam coils or water coils? Are air blenders indicated on all AHUs?

X. Are there aluminum grilles on shower, sterilizer, etc., exhaust? Is stainless steel ductwork or aluminum ductwork required? Is it clearly indicated on drawings as to extent? Has it been specified?

Y. Are there sealing and sloping of shower, cage washer, etc., exhaust ducts? When more than one type of duct material is used, is extent and location clearly defined?

Z. Has adequate relief from rooms been provided? Are there door louvers, undercut doors, transfer grilles and direct exhaust? Have they been coordinated?

AA. Will door louvers defeat needed acoustical privacy (i.e., conference rooms, private offices, VP office)? Will door louvers defeat needed door fire rating? Are door louvers located in accordance with code?

BB. Are the types of branch takeoffs and duct splits shown? Are details included on drawings?

CC. Are there intermediate drip pans on cooling coil banks? Are they piped to floor drain? Include detail.

DD. Are there drains for kitchen exhaust duct risers?

EE. Is there excessive duct heat gain from nearby steam pipes and other heat sources?

FF. Are there combustion air intakes for boilers, water heaters, etc. Are vents, stacks, breeching, and chimneys shown, specified, and detailed? Are termination heights clearly indicated?

GG. Locate exhaust grilles near floor in operating rooms, flammable storage rooms, chlorine storage rooms, battery rooms (high and low), etc.

HH. Do not use corridors as return air plenums in hospitals, nursing homes, offices, and other facilities.

II. Have insulated louver blank-off panels or sheets been included where required?

JJ. Are filters provided in makeup air to elevator equipment rooms? Are filters provided for air cooled condensers and condensing units located indoors?

KK. Are there motor operated dampers in wall louvers? Do not use operable louvers. Use stationary louvers with motor operated dampers behind when required.

LL. Are casings adequately described as prefabricated or field fabricated? Is extent of sound paneling clear? Has adequate pressure rating been specified?

MM. Has Architect provided adequate framing for linear diffuser in metal lath and plaster or dry wall bulkheads? Do not dimension diffuser lengths for wall to wall installations–note dimension as "wall to wall."

NN. Have fan systems been checked for excessive sound transmission?

OO. Is there adequate space for servicing fans, motors, belts etc.

PP. Has sufficient space been provided between coils of AHUs to accommodate thermostats?

QQ. Are adequate service space or equipment size access panels noted on drawings to equipment installed above ceilings? Coordinate with Architect who furnishes, installs, provides.

RR. Are there adequate straight duct branch length or straightening vanes between main duct and diffuser?

SS. Do ducts pierce partitions at 90 degree angle wherever possible?

TT. Are wash down systems or fire protection systems required for fume hoods or kitchen hoods?

UU. Are fume hood exhaust systems balanceable? Are orifice plates required?

VV. Are correct outside air quantities and pressurization included?

WW. Is smoke control system required?

XX. Avoid contamination of air intake from exhaust air, contaminated vents, vehicle exhaust, etc. Are locations in accordance with code?

YY. Are static pressure sensors indicated or specified?

ZZ. Are fire and smoke dampers coordinated with fire and smoke walls? Are fire rated floor/ceiling assemblies used? Will diffusers, registers, and grilles require fire dampers? Are smoke dampers required for air handling units or fans?

AAA. Is floor suitable for "built-up" air handling units?

BBB. Have ventilation systems been provided for equipment rooms and other non-air conditioned spaces?

CCC. Are flow measuring devices located? Is there adequate straight run?

DDD. Is there adequate straight duct upstream of terminal units? VAV, constant volume reheat, dual duct, fan powered, and other air terminal unit runouts should be sized based on the ductwork criteria established for sizing the ductwork upstream of the air terminal unit, and not on the terminal unit connection size. The transition from the runout size to the air terminal unit connection size should be made at the terminal unit. A minimum of 3 feet of straight duct should be provided upstream of all air terminal units.

EEE. Is system compatible with architectural floor/ceiling assemblies?

FFF. Do toilet rooms have code required minimum exhaust (*BOCA*–75 CFM per WC and Urinal; *SBCCI*–2.0 CFM/Sq.Ft.; *UBC*–5 AC/Hr.)?

GGG. Locate exterior wall louvers, especially intake louvers, a minimum of 2′0″ above roof, finished grade, etc.

HHH. Locate gravity roof ventilators, especially intake ventilators, a minimum of 1′0″ from finished roof to top of roof curb.

III. Are air conditioning condensate drains piped to storm water or sanitary?

35.08 Process Exhaust Systems

A. Branches and laterals should be connected above duct centerline. If branches and laterals are connected below, the duct centerline drains will be required at the low point.

B. Provide blast gates or butterfly dampers at each branch, at each submain, and at each equipment or tool connection. Wind loading on blast gates needs to be considered when installed on the roof or outside the building, especially those blast gates which are normally open.

C. Blast gate blades for process exhaust systems should be specified with an EPDM wiper gasket to provide a tight seal. For blast gates installed for future use, it is rec-

ommended that the blade be removed and a gasketed blind flange be provided where the blade goes in the duct to reduce leakage.

D. Does duct pitch to low points and drains? Are drains provided at all low points?

E. Has correct duct material been specified? Is it Stainless Steel, Halar Coated Stainless Steel, FRP or PVC? PVC is not recommended and maximum size is 8″ round.

F. Has proper pressure class been specified upstream and downstream of scrubbers and other abatement equipment?

G. Is ductwork installed outside or in unconditioned spaces and will condensation occur on the outside or inside this duct? Is duct insulation or heat tracing required?

H. Are adequate butterfly balancing dampers shown for system balancing?

I. Are process exhaust fans on emergency power as required by code?

J. Process exhaust ductwork cannot penetrate fire rated construction. Fire dampers are generally not desirable. If penetrating fire rated construction cannot be avoided, process exhaust ductwork must be enclosed in a fire rated enclosure until it exits the building, or sprinkler protection in side the duct may be used if approved by authority having jurisdiction.

K. Are pressure ports provided at the ends of all laterals, submains, and mains?

L. Are drains required in fan scroll, scrubber, or other abatement equipment?

M. Are flexible connections provided at fans and are flexible connection specified suitable for application?

N. Are stacks properly located and is discharge height adequate to prevent contamination of outside air intakes, CT intakes, combustion air intakes? Are termination heights clearly indicated?

O. Have redundancy requirements been met?

P. Are adjustable or variable frequency drives required, located, and coordinated with electrical engineer?

35.09 Refrigeration

A. See Piping Systems–General for additional requirements.

B. Is future machine space indicated on drawings?

C. Is space for servicing indicated on drawings?

D. Are there rigging supports for large water boxes and compressor shell?

E. Is noise transmission likely to occupied spaces?

F. Is there adequate control of chilled water temperature?

G. Are sprinklers required for wood fill towers? ***NFPA 214.***

H. Is refrigerant relief piping shown on drawings? Is it piped to outside?

I. Is noise from cooling towers likely to be a problem?

J. Will cooling tower discharge air pocket or recirculate?

K. Should cooling tower be winterized?

L. Have cooling tower support locations been cleared with Structural Engineer. When determining cooling tower enclosure height, has height of vibration isolators been considered (8″–12″ high) and has height of safety rail been considered?

M. Are cooling tower discharge duct connections necessary?

N. Are flow diagrams required? Have they been coordinated?

O. Are present and ultimate duties noted where applicable and coordinated with pumps and coils, etc.?

P. Is Ethylene or propylene glycol required? Has it been specified and equipment capacities de-rated?

Q. Has additional insulation been included for low temperature systems?

R. Has split single-phase protection been included for packaged (single and/or split systems) air conditioning and heat pump compressor motors?

35.10 Controls

A. Are all panels located? Have they been coordinated with Electrical Engineer? Are they local or central?

B. Are flow meter locations an adequate distance up- and downstream of orifice?

C. Are thermostat and humidistat locations indicated? Do not mount stats on glass panels and door frames. Avoid middle of wall locations.

D. Are control settings, schedules, and diagrams indicated or specified?

E. Are temperature tolerances in lab areas clearly specified?

F. Are power and control wiring diagrams shown? Is interlocking wiring included?

G. Have reheat coils requiring full capacity in summer been supplied from a constant temperature hot water supply?

H. Are low-leak dampers specified on intakes and elsewhere as required?

I. Have compressor location and motor size been coordinated with Electrical Engineer?

J. Are all AHUs and systems accounted for on control design?

K. Coordinate purchase and installation of duct smoke detectors and duct fire stat locations with electrical department for connection to building fire detection system.

L. Are direct digital controls appropriate?

M. Are valve positions (open or closed) indicated where applicable?

N. Is compressor size for ultimate duty?

35.11 Sanitary and Storm Water Systems

A. See Piping Systems–General for additional requirements.

B. Adjust sewer inverts to keep tops of pipe in line (note this on the drawings).

C. Maintain at least minimum cover on sewers for entire run.

D. Has sewer authority been contacted for the following:

1. Are sewer authority mains capable of handling additional discharge?
2. Location, size, and depth of sanitary and storm sewer mains?
3. Connection requirements?
4. Requirements for grease traps, oil/water interceptors, etc.?
5. Has DER or EPA been contacted?
6. Have storm water management requirements been determined?

E. Sewer profiles are usually required where contours vary extensively or where possible interference with other lines exists. Indicate contours where required.

F. Indicate sewer inverts at points of connection to public sewers, at building walls, at crossover points, and at points of possible interference. Are all underground utilities coordinated with foundations and grade beams?

G. Indicate foundation drain tile inverts. Provide back water valves (BWVs) at connection to storm water system. Check accessibility; is manhole required?

H. Is there a dry manhole for BWVs outside building or deep BWVs inside building?

I. Provide headwall and rip rap for storm water discharge to drainage ditch, storm water retention pond/tank, or stream.

J. Size site storm sewers large enough to prevent stoppage by leaves, paper, silt, etc. Except for light duty sewers, use 8″ or 10″ pipe minimum.

K. Are all plumbing fixtures designated and scheduled?

L. Coordinate fixture locations with final architectural plans. Check ADA requirements. Are handicapped fixtures identified?

M. Provide BWVs for drains and groups of drains connected to storm water below grade or where backflow is possible above grade.

N. Vent sumps for sanitary and storm water drainage.

O. Is elevation of mains selected to be above footings? Advise Structural Engineer if mains must run below footings or through footings.

P. Is there adequate ceiling space for AHU floor drain traps on upper floors? Are deep seal traps required? Are they indicated?

Q. Are drains for overflows piped?

R. Are there separate vapor vents for sterilizer and bed pan washers?

S. Are grease traps required for commercial kitchens? Are sand interceptors and/or oil/water separators required for garages and parking areas? Is oil and/or water collected by oil/water separator to be treated as hazardous waste?

T. If oil filled transformer is located inside building, provide transformer room with drain and pipe to accessible storage tank.

U. Provide floor drains for air handling units, boilers, chemical feed equipment, air compressors, pumps, generators, etc., especially for relief valve discharge and pump stuffing box discharge.

V. Are disposals directly connected to heavy flow mains? Do not connect to grease interceptor.

W. Provide floor drain to create indirect waste connection for commercial dishwashers, kitchen sinks, and kitchen equipment processing food.

X. Is plumbing fixture connection schedule included?

Y. Does general piping or equipment interfere with overhead door's travel?

Z. Do not run horizontal piping in solid masonry walls.

AA. Is there adequate AHU pad height to allow condensate drain from pan to be properly trapped. Are condensate drains piped to storm or sanitary made with indirect connections? Do local authorities require condensate drains to be piped to sanitary or to storm? Can condensate drains be discharged onto roof or grade?

BB. Are floor drains, roof drains, and trench drains coordinated with structural system? Are drains coordinated with building expansion joints?

CC. Are air conditioning and steam condensate (when wasted) piped to storm water or sanitary? Is steam condensate cooled?

DD. Are automatic trap priming systems required?

EE. Are floor drain, roof drain, and trench drain types suitable for duty and traffic rating?

FF. Are flow or riser diagrams required by plumbing authorities? Are fixture units clearly indicated on riser diagrams when required?

GG. Is minimum size of vent through roof indicated (i.e., recommend 3″)? Has minimum size pipe below floor been coordinated with local codes (i.e., Allegheny Co. 4″ minimum pipe size below floor)?

HH. Are fixtures and drains trapped and vented in accordance with applicable code?

II. Will drainage to grade freeze and create slippery condition?

JJ. Is tub overflow assembly accessible? Use solid connection, if not.

KK. Are cooling tower and evaporative cooler overflows, bleeds, and drains piped to sanitary?

LL. Do not use cleanouts on Washington, D.C. projects. Verify requirements.

MM. Are acid waste and vent systems clearly indicated on the drawings and specified?

NN. Site drainage: Are adequate manholes, catch basins, and other items shown on the drawings and specified?

OO. Are future connections and/or expansions considered in slope of piping, size of piping, and sewer connection sizing?

PP. Provide manways for septic and sewage holding tanks. Manholes and covers should be waterproof/watertight.

35.12 Domestic Water Systems

A. See Piping Systems–General for additional requirements.

B. Has water authority been contacted to obtain the following:

1. Water static and residual pressures and flows at water main? Are these pressures and flows adequate?
2. Location and size of water mains?
3. Water hardness and corrosiveness of water?
4. Backflow prevention requirements?
5. Water meter location requirements and meter pit requirements if necessary?

C. Are pressure regulating valves required? Do pressures exceed 60 psi; if so, pressure reducing valves should be provided.

D. Are there submain section valves?

E. Are there provisions for piping and building expansion?

F. Have all wall, box, and yard hydrants been provided and specified?

G. Are water softeners for laundry and boiler makeup required?

H. Is makeup water connected to boiler, heating, chilled, condenser, and other HVAC water systems? Is freeze protection required? Is sufficient pressure available to overcome static head?

I. Provide hose bibbs at cooling towers and in boiler rooms, mechanical rooms, large toilet rooms, dormitory toilet rooms, and kitchens.

J. In boiler and chiller rooms, provide service sink and water sampling connections.

K. Are flow or riser diagrams required by plumbing authorities? Are fixture units clearly indicated on riser diagrams when required?

L. Is a hot water recirculating pump required, located, scheduled, and specified?

M. Are all hospital, laboratory, kitchen, and other special equipment connections shown on the drawings? Are hospital, laboratory, kitchen, and other special equipment connection schedules required and included?

N. Are backflow preventers provided at service entrance, at fire protection service, and at connection to HVAC water systems fill connections? Use reduced pressure backflow preventers on all HVAC systems and double-check backflow preventers on domestic water and fire protection service.

O. Is pressure boosting system required?

P. Is a main shutoff valve provided? Are shutoff valves shown at each toilet room and groups of two or more plumbing fixtures?

Q. Are all plumbing fixtures shown on the drawings and specified?

R. Is a water meter required? Is Sub-metering required?

S. Are balancing valves on hot water recirculation system shown?

T. Use ¾″ cold water connection to eye wash units.

U. Are water heater connections shown (gas, water, vents, etc.)?

V. Is dishwasher booster heater connected?

W. Are future connections and/or expansions considered in size of piping and service entrance?

X. Are all underground utilities coordinated with foundations?

35.13 Fire Protection

A. See Piping Systems–General for additional requirements.

B. Are Siamese connections shown and coordinated with Architect?

C. Are check valves and shutoff valves shown on drawings?

D. Have fire extinguishers and/or cabinets been specified by Architect or Engineer? Have fire hoses and/or cabinets been specified by Architect or Engineer?

E. Is fire protection for kitchen hoods required?

F. Is there adequate space for sprinkler mains?

G. Are dry systems provided for areas subject to freezing?

H. Is there a sprinkler for trash and linen chutes?

I. Are there drains for ball drips of Siamese connections?

J. Are pressures noted for hydraulically calculated systems?

K. Is the extent of sprinklered area indicated? If more than one type of sprinkler system is required (wet, dry, pre-action, deluge, etc.), are they clearly indicated on the drawings?

L. Are fire department valves clearly indicated on the drawings?

M. Are special fire protection systems included?

N. Are standpipes and fire department valve shown?

O. Is sprinkler zoning compatible with fire alarm zoning?

P. Are all test connections shown and locations coordinated with Architect? Are drains for test connection provided?

Q. Has water authority been contacted to obtain the following:

1. Water static and residual pressures and flows at water main? Are these pressures and flows adequate or is fire pump required?
2. Location and size of water mains?
3. Water hardness and corrosiveness of water?
4. Backflow prevention requirements?
5. Water meter location requirements and meter pit requirements if necessary?
6. Street or on site fire hydrant requirements?
7. Fire hydrant and fire department connection size, thread type, etc.?

R. Have electrical requirements for fire pump, tamper switches, flow switches, etc., been coordinated with Electrical Department?

S. Have fire pump requirements been coordinated between spec and drawings?

T. Have fire hose and fire extinguisher locations been coordinated with Electrical Department for wiring of blue indicator light?

U. Who paints fire protection piping and what color (red)?

35.14 Natural Gas Systems

A. See Piping Systems–General for additional requirements.

B. Determine minimum gas pressure required. Is gas company pressure available at street adequate for equipment? Has gas company been contacted to obtain the following:

1. Pressures and flows at gas main? Are these pressures and flows adequate?
2. Location and size of gas mains?
3. Gas meter location requirements and meter pit requirements if necessary?

C. Has gas meter size been coordinated with gas company? Has capacity requirement and site location been given to gas company? Is meter required to be located inside or outside? Who provides gas meter and regulator assembly? Does gas company? Who provides gas piping from main to curb box, from curb box to meter assembly, from meter assembly to building, and inside building?

D. Have gas pressure regulators been evaluated for low load conditions and during start-up? It is recommended that multiple gas pressure regulators be used, especially on large central utility plant natural gas systems, not only for low load conditions but for replacement of regulators without shutdown of the entire plant. For instance, the natural gas system design may use two regulators sized at 50%-50%,

33%-67%, or 40%-60%, or it may use three regulators sized at 15%-35%-50% or 25%-25%-50%.

E. Is there gas meter access and room ventilation (when required)?

F. Are there drip pockets if gas lines cannot drain back to meter and adequate space for pitch?

G. Are there submain section gas cocks?

H. Are gas vent valves and vents from pressure regulating valves piped to outside?

I. Do not locate natural draft burners in room under "negative" pressure.

J. Coordinate gas train with gas pressure available and with Owner's insurance carrier.

K. Are stacks, vents, and breeching shown on the drawings and properly sized and specified? Coordinate with design team other equipment requiring gas vents (i.e., water heaters, shop equipment, kitchen equipment, lab equipment, hospital equipment).

L. Is combustion air for fuel fired equipment properly designed in accordance with code? Watch for water heaters in janitor closets.

M. What pressures are permitted to be run inside the building?

N. Is piping run in plenum? If so, valves cannot be located in plenum, including walls.

O. Check with local gas company for welded and screwed pipe requirements (concealed, exposed, etc.). Screwed pipe and fittings may only be used if gas service is less than 1 psig and vertical runs are less than four stories. Otherwise use welded pipe.

P. Plastic pipe can only be used for underground service. Require contractor to install #14 insulated tracer wire 4 to 6 inches above all underground plastic lines.

35.15 Fuel Oil Systems

A. See Piping Systems–General for additional requirements.

B. Do not locate natural draft burners in room under "negative" pressure.

C. Is suction lift within allowable limits of fuel oil pump?

D. Is underground fuel oil tank location coordinated with site plan. Does it have adequate cover? Has truck traffic been considered? Are leak detection systems and double wall piping systems shown on the drawings and specified?

E. Are tank vent and fill indicated and away from air intakes? Are vents properly sized?

F. Are fuel oil heaters required (#4, #5, #6 fuel oils)?

G. Is a tank heater required (they are not permitted with fiberglass tanks)?

H. Is a compressed air for tank gauge provided?

I. Is specified tank suitable for installation? Has it been coordinated with Owner? Is future conversion to heavy oil a consideration?

J. Are leak detection, double wall piping, spill containment, double wall tanks, etc., properly specified and shown on the drawings?

K. Are stacks, vents, and breeching shown on the drawings and properly sized and specified? Coordinate with design team other equipment requiring vents (i.e., water heaters, shop equipment, lab equipment, hospital equipment).

L. Is combustion air for fuel fired equipment properly designed in accordance with code? Watch for water heaters in janitor closets.

M. Are DER tank requirements met? Have Pennsylvania state police requirements been met?

N. Are emergency vents properly sized for indoor tanks?

O. Are manholes and covers for fill and access openings specified and/or detailed to be waterproof/watertight?

35.16 Laboratory and Medical Gas Systems

A. Is separate zone valve required?

B. Are medical gas alarm panels required?

C. Is air intake for hospital compressor indicated? Is it outside? Does it provide clean air?

D. Vacuum pump discharge should not be at rubber membrane roofs, due to adverse reaction of oil with membrane materials.

E. Are *NFPA 99* requirements met?

35.17 General

A. Are all mechanical items specified and coordinated with other disciplines as to who provides, furnishes, and/or installs? Have all items on specification coordination list been coordinated? Do all disciplines have the most current drawings showing mechanical equipment?

B. Are there a north arrow, title blocks, and engineer's stamp with signature?

C. Are scales noted on plans? Does project or client require graphic scales?

D. Are there client and project numbers on all projects, and company name, logo, address, etc., on all drawings?

E. Check for completeness of general notes, legend, abbreviations, and title blocks.

F. Check column numbers and grids.

G. Check room names and numbers.

H. Is extent of demolition clearly defined? Is what is to remain clearly defined? Are points of connection between new and old clearly defined?

I. Check coordination and contrast of new and existing work.

J. Coordinate the following with architectural, structural, and electrical departments:

1. Clearances between lighting fixtures, structure, and ducts and pipes.
2. Clearances between conduits out of electrical panels and pull boxes, structure, and ducts and pipes.
3. Wiring of filters (roll filters and air purification systems).

K. Does electrical department have the final motor list and heater list?

L. Have existing mechanical/electrical services and available space for new work been adequately field checked?

M. Advise electrical department of relocated mechanical equipment having electrical components.

N. Has division of work between Architectural, Structural, Mechanical, and Electrical disciplines been coordinated (as to who furnishes, install and/or provides) on such items as:

1. Starters and disconnect switches?
2. Line and low voltage control wiring and power wiring to control panels?
3. Access panels?
4. Fire extinguishers, fire hoses, and/or cabinets?
5. Catwalks and ladders?
6. Under-window unit discharge grilles on built in cabinets?
7. Louvers?
8. Door grilles, undercut doors?
9. Generators, muffler, fuel oil piping, engine exhaust, engine cooling air ductwork, and accessories?
10. Painting and priming?
11. Mechanical equipment screens?
12. Equipment supports and concrete housekeeping pads?
13. Roof curbs (equipment, ductwork, and piping), flashing, and counter flashing?
14. Site work/building utility design termination (5′0″ outside of foundation wall)?
15. Foundation drains?
16. Excavation?
17. Kitchenette units?
18. Bus washer, vehicle lifts, hydraulic piping and accessories, and paint booths and accessories?
19. Countertop plumbing fixtures; built in showers?
20. Kitchen hoods?
21. Laboratory fume hoods?

O. Where ceiling height and door or window head heights provide no leeway to lower ceiling, have mechanical and electrical work space above ceiling been closely checked?

P. Check framing of holes in existing structures.

Q. Is structure adequate for new mechanical equipment in existing buildings?

R. Is there adequate clearance for removal of ceiling systems for access to equipment. Tee bar system requires 3″ minimum from underside of ceiling to equipment.

S. Have heating and ventilation of bathrooms and toilet rooms been provided?

T. Is there equipment room, PRV room, electrical room, and electrical closet ventilation?

U. Has insulation or ventilation been provided to overcome radiant heat from boiler or incinerator stacks?

V. Has specified equipment been properly described by current model designation?

W. Have all items specified "As indicated on the drawings" been coordinated? Coordinate references between drawings, details, sections, risers, and specifications.

X. Is there any material or equipment for which there is no catalog data in the office library?

Y. Have details been coordinated?

Z. Has space for future ducts, pipes, fans, pumps, chillers, boilers, cooling towers, water heaters, and other equipment been clearly indicated?

AA. Are "floating floors" required for noise control? Have they been specified and detailed?

BB. Has existing area been adequately field checked?

CC. Are elevator machine rooms free of piping, ductwork, and equipment except elevator machine equipment? Is elevator machine room ventilated? Does elevator machine room need to be air conditioned?

DD. Have chemical treatment systems been included?

EE. Have handwash sinks been included in mechanical equipment rooms?

FF. Have chain operators for valves more than 7′-0″ above finished floor been specified?

GG. Are General Notes, drawing notes, and Keyed Notes included?

HH. Is key plan needed?

II. Are applicable standard details included and coordinated?

JJ. Have applicable codes been researched?

KK. Should smoke and fire walls be indicated?

LL. Are present and ultimate duties included in schedules where applicable and coordinated with Electrical Engineer? Are future flows accounted for in duct and pipe sizing and appropriate provision made?

MM. Have authorities having jurisdiction been consulted regarding fire detection and protection systems, applicable codes, etc.?

NN. Is minimum head room (6′-8″) maintained in equipment rooms?

OO. Is verification that building meets *ASHRAE Standard 90* or other Energy Conservation Code required?

PP. Is access to equipment with electrical connections (such as ceiling mounted heat pumps) adequate to satisfy NEC?

QQ. Have all equipment housekeeping pads been indicated, specified, and coordinated?

RR. Is asbestos present in existing building? Is preparation of removal documents part of Contract?

35.18 Architect and/or Owner Coordination

A. Have all shafts/chases been coordinated? Are they large enough?

B. Do shafts/chases line up floor to floor? Are structural members located in shaft space?

C. Have pipe or duct chases been provided where required?

D. Will partitions accommodate piping and plumbing fixtures?

E. Has suitable type stationary louver been specified?

F. Are bird screens (not insect screens) specified? Are bird screens located on the inside or outside of louver? Outside of louver easier to clean but appearance is undesirable.

G. Have louver locations and sizes been coordinated? Who provides, furnishes, and/or installs louvers?

H. Have plumbing fixtures as required been specified under the architectural section?

I. Have all plumbing fixtures been coordinated?

J. Has all special equipment been coordinated?

K. Have NIC or future items requiring "stub-up" services been identified?

L. Have masonry air shafts been avoided? If not, are they specified to be airtight?

M. Has access to roof mounted equipment been provided?

N. Have provisions for equipment replacement been made?

O. Have supply air ceiling plenums been coordinated? Are partitions floor to floor where required? Is supply air plenum area sealed where required?

P. Have return air ceiling plenums been coordinated? Are partitions floor to floor? If so, have provisions been provided to return air from these spaces?

Q. Have trenches, sumps, and covers been coordinated?

R. Have under-window units been coordinated?

S. Have air outlet types been coordinated?

T. Have thermostat types been selected and approved by Owner?

U. Have plumbing fixtures and types been approved? Have countertop fixtures been coordinated? Who provides, furnishes, and/or installs countertop fixtures?

V. Include vibration isolators, grillage, and cooling tower safety rail when dimensioning height of cooling tower for architectural screen.

W. Have all skylights, roof hatches, bulkheads, and multiple height ceilings been coordinated with ductwork, piping, and other mechanical equipment?

X. Who provides, furnishes, and/or installs roof curbs for mechanical equipment?

Y. Who provides, furnishes and/or installs flashing and counterflashing?

Z. Who provides cutting and patching?

35.19 Structural Engineer Coordination

A. Have equipment locations, sizes, and weights been given to the Structural Engineer? Have equipment housekeeping pad locations and sizes been coordinated? Has final and complete structural list been given to Structural Engineer?

B. Have all floor, roof, and wall openings been coordinated?

C. Have pipes 6 inches and larger been located and coordinated with structural engineer?

D. Have all sleeved beams, grade beams, and foundations been coordinated? Have pipes and ducts been coordinated?

E. Has structural framing in shafts been considered?

F. Has mechanical layout been coordinated with structural system, especially in post tensioned concrete structural systems (penetrations at columns and column lines are not normally possible)?

G. Is structural system adequate for future equipment?

H. Where equipment must be "rolled" into place, is the structure over which equipment will be rolled adequate?

I. Have catwalks been coordinated?

J. Have pipe risers been coordinated?

K. Do structural openings allow for insulation and ductwork reinforcing?

L. Have anchor locations and associated forces been given to Structural Engineer? Avoid locating anchors at joist or joist girder locations.

M. Have louver openings, sizes, and framing been coordinated with Structural Engineer?

35.20 Electrical Engineer Coordination

A. Has final and complete motor list been given to Electrical Engineer?

B. Have all electrical and telecommunication rooms and closets been ventilated? Do they need to be air conditioned?

C. Have duct smoke detectors, duct fire stats, and/or smoke dampers been coordinated?

D. Have valve position indicators/tamper switches been coordinated?

E. Have sprinkler flow switches and alarms been coordinated?

F. Have fuel tank level alarms and gauges been coordinated?

G. Have cooling tower electric basin heaters and vibration switches for propeller fans been coordinated?

H. Have medical gas alarms been coordinated?

I. Have automatic trap priming system for kitchen or other areas been coordinated?

J. Have automatic trap priming system for AHUs been coordinated?

K. Has lighting inside AHUs been coordinated?

L. Has power at pneumatic tube stations been coordinated?

M. Has power for ATC compressors and refrigerated air dryers been coordinated?

N. Who provides starters and disconnect switches? Who provides line voltage and low voltage control wiring? Who provides power wiring to control panels? Have starters, wall switches, remote starter pushbuttons, and disconnect switches been located on mechanical drawings?

O. Have 2 disconnects been provide at duplex pumps?

P. Are there automatic fire suppression systems for fume hoods and kitchen hoods?

Q. Are there alarms on sump pumps, condensate pumps, sewage pumps, hot water generators, and similar items?

R. Are there chiller oil heaters and control circuits (winterize air cooled chillers)?

S. Are there diesel generator fuel oil pumps on emergency power? Who provides engine exhaust, fuel oil piping, day tank, muffler, cooling air, fuel storage tank, etc.?

T. Steam or water flow on BTU meter recorders?

U. Have shower controls been coordinated?

V. Automatic fire suppression systems for computer rooms? Are AHUs interlocked with computer room shutdown system?

W. Smoke or thermal detectors for AHUs and RA fans. Who furnishes, installs, and/or provides them?

X. Has heat tracing for piping systems been coordinated?

Y. Electric fuel tank heating systems?

Z. Auxiliary equipment on water chillers.

AA. Has motor list been coordinated with equipment schedules?

BB. Has motor list been coordinated with control diagrams?

CC. Have electric humidifiers been coordinated?

DD. Hot water generator or boiler circulating pumps?

EE. Has relocated equipment been coordinated?

FF. Allowance for lighting fixtures access? Have height of lighting fixtures been coordinated, especially high hat fixtures?

GG. No ductwork, piping, or other mechanical equipment should be in electrical rooms or closets.

HH. Are motor control centers shown and specified? Are starters shown and specified?

II. Is there adequate space for MCCs?

JJ. Electric water level detectors?

KK. Are electric motor operated dampers wired?

LL. Are there air handling light fixtures, supply, return, and heat transfer?

MM. Has extent of return air ceilings been coordinated with Electrical Engineer?

NN. Equipment on emergency power? Include control air compressor and dryer.

OO. Are explosionproof motors, starters, disconnect switches, etc., required?