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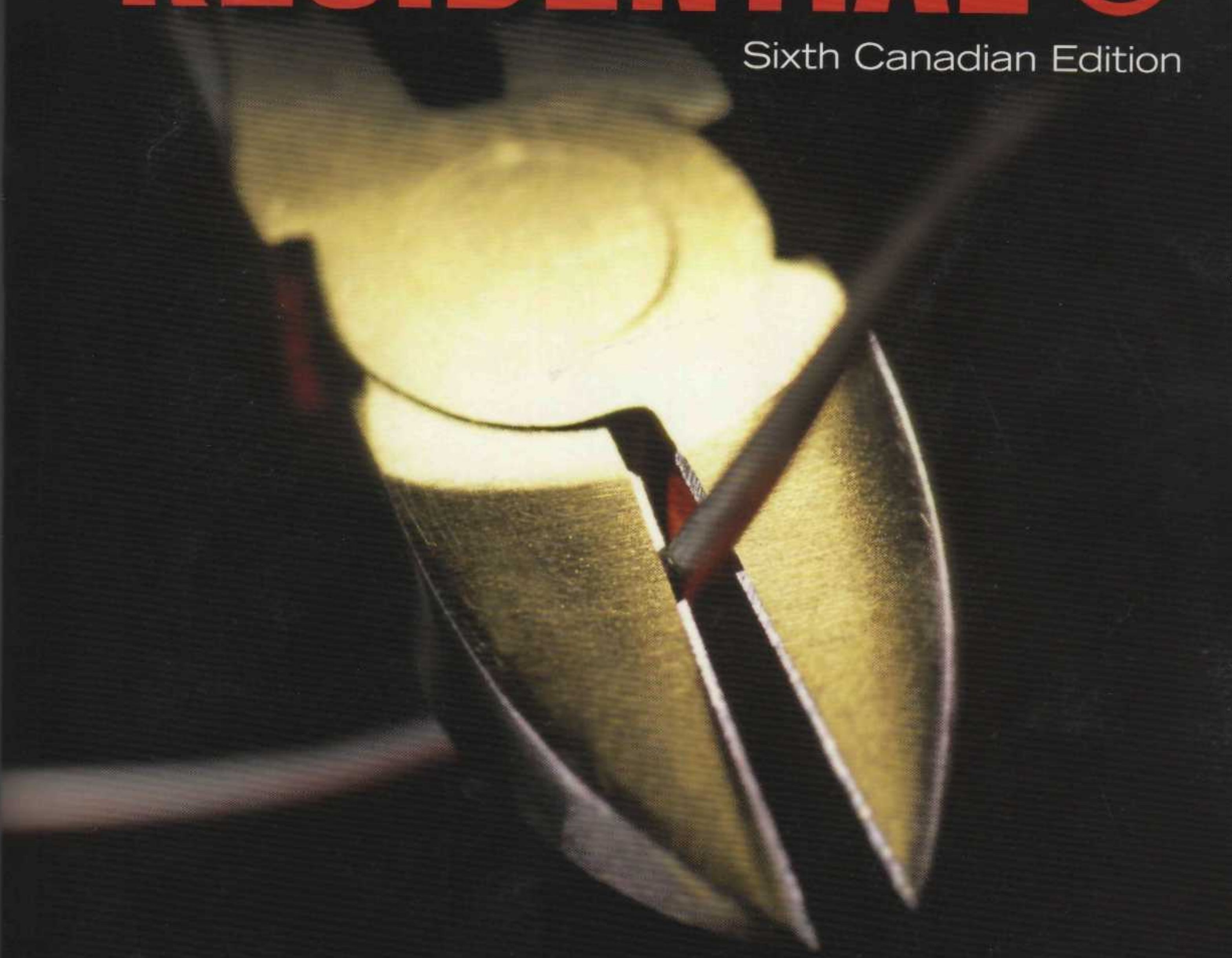
ELECTRICAL WIRING
RESIDENTIAL

Sixth Canadian Edition



MULLIN • BRANCH • GEROLIMON • TODD • TRINEER

ELECTRICAL WIRING: RESIDENTIAL

Sixth Canadian Edition

Ray C. Mullin
Tony Branch
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NELSON EDUCATION

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Electrical Wiring: Residential, Sixth Canadian Edition

by Ray C. Mullin, Tony Branch, Sandy F. Gerolimon, Bill Todd, and Craig Trineer

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Managing Designer:
Franca Amore

Cover Design:
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Cover Image:
© Pegaz / Alamy

Compositor:
Integra Software Services Pvt. Ltd.

Printer:
RR Donnelley

Printed and bound in the United States of America
1 2 3 4 15 14 13 12

For more information contact Nelson Education Ltd., 1120 Birchmount Road, Toronto, Ontario, M1K 5G4. Or you can visit our Internet site at http://www.nelson.com

Library and Archives Canada Cataloguing in Publication Data

Electrical wiring : residential / Ray C. Mullin ... [et al.]. — 6th Canadian ed.

"Based on the 2012 edition of the *Canadian Electrical Code*".
Includes index.
First edition by Ray C. Mullin, James I Fraser.
ISBN 978-0-17-650381-9

1. Electric wiring, Interior.
2. Dwellings—Electric equipment.
I. Mullin, Ray C.

TK3285.M84 2012 621.319'24
C2012-903819-9

ISBN-13: 978-0-17-650381-9
ISBN-10: 0-17-650381-1

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CONTENTS

INTRODUCTION

This sixth Canadian edition of *Electrical Wiring: Residential* is based on the 2012 edition of the *Canadian Electrical Code, Part I: The Safety Standard for Electrical Installations (CEC).* The authors welcome readers' suggestions for improvements that may be included in subsequent editions of the text.

Electrical Wiring: Residential provides an entry-level text that is both comprehensive and readable. It is suitable for colleges, technical institutes, vocational/technical schools, and electrical programs in high schools, and for readers who want to study the subject on their own.

The wiring in the home illustrated in *Electrical Wiring: Residential* incorporates more features than are absolutely necessary, to present as many *CEC* rules as possible so that students are provided with the information they need to complete a safe installation. The text focuses on the technical skills required to perform electrical installations. Topics include calculating conductor sizes, calculating voltage drop, sizing services, connecting electrical appliances, grounding and bonding equipment, and installing recessed fixtures. These are critical skills that can make the difference between an installation that "meets code" and one that is exceptional. The electrician must understand that the reason for following *CEC* regulations is to achieve an installation that is essentially free from hazard to life and property.

The *CEC* is the basic standard for the layout and construction of all electrical systems in Canada. However, some provincial and local codes may contain specific amendments that must be adhered to in all electrical wiring installations in those jurisdictions.

The authors encourage the reader to develop a detailed knowledge of the layout and content of the *CEC,* which must be used in conjunction with a comprehensive study of *Electrical Wiring: Residential* to derive the greatest benefit from the text.

The *CEC* is divided into numbered sections, each covering a main division. These sections are further divided into numbered rules, subrules, paragraphs, and subparagraphs. All references in the text are to the *section* or to the *section rule number.* For example, *Rule 8–200(1)(a)(i)* refers to *Section 8*, *Rule 8–200*, *Subrule 1*, *Paragraph a*, *Subparagraph i*. This explanation should assist the student in locating *CEC* references in the text.

Thorough explanations are provided throughout, as the text guides the student through the steps necessary to become proficient in the techniques and *CEC* requirements described.

PREFACE

Electrical Wiring: Residential will prove a valuable resource to instructors and students alike. It includes 2012 *Canadian Electrical Code, Part I* (*CEC*) references and wiring techniques. Each chapter is a complete lesson ending with review questions to summarize the material covered. The chapters are sequenced to introduce the student to basic principles and wiring practices, and progress to more advanced areas of residential electrical wiring.

This text assumes no prior knowledge of residential electrical wiring, but the student will need a reasonable level of mechanical aptitude and skill to be successful in the practical application of the techniques discussed.

The text guides the student through the working drawings for a residential electrical installation, the proper wiring of receptacles, and the minimum required number of lighting and power branch circuits. Voltage drop calculations based on the *CEC* are shown. Grounding, bonding, and ground-fault circuit interrupters are discussed together with the lighting branch circuits for all of the rooms in the house, as well as for the garage, workshop, and exterior. Special-purpose outlets for ranges, dryers, air conditioners, water heaters, and water pumps are explained, as are electric, oil, and gas heating systems; heat detectors, smoke detectors, and smoke alarms; swimming pools, spas, and hot tubs; and low-voltage-signal systems, security systems, and low-voltage remote-control systems, or Smart House Wiring.

The text details service-entrance equipment and the installation of the electrical service, including the calculations for the sizing of the service-entrance conductors, conduit, switch, grounding conductor, and panel.

FEATURES

- New! All text material fully updated to reference the 2012 edition of the *CEC*.
- New! Standby Power Systems (Unit 25).
- New! Residential Utility-Interactive Solar Photovoltaic Systems (Unit 26).
- New Appendix! EIA/TIA 568A & 568B for wire colour pin layout (Appendix C).
- Updated data network and home automation sections.
- Metrification is in keeping with the 2012 *CEC*.
- Descriptions of Canadian practice and applications.
- Numerous diagrams of CSA-approved equipment found in everyday wiring installations.
- Step-by-step explanations of wiring a typical residence.
- Complete set of blueprints to help apply *CEC* theory to real working drawings.

SUPPLEMENTS

About NETA

The Nelson Education Teaching Advantage (NETA) program delivers research-based instructor resources that promote student engagement and higher-order thinking to enable the success of Canadian students and educators.

Instructors today face many challenges. Resources are limited, time is scarce, and a new kind of student has emerged: one who is juggling school with work, has gaps in his or her basic knowledge, and is immersed in technology in a way that has led to a completely new style of learning. In response, Nelson Education has gathered a group of dedicated instructors to advise us on the creation of richer and more flexible ancillaries that respond to the needs of today's teaching environments.

The members of our editorial advisory board have experience across a variety of disciplines and are recognized for their commitment to teaching. They include:

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In consultation with the editorial advisory board, Nelson Education has completely rethought the structure, approaches, and formats of our key textbook ancillaries. We've also increased our investment in editorial support for our ancillary authors. The result is the Nelson Education Teaching Advantage.

NETA Assessment is the aspect of the program that relates to testing materials. Under *NETA Assessment*, Nelson's authors create multiple-choice questions that reflect research-based best practices for constructing effective questions and testing not just recall but also higher-order thinking. Our guidelines were developed by David DiBattista, a 3M National Teaching Fellow whose recent research as a professor of psychology at Brock University has focused on multiple-choice testing. All Test Bank authors receive training at workshops conducted by Professor DiBattista, as do the copyeditors assigned to each Test Bank. A copy of *Multiple Choice Tests: Getting Beyond Remembering,* Professor DiBattista's guide to writing effective tests, is included with every Nelson Test Bank/Computerized Test Bank package.

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INSTRUCTOR'S RESOURCE CD: Key instructor ancillaries are provided on the *Instructor's Resource CD* (ISBN 978-0-17-662884-0), giving instructors the ultimate tool for customizing lectures and presentations. The IRCD includes:

- Instructor's Manual: The *Instructor's Manual* was written by Sandy Gerolimon, Humber College. It is organized according to the textbook chapters and includes solutions to all in-text review questions.
- NETA Assessment: The Test Bank was written by Anthony Fazzari, Mohawk College. It includes over 280 multiple-choice questions written according to NETA guidelines for effective construction and development of higher-order questions. Also

included are approximately 125 true/false questions, approximately 125 essay-type questions, a number of short-answer and completion questions. Test Bank files are provided in Word format for easy editing and in PDF format for convenient printing whatever your system.

The Computerized Test Bank by ExamView® includes all the questions from the Test Bank. The easy-to-use ExamView software is compatible with Microsoft Windows and Mac. Create tests by selecting questions from the question bank, modifying these questions as desired, and adding new questions you write yourself. You can administer quizzes online and export tests to WebCT, Blackboard, and other formats.

- PowerPoint® Presentations: Microsoft® PowerPoint® lecture slides for every chapter have been created by Sandy Gerolimon, Humber College. There is an average of 20–30 slides per chapter, many featuring key figures from *Electrical Wiring: Residential*, Sixth Canadian Edition. Principles of clear design and engaging content have been incorporated throughout.
- Image Library: This resource consists of digital copies of figures, short tables, and photographs used in the book. Instructors may use these jpegs to create their own PowerPoint presentations.
- DayOne: DayOne—Prof InClass is a PowerPoint presentation that you can customize to orient your students to the class and their text at the beginning of the course.

BLUEPRINTS: Revised and updated by Miroslav Lukic, Mohawk College, and technically checked by the text authors, the set of blueprints (ISBN 978-0-17-665356-9) accompanies this textbook.

ACKNOWLEDGMENTS

Every effort has been made to be technically correct and to avoid typographical errors. The authors wish to acknowledge the valuable assistance of Bill Wright in the preparation of the original architectural drawings for this book. Much gratitude is extended to Miroslav Lukic, Mohawk College, for revising the blueprints for this edition. Thank you to Jack Martin, Conestoga College, for a thorough technical check of the text for adherence to the *CEC* 2012. Thank you as well to the people from Nelson Education Ltd. for their encouragement and professional advice.

The authors are also indebted to reviewers of each text in the *Electrical Wiring* series for their comments and suggestions:

Scott MacLennan, Cambrian College
Steven Draves, Canadore College
Kent Gilbert, Conestoga College
Dean Lahey, Conestoga College
Tony Poirier, Durham College
Charlie Rentner, Georgian College
Glenn Kinaschuk, Mohawk College
Shawn MacAulay, Nova Scotia Community College

We wish to thank the following for contributing data, illustrations, and technical information:

AFC/A Nortek Co.
AFL Global
Anchor Electric Division, Sola Basic Industries
Appleton Electric Co.
Arrow-Hart, Inc.
Brazos Technologies, Inc.
Brian Cameron
BRK Electronics, A Division of Pittway Corporation
Broan-NuTone Canada
Bussmann Division, Cooper Industries
Canadian Standards Association
Carlon
Chromalox
Cisco
Commander
Contrast Lighting M.L. Inc.
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Electri-Flex Co.
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Woodhead Industries, Inc.
Gary Gudbranson, www.cottageontheedge.com

For any further information or to give feedback on this text, you can contact the authors by e-mail at

bill.todd@humber.ca
sandy.gerolimon@humber.ca
craig.trineer@humber.ca
tony.branch@humber.ca

UNIT 1

General Information for Electrical Installations

OBJECTIVES

After studying this unit, the student will be able to

- identify the purpose of codes and standards related to electrical systems
- describe the importance of the *Canadian Electrical Code (CEC)*
- describe the layout of the *CEC*
- identify approved equipment
- explain the importance of electrical inspection
- identify links to websites relating to the electrical trade
- list the agencies that are responsible for establishing electrical standards and ensuring that materials meet the standards
- discuss systems of measurement used on construction drawings
- begin to refer to the *CEC*

SAFETY

Electrical installations are required to be safe. Because of the ever-present danger of electric shock and/or fire due to the failure of an electrical system, electricians and electrical contractors must use approved materials and methods. Therefore, codes and standards are used to ensure that the exposure of users, installers, and maintenance personnel to the shock and fire hazards associated with electrical systems is minimized.

CODES AND STANDARDS

Codes are standards that deal with life safety issues and are enforceable by law. Residential electrical wiring systems are required to meet building codes and electrical codes. Building codes dictate such things as which rooms and areas (such as stairwells) require luminaires (lighting fixtures) and how they are to be controlled. Electrical codes deal with the actual installation of the luminaires and controls. Municipal, provincial, and federal governments can pass laws regarding the installation of electrical equipment.

The *Canadian Electrical Code (CEC)* is the standard that governs electrical work across Canada. It is adopted by the provinces, is enacted in legislation, and is the basis of a bill (with provincial amendments) that passes through the provincial legislature, becoming law and enforced by municipalities or provincial electrical safety authorities.

The first edition of the *CEC* was published in 1927. It is revised every three years to take into account changes in equipment, wiring systems, and new technologies. The standards steering committee for the *CEC* solicits comments and proposals from the electrical industry and others interested in electrical safety. Information about the structure and operation of the committee, how to propose an amendment, or how to request an interpretation can be found in *CEC Appendix C*. Copies of the *CEC* can be ordered from the Canadian Standards Association.

The object of the *CEC* is to provide a minimum safety standard for the installation and maintenance of electrical systems to safeguard people from the hazards of fire and electric shock arising from the use of electrical energy. Meeting the requirements of the *CEC* ensures an essentially safe installation.

The *CEC* does not take economics into consideration. For instance, a house built using wood frame construction may be wired with non-metallic-sheathed cable or armoured cable. Both meet the requirement of the *CEC*, but one costs several times as much as the other.

The *CEC* is divided up into evenly numbered sections, each one covering a main division of the work. Each section has a title that describes what will be covered by the section. Ten general sections cover basic installation requirements (see Table 1–1). The rest are amending or supplementary sections, which change the general requirements of the code for specific types of equipment or installation (see Table 1–2). Rules in one amending section cannot be applied to another amending section unless they specifically state that they may.

The sections are divided into subsections and numbered rules with captions. For example, Section 12–500 contains non-metallic-sheathed cable rules, where 12 identifies the section, 500 is the rule number in the section. 12–500 is the first rule of the subsection that deals with the installation of non-metallic-sheathed cable. The 12–500 series of rules (12–500 to 12–526) describe how non-metallic-sheathed cables are to be installed.

SECTION	TITLE
0	Object, scope, and definitions
2	General rules
4	Conductors
6	Services and service equipment
8	Circuit loading and demand factors
10	Grounding and bonding
12	Wiring methods
14	Protection and control
16	Class 1 and Class 2 circuits
26	Installation of electrical equipment

Table 1–1 General sections of the *CEC*. (Courtesy of CSA Group)

Tables

At the end of the main body of the *CEC* are a number of tables. An index of the tables precedes the tables. At the top of each table is a list of rules that refer you to the table, which can be helpful in looking up rules. The tables cover such things as the ampacity of wires, number of conductors in raceways, number of conductors in boxes, and depth of cover over conductors installed underground.

Diagrams

After the tables are a number of diagrams. An index of the diagrams precedes the diagrams. Some of the diagrams included show pin configurations for both locking and non-locking receptacles.

Appendices

Of the 11 appendices, the two important to you are *Appendix B* and *Appendix D*. *Appendix B* is Notes on Rules. These notes give supplemental information about rules. Whenever a rule refers to *Appendix B*, you must read that information. *Appendix B* uses the same numbering system as the main body of the *CEC*. Simply look up in *Appendix B* the rule number from the main body of the *CEC*.

EXAMPLE:

Rule 6–112 Support for the attachment of overhead supply or consumer's service conductors (See *Appendix B*).

SECTION	TITLE
28	Motors and generators
30	Installation of lighting equipment
32	Fire alarm systems and fire pumps
62	Fixed electric space and surface heating systems
68	Pools, tubs, and spas
76	Temporary wiring

Table 1–2 Some supplementary or amending sections of the *CEC*. (Courtesy of CSA Group)

6–112 in *Appendix B* outlines the components that may be used for an overhead mast service and methods of installation.

Appendix D is tabulated general information. This textbook will refer to several tables, including *Tables D1, D3,* and *D6.*

Table of Contents and Index

The *CEC* provides an index and a table of contents to help you look up information. If you know exactly what you want look up, use the index in the back of the book. If you just have a general idea of what you are looking for, use the table of contents at the front of the book.

Code Terminology

Shall: indicates a mandatory requirement.

- shall be: compulsory, mandatory, a requirement
- shall have: the same as *shall be*
- shall not: not permitted, not allowed, must not be
- shall be permitted: is acceptable, is allowed, is permitted

May: indicates permitted or allowable

Acceptable: means acceptable to the authority having jurisdiction

Notwithstanding: in spite of

Practicable: feasible or possible

This text is designed to be used in conjunction with the *CEC*. Throughout the text, reference will be made to the rules, tables, and appendices found in the 22nd (2012) edition of the *CEC*. To distinguish these from the tables and appendices in this text, all references to them are in italics.

Standards

Standards describe minimum performance levels for equipment and systems. The *Canadian Electrical Code, Part II*, found in *Appendix A* consists of safety standards for electrical equipment and is a mandatory part of the *CEC*. Another standard used in the electrical field is TIA-570A, which is used when installing communication cabling.

PERSONNEL SAFETY

When it comes to personnel safety, you have to make it your responsibility.

When you ask most people if they work safely, they answer that they do. The question is, do you know enough about safe working practices to work safely? See if you can answer the five questions below. If you can't, you require additional safety training.

- What are the proper procedures for locking out and tagging electrical equipment?
- When is a worker required to wear a safety belt or safety harness on a construction site?
- What are five pieces of personal protective equipment?
- What are the eight classes of products identified by WHMIS symbols?
- What precautions should be taken when using ladders for electrical installations?

You can obtain information about safe working practices from the provincial government, construction safety associations, and construction unions.

TESTING AND ACCREDITATION

All electrical equipment sold or installed in Canada is required to be approved for its intended use. Approved equipment has met specified safety standards of federal and provincial governments. Currently several companies are accredited to approve electrical equipment. Equipment that has been approved by an approval agency will have an identifying label such as CSA or ULC. If you are unsure about an approval label other than CSA or ULC, look for C at the eight o'clock position on the label. For equipment that has not been approved, arrangements may be made for field approval by contacting the inspection authority in your province. This authority should also be able to provide you with a complete list of companies that can approve electrical equipment in your province.

Standards Council of Canada (SCC)

The objective of the Standards Council of Canada (SCC) is to promote efficient and effective voluntary standardization as a means of advancing the national economy and benefiting the health, safety, and welfare of the public.

(Courtesy of the Standards Council of Canada)

The SCC is mandated with overseeing the National Standards System, which is a network of organizations and individuals involved in voluntary standards development, promotion, and implementation in Canada. The SCC also accredits organizations engaged in standards development, certification, testing and quality management, and environmental registration.

The SCC is also involved in various international activities to promote standardization and to highlight its value and benefit to global trade. Among other endeavours, the council assists International Trade Canada in formulating Canadian policy positions on standards issues in the World Trade Organization, the key body where international trade rules are established. The council also manages Canadian participation in the standards development initiatives of the International Organization for Standardization and the International Electrotechnical Commission, two of the world's largest voluntary standardization bodies.

For more information, contact

Standards Council of Canada
270 Albert Street, Suite 200
Ottawa, ON K1P 6N7
Tel: 613-238-3222
www.scc.ca

Canadian Standards Association (CSA)

CANADIAN STANDARDS ASSOCIATION

(Courtesy of CSA Group)

The Canadian Standards Association is a not-for-profit organization that was formed in 1919 to develop standards for a variety of organizations and disciplines. These standards are the cornerstone for product certification, and are subsequently approved by provincial and federal government authorities to become recognized throughout the country.

Thousands of manufacturers work directly with the CSA on the certification process, and the CSA mark appears on many new products every year.

For more information, contact

Canadian Standards Association
Customer Service Department
5060 Spectrum Way, Suite 100
Mississauga, Ontario L4W 5N6
Tel: 416-747-4000
1-800-463-6727
Fax: 416-747-2473
www.csa.ca

Underwriters Laboratories of Canada (ULC)

(Courtesy of the Underwriters Laboratories of Canada)

Underwriters Laboratories of Canada is a not-for-profit organization that maintains and operates laboratories and the certification service for testing and classification of devices, constructions, materials, and systems to determine their relation to life, fire, and property hazards.

ULC also publishes standards, specifications, and classifications for products having a bearing on fire, accident, or property hazards.

For more information, contact

Underwriters Laboratories of Canada
7 Underwriters Rd.
Toronto, ON
M1R 3A9
Tel: 1-866-937-3852 or 416-757-3611
Fax: 416-757-8727
www.ulc.ca
E-mail: customerservice@ulc.ca

ELECTRICAL INSPECTION

The *CEC* requires that a permit be obtained for the inspection of all work with respect to the installation, alteration, or repair of electrical equipment. It is the responsibility of the electrical contractor or person doing the work to obtain the permit. When the installation has passed inspection, the inspection authority will issue a connection permit (also called *authorization for connection* or *current permit*) to the supply authority. The supply authority will then make connection to the installation.

Since local codes vary, the electrician should also check with the local inspection authority that enforces the *CEC*. Electrical utility companies can supply additional information on local regulations. The electrician should never assume that the *CEC* is the recognized standard everywhere. Any city or province may adopt electrical installation and licensing laws. In many cases these laws are more stringent than the *CEC*.

PROPERTY	SI UNIT	SYMBOL
Length	Metre	m
Area	Square metre	m^2
Volume	Cubic metre	m^3
Time	Second	s
Speed (velocity)	Metre/second	m/s
Acceleration	Metres/second/second	m/s^2
Temperature	Degrees celsius	°C
Force	Newton	N
Energy	Joule	J
Work	Joule	J
Power	Watt	W
Mass	Kilogram	kg
Weight	Kilogram	kg
Pressure	Pascal	Pa
Flow	Litres/minute	L/m
Electric charge	Coulomb	C
Electric current	Ampere	A
Electric potential difference	Volt	V
Luminous flux	Lumen	lm
Illuminance	Lux	lx

Table 1–3 Metric units of measure.

UNITS OF MEASURE

Two common systems of measurement are used in Canada: the International System of Units (abbreviated SI from its French name: Système international d'unités), or metric, and the American standard unit (ASU), which uses inches and pounds. Although SI is the official system of measurement in Canada, the ASU system is widely used. Refer to Tables 1–3 to 1–5.

Length

The basic SI unit of measure for length is the metre. The SI system has a base of 10 (the next larger unit is 10 times the size of the smaller unit) and uses prefixes to identify the different units of length.

PREFIX	VALUE
Mega (M)	1 000 000
Kilo	1000
Hecto	100
Deka (deca)	10
Base unit (metre)	1
Deci	0.1
Centi (c)	0.01
Milli (m)	0.001
Micro (μ)	0.000 001
Nano (n)	0.000 000 001

Table 1–4 SI prefixes.

Construction drawings normally give SI dimensions in millimetres or metres to prevent confusion.

The ASU commonly uses inches, feet, yards, rods, and miles to measure length.

UNIT	VALUE
Inch	1/36 yard
Foot	12 inches
Yard	3 feet
Rod	5 1/2 yards, 16 1/2 feet
Mile	320 rods, 1760 yards, 5280 feet

Table 1–5 ASU units.

Construction drawings may use feet (″), inches (″), and fractions of an inch as units of measure. A standard steel tape measure that uses ASU units is divided into feet, inches, and fractions of an inch. The first 12 inches of the tape normally has

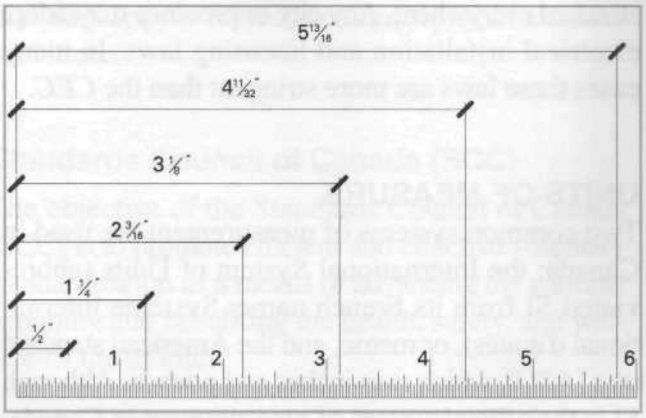


Fig. 1–1 Reading tape measure divisions.

divisions of $^1/_{32}$ of an inch. The remainder of the tape is divided into 16ths of an inch. Fig. 1–1 shows how to read a tape measure using ASU units. An architect's scale is used for working with construction drawings that use ASU units. Scales are covered in Unit 2. Table 1–6 gives useful conversions from ASU to metric units.

Common Conversions

Trade Sizes

Raceways such as rigid conduit and electrical metallic tubing (EMT) are designated by trade sizes. This is because the actual inside diameter of a conduit or tubing is not its stated size. For example, $^1/_2''$ (trade size) rigid steel conduit has an inside diameter of 0.632 inches, $^1/_2''$ EMT has an internal diameter of 0.622 inches, and $^1/_2''$ ENT (non-metallic tubing) has an internal diameter of 0.560 inches. All are considered to be $^1/_2''$ (or 16 mm) trade size.

The 2012 *CEC* designates raceways in metric units only: The actual size of the raceway has not changed, only the fact that metric units of measure are used to designate the trade size of the raceway. Table 1–7 lists the equivalent metric and American designator units.

Outlet boxes are still referenced in inches. The volume of the boxes is given in both cubic inches and mL (cc).

American wire gauge sizes (AWG) are still used in the 2012 *CEC*. Metric wire sizes are not identical to AWG sizes. Standard metric sizes generally fall between American wire gauge sizes. Table 1–8 gives standard AWG sizes and their circular mil area and metric wire sizes and their equivalent circular mil size.

METRIC DESIGNATOR	AMERICAN DESIGNATOR
12	$^3/_8$
16	$^1/_2$
21	$^3/_4$
27	1
35	$1^1/_4$
41	$1^1/_2$
53	2
63	$2^1/_2$
78	3
91	$3^1/_2$
103	4
129	5
155	6

Table 1–7 Metric and American designators for common trade sizes of raceways.

PROPERTY	ASU UNIT	MULTIPLICATION FACTOR FOR CONVERSION TO SI	SI UNIT
Length	Inch	× 25.4	Millimetre
	Foot	× 304.8	Millimetre
	Yard	× 914.4	Millimetre
	Rod	× 5.0292	Metre
	Furlong	× 201.17	Metre
	Mile	× 1.609347	Kilometre
Area	Sq. in.	× 645.16	Sq. mm
	Sq. ft.	× 92903	Sq. mm
	Sq. yd.	× 0.8354	Sq. m
Volume	Cu. In.	× 16.39	cc or mL
	Cu. ft.	× 0.02832	Cubic metres
	Cu. yd.	× 0.7646	Cubic metres
Liquid volume	Fl. oz	× 29.6	Millilitres
	Gallons	× 3.78	Litres

Table 1–6 Converting ASU to SI, or metric, units.

AMERICAN WIRE SIZE AWG	CIRCULAR MILS OR EQUIVALENT CIRCULAR MILS	METRIC WIRE SIZE mm^2
	937	0.50
20	1020	
18	1620	
	1974	1.0
16	2580	
	2960	1.5
14	4110	
	4934	2.5
12	6530	
	7894	4.0
10	10380	
	11840	6.0
8	16510	
	19740	10.0
6	26240	
	31580	16
4	41740	
	49340	25
3	52620	
2	66360	
	69070	
1	83690	
	98680	50
1/0	105600	
2/0	133100	
	138100	70
3/0	167800	
	187500	95
4/0	211600	

Table 1–8 Standard AWG wire sizes and metric (mm^2).
(Courtesy of Thomas & Betts Incorporated)

REVIEW

1. What is the difference between a code and a standard?

2. What code sets standards for the installation of electrical equipment?

3. What authority enforces the standards set by the *CEC*?

4. Does the *CEC* provide minimum or maximum standards?

5. What do the letters CSA signify?

6. Does compliance with the *CEC* always result in an electrical installation that is adequate, safe, and efficient? Why?

___

___

___

___

___

7. What are the general sections of the *CEC*?

___

___

8. Is the section of the *CEC* that deals with wiring methods a general section or an amending section?

___

9. When is an electrical installation required to be inspected?

___

___

10. What should you look for when trying to determine if a piece of electrical equipment is approved for use in Canada?

___

___

11. If a piece of electrical equipment is not approved for use in Canada, what should you do?

___

___

12. When the words "shall be" appear in a code reference, they mean that it (must) (may) (does not have to) be done. (Underline the correct answer.)

UNIT 2

Drawings and Specifications

OBJECTIVES

After studying this unit, the student will be able to

- identify the line types used in construction drawings
- visualize building views
- read common scales
- explain how electrical wiring information is conveyed to the electrician at the construction or installation site
- demonstrate how the specifications are used in estimating cost and in making electrical installations
- identify and explain the application of the various common line types used on drawings
- explain why symbols and notations are used on electrical drawings
- identify symbols used on architectural, mechanical, and electrical drawings

TECHNICAL DRAWINGS

Technical drawings are used to show the size and shape of an object to the viewer. The basic elements of a technical drawing are lines, symbols, dimensions, and notations.

Lines

The lines that make up working drawings are sometimes referred to as the *alphabet of lines* since each one is unique and conveys a special meaning. Fig. 2–1 shows types of lines commonly found on construction drawings.

Visible Lines Visible lines are continuous lines that show the visible edges of an object. An example of a visible line would be the outside edge of the foundation wall shown on sheet 3 of the drawings provided with this book.

Hidden Lines Hidden lines are short dashed lines. They show the edges of an object that are hidden from view by surfaces that are closer to the viewer. Hidden lines are used to show the building footings on sheet 1 of the drawing set.

Centre Lines Centre lines show the centre of an arc or circle. They consist of alternating long and short dashes. The exact centre of a circle is normally indicated by the crossing of two short dashes.

Section Lines A sectional view (also called a *section* or *cross-section*) is a view of a building in which we imagine a portion of the building has been sliced off to reveal the internal construction details. Section lines show the solid parts (e.g., walls, floors) of the

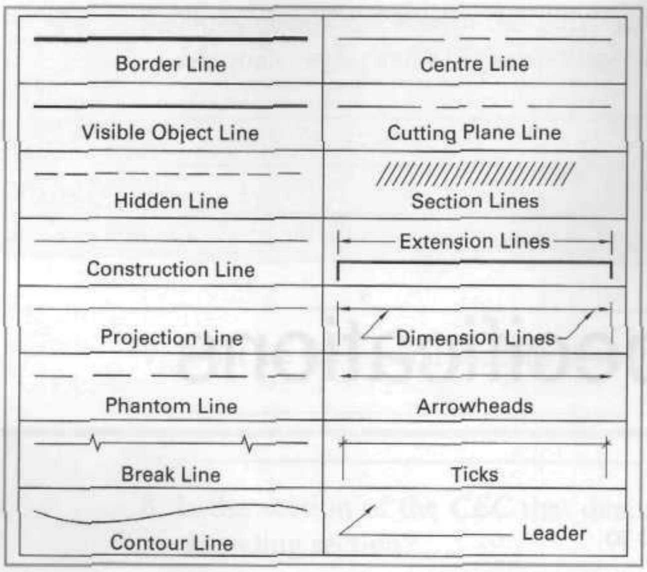
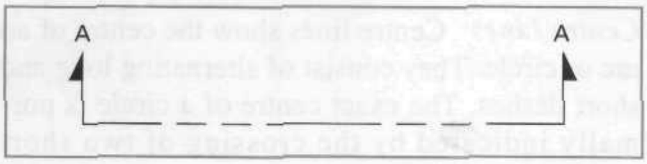


Fig. 2–1 Line types.

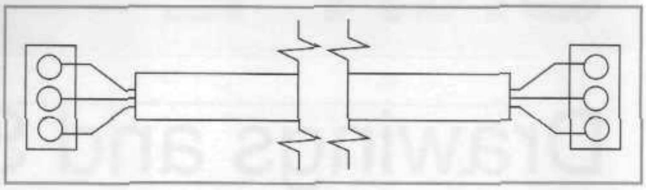
portion of the building shown in the sectional view. Section lines are also called *cross-hatching*. Different types of *cross-hatching* represent different types of materials used in the building. In Section A-A on sheet 4 of the drawings, different types of cross-hatching indicate concrete used for the basement floor, cement blocks used for the basement walls, and bricks used on the outside walls above grade.

Cutting Plane Lines Cutting plane lines consist of a long dash followed by two short dashes. They indicate where a building is being sectioned. The basement floor plan, sheet 4 of the drawings, uses a cutting plane line to show where the building is being sectioned. The arrows at each end of a cutting plane line indicate the direction you are looking when you are viewing the section. Refer to Section A-A on sheet 4.

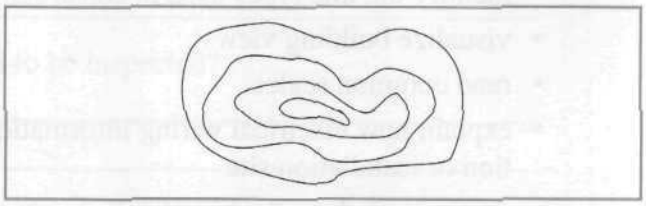


Phantom Lines Phantom lines are short dashed lines (about 1.5 times as long as the dashes for hidden lines) that show an alternative position. Fig. 5–11 on page 80 shows two single-pole, double-throw (SPDT) switches. Closed switch positions are shown by a phantom line.

Break Lines Break lines are used where only a part of the drawing needs to be shown. For example, a break line might be used in a connection diagram where it is necessary to show the termination of both ends of a cable but not the cable in between.



Contour Lines Contour lines are used on plot plans to show changes in elevation. Dashed contour lines indicate existing grades, and solid contour lines show finished grades.



Lineweight refers to the thickness of a line used on a drawing. Object lines have a heavier lineweight (are thicker) than other lines such as hidden lines or dimension lines. Items of other trades that appear on electrical drawings normally have a lighter weight (are thinner) than the electrical items.

VISUALIZING A BUILDING

Pictorial drawings are three-dimensional drawings that show two or more surfaces of an object in one view. Three types of pictorial drawings are shown in Fig. 2–2. Fig. 2–3 shows a pictorial drawing of the wiring of a house.

Unfortunately, pictorial drawings distort shapes such as angles, arcs, and circles and are hard to dimension. Since it is important that construction

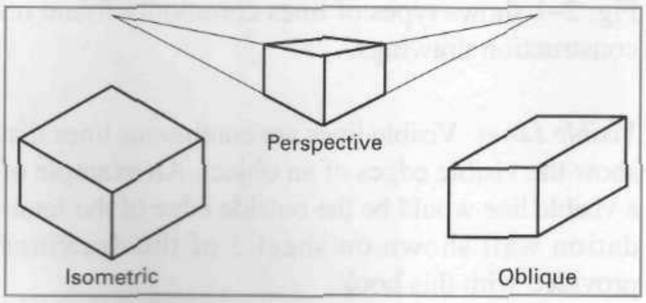


Fig. 2–2 Pictorial drawings.

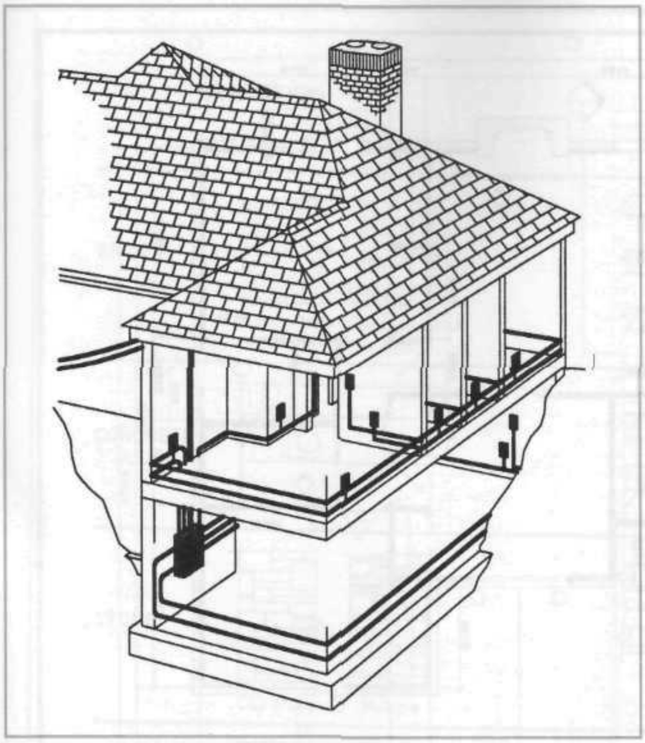


Fig. 2–3 Three-dimensional view of house wiring.

drawings show the exact size and shape of an object, most construction drawings are two-dimensional drawings.

Construction drawings are made using orthographic projection, which shows the true size and shape of an object through a number of views. Each view shows two dimensions. To visualize an object (such as a house), two or more views will often be required. Fig. 2–4 shows an example of orthographic projection.

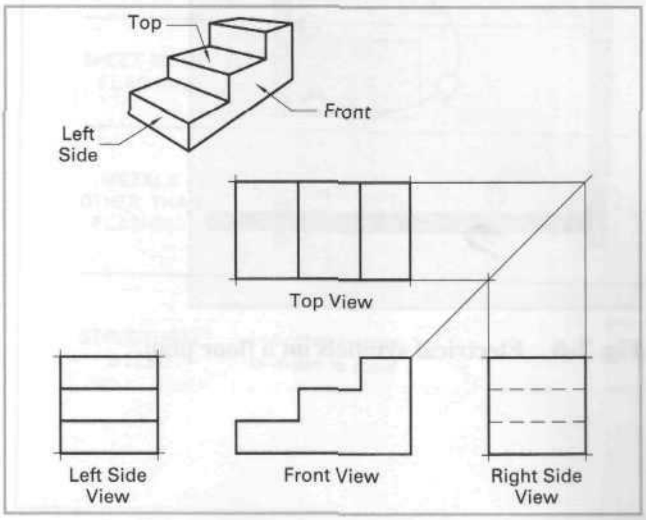


Fig. 2–4 Orthographic projection.

Construction drawings use the terms *plan* for a top view and *elevation* for a side view.

BUILDING VIEWS

Plan Views

A plan view shows how a building will look when viewed from directly above it. Plan views are used to show lengths and widths. Floor plans and site plans are examples of plan views. Fig. 2–5 shows the first-floor plan of the house used in this book.

Elevations

An elevation is a side view of the building. Elevations are used to show heights and widths. Elevations are commonly used to show outside walls, interior walls, and the placement of such things as cupboards and equipment. Fig. 2–6 shows the front (south) elevation of the house.

Sections

A sectional view of the building (after a portion of the building has been removed) is used to show the interior construction details of the building. Fig. 2–7 shows a portion of Section A-A on drawing sheet 4.

SYMBOLS AND NOTATIONS

Graphical symbols are used on construction drawings to represent equipment and components. Symbols are used to show the size, location, and ratings of equipment. The Standards Council of Canada (SCC) approves national standards for symbols used on construction drawings and *accredits organizations such as the CSA that are* engaged in standards development. CSA standard Z99.3-1979 (1989) includes symbols for electrical drawings. They relate closely to the symbols published by the Institute of Electrical and Electronics Engineers (IEEE) and the American National Standards Institute (ANSI), which publish similar standards for the United States. Fig. 2–8 is a portion of a floor plan showing the symbols for two three-way switches controlling an overhead light and two duplex receptacles. Fig. 2–9 (A–E) shows symbols commonly used on construction drawings.

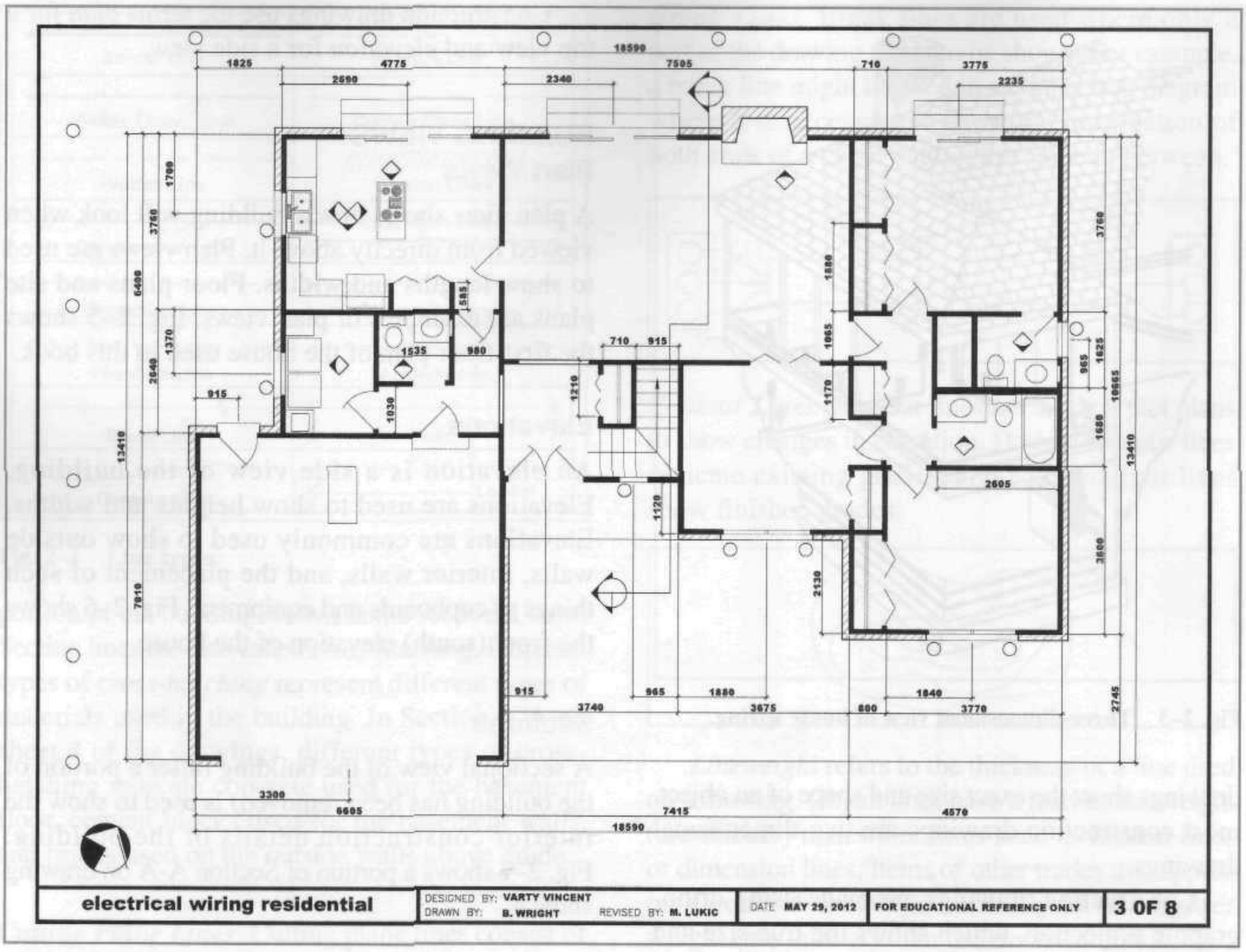


Fig. 2–5 Floor plan.

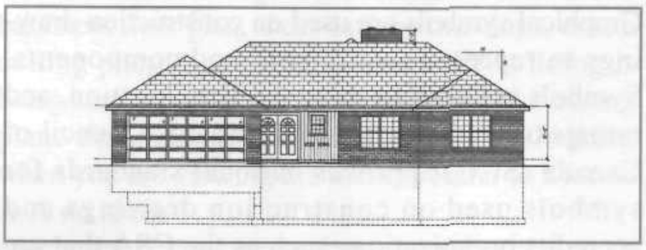


Fig. 2–6 Front elevation.

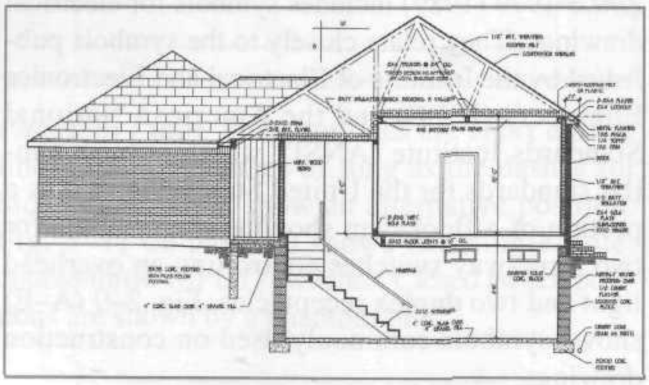


Fig. 2–7 Typical wall section.

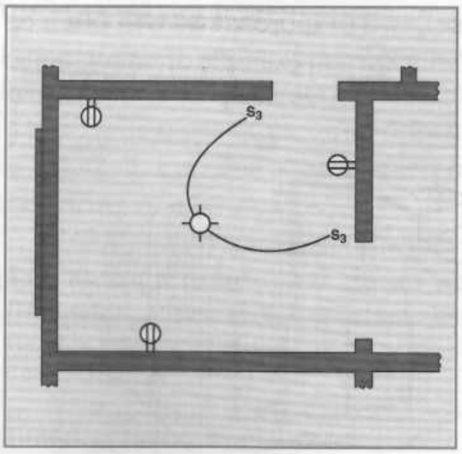


Fig. 2–8 Electrical symbols on a floor plan.

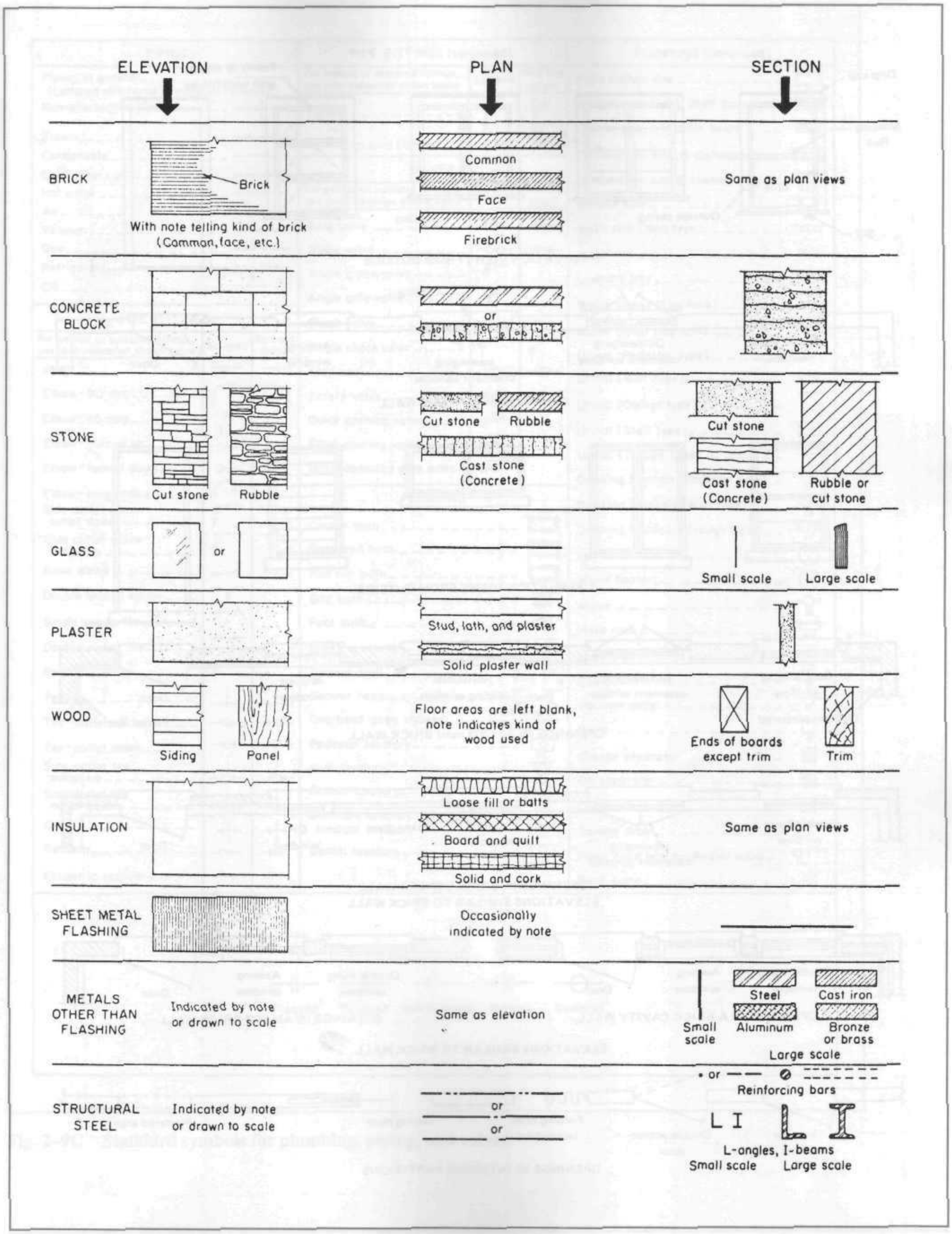


Fig. 2–9A Architectural drafting symbols.

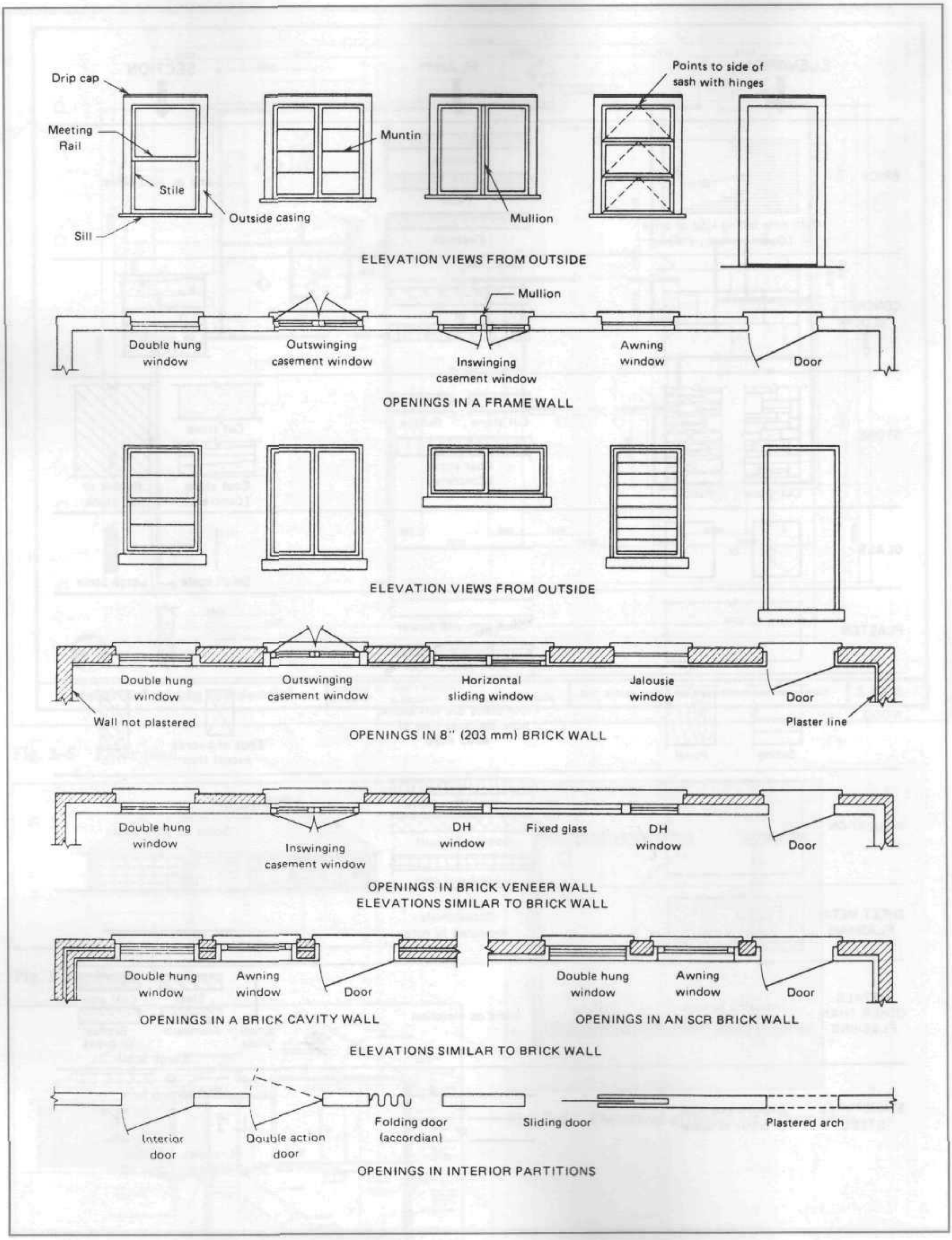


Fig. 2–9B Architectural drafting symbols (continued).

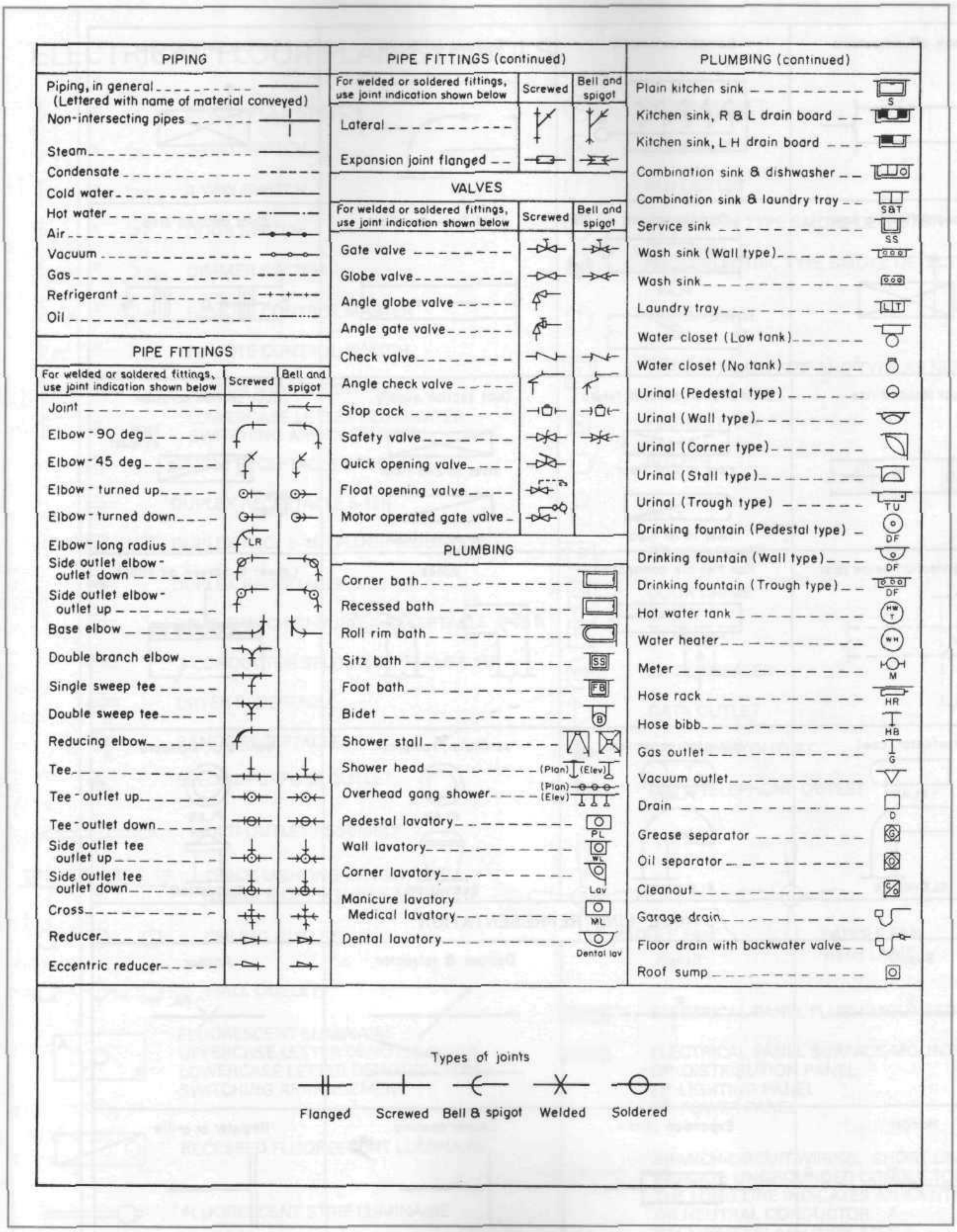


Fig. 2–9C Standard symbols for plumbing, piping, and valves.

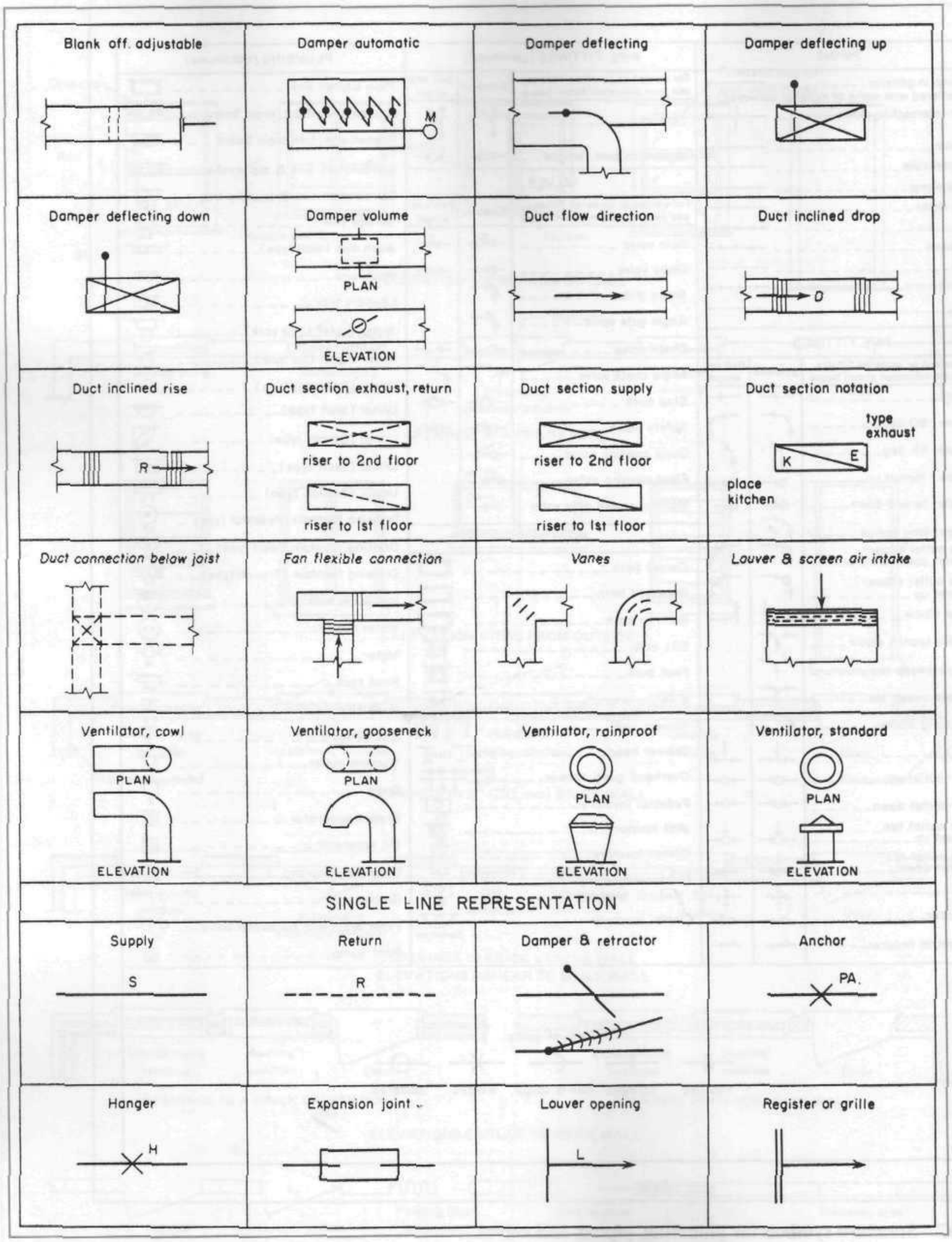


Fig. 2-9D Sheet metal duct work symbols.

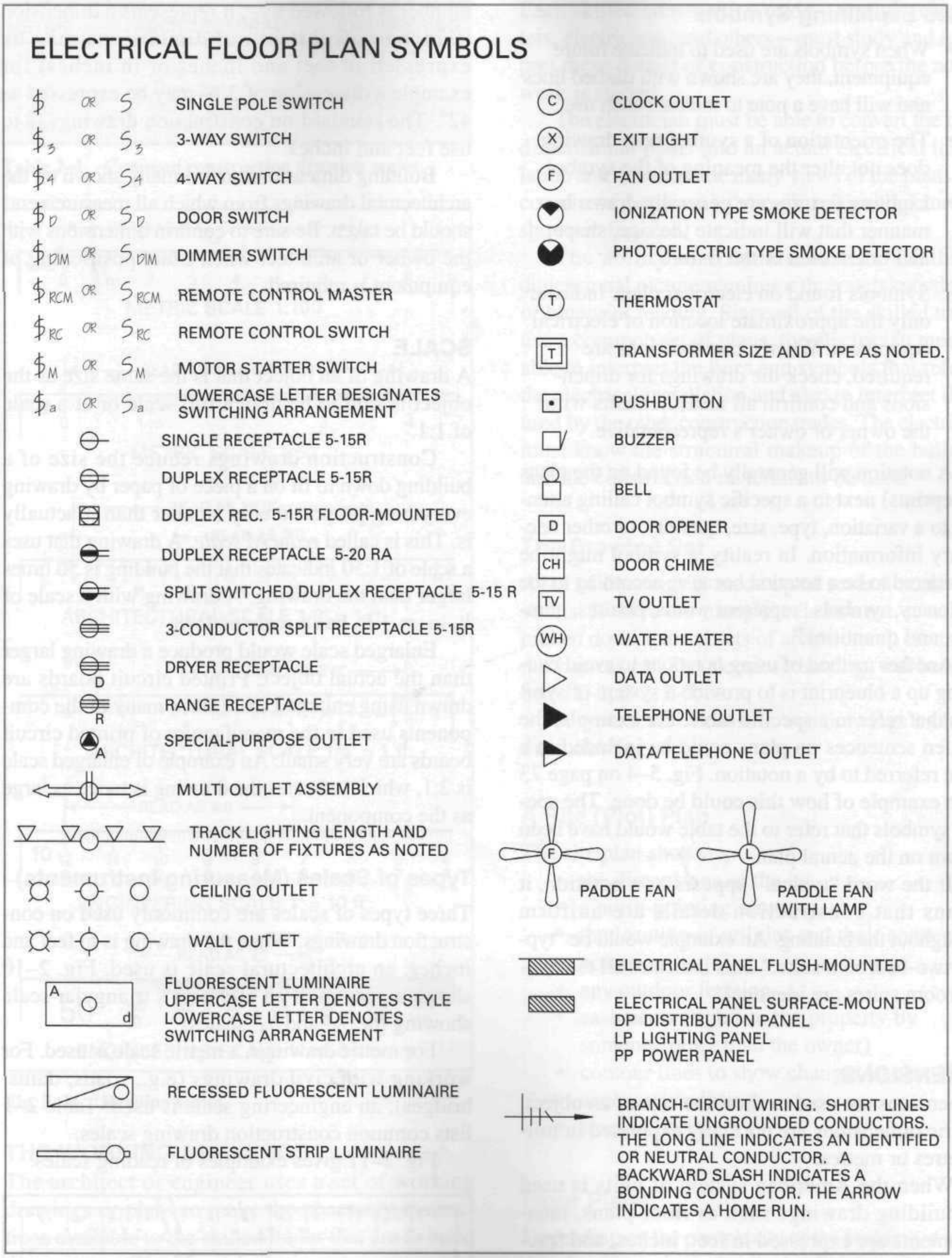


Fig. 2–9E Electrical symbols for floor plans.

Notes Explaining Symbols

- When symbols are used to indicate future equipment, they are shown with dashed lines and will have a note to indicate such use.
- The orientation of a symbol on a drawing does not alter the meaning of the symbol.
- Lighting fixtures are generally drawn in a manner that will indicate the size, shape, and orientation of the fixture.
- Symbols found on electrical plans indicate only the approximate location of electrical equipment. When exact locations are required, check the drawings for dimensions and confirm all measurements with the owner or owner's representative.

A notation will generally be found on the plans (blueprints) next to a specific symbol calling attention to a variation, type, size, quantity, or other necessary information. In reality, a symbol might be considered to be a notation because, according to the dictionary, symbols "represent words, phrases, numbers, and quantities."

Another method of using notations to avoid cluttering up a blueprint is to provide a system of symbols that refer to a specific table. For example, the written sentences on plans could be included in a table referred to by a notation. Fig. 5–4 on page 73 is an example of how this could be done. The special symbols that refer to the table would have been shown on the actual plan.

If the word "typical" appears as a notation, it means that construction details are uniform throughout the building. An example would be "typical two-bedroom suite." This indicates all the two-bedroom suites are identical.

DIMENSIONS

Dimensions are used to show the size of an object. Metric dimensions are normally expressed in millimetres or metres.

When the American system of units is used on building drawings such as floor plans, measurements are expressed in feet, inches, and fractions of an inch. This is referred to as *architectural practice*. There are 12 in. in 1 ft. A′ mark after a number indicates a measurement in feet. If the number is followed by ″, it represents a dimension in inches. Architectural dimensions may be expressed in feet and inches or in inches; for example a dimension of 3′6″ may be expressed as 42″. The standard on construction drawings is to use feet and inches.

Building dimensions are normally shown on the architectural drawings from which all measurements should be taken. Be sure to confirm dimensions with the owner or architect when exact positioning of equipment is required.

SCALE

A drawing of an object that is the same size as the object is said to be drawn full scale or at a scale of 1:1.

Construction drawings reduce the size of a building down to fit on a piece of paper by drawing everything proportionally smaller than it actually is. This is called *reduced scale*. A drawing that uses a scale of 1:50 indicates that the building is 50 times larger than the drawing. A drawing with a scale of $\frac{1}{4}$ in. = 1 ft. has a scale of 1:48.

Enlarged scale would produce a drawing larger than the actual object. Printed circuit boards are drawn using enlarged scale since many of the components used in the manufacture of printed circuit boards are very small. An example of enlarged scale is 2:1, which indicates the drawing is twice as large as the component.

Types of Scales (Measuring Instruments)

Three types of scales are commonly used on construction drawings. When the drawing is in feet and inches, an architectural scale is used. Fig. 2–10 shows a portion of an architect's triangular scale showing the $\frac{1}{8}$″ and $\frac{1}{4}$″ scales.

For metric drawings, a metric scale is used. For working with civil drawings (e.g., roads, dams, bridges), an engineering scale is used. Table 2–1 lists common construction drawing scales.

Fig. 2–11 gives examples of reading scales.

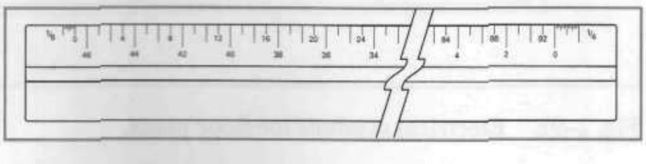


Fig. 2–10 Architect's scale.

METRIC	ARCHITECTURAL	ENGINEERING
1:20	1/2″ = 1′0″	1″ = 10
1:50	1/4″ = 1′0″	1″ = 20
1:100	1/8″ = 1′0″	1″ = 30
1:200	1/16″ = 1′0″	1″ = 40
1:500	1/32″ = 1′0″	1″ = 50

Table 2–1 Common construction drawing scales.

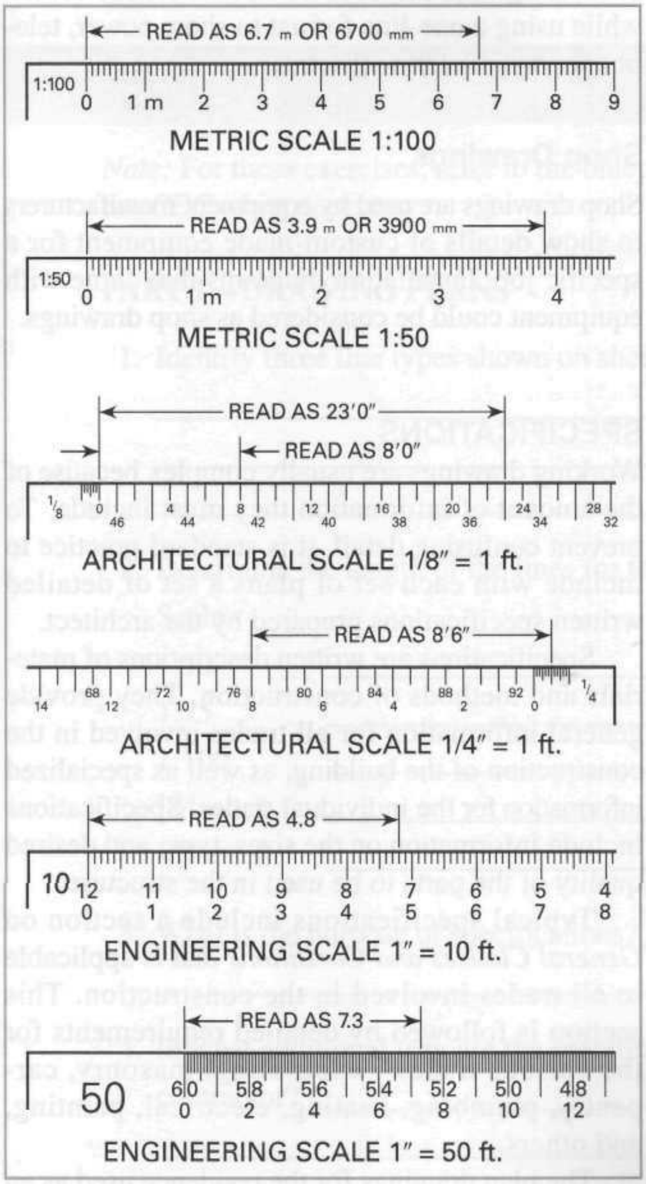


Fig. 2–11 Reading scales.

THE WORKING DRAWINGS

The architect or engineer uses a set of working drawings or plans to make the necessary instructions available to the skilled trades that are to build the structure. The plans show sizes, quantities, and locations of the materials required and the construction features of the structural members. Each skilled construction trade—masons, carpenters, electricians, and others—must study and interpret these details of construction before the actual work is started.

The electrician must be able to convert the two-dimensional plans into an actual electrical installation and visualize the many views of the plans and coordinate them into a three-dimensional picture, as shown in Fig. 2–3.

The ability to visualize an accurate three-dimensional picture requires a thorough knowledge of blueprint reading. Since all of the skilled trades use a common set of plans, the electrician must be able to interpret the lines and symbols that refer to the electrical installation and also to interpret those used by the other construction trades. The electrician must know the structural makeup of the building and the construction materials to be used.

The Drawing Set

A set of drawings is made up of several numbered sheets. If there are many sheets in a set, it will be broken down into subsets of architectural, electrical, mechanical, etc. The electrical drawings will be numbered E-1, E-2, E-3, etc.

A typical set of construction drawings includes the following.

A Site (Plot) Plan

The site plan shows

- the dimensions of the lot
- a north-pointing arrow
- the location of utilities and their connection points
- any outdoor lighting
- easements (rights to the property by someone other than the owner)
- contour lines to show changes in elevation
- accessory buildings
- trees to be saved

Floor Plans

Depending on the complexity of the building, a set of drawings for a single-family dwelling may have only a single floor plan for each storey of the building. As the complexity of the building increases there will be a number of floor plans for each storey (one for each trade). A logical breakdown would be

architectural
electrical
mechanical
plumbing
HVAC (heating, ventilating, and air conditioning)
structural

On very complex installations, each electrical system such as power, lighting, voice/data, fire alarm, and security/access control may have its own plan for each storey.

Use architectural floor plans to find room measurements, wall thickness, the sizes of doors and windows, and the swing of doors. The floor plans of other trades will show the locations of the equipment associated with that trade.

Elevations

Elevations show the vertical faces of buildings, structures, and equipment. Elevations are used to show both interior and exterior vertical faces. Sheet 7 of the drawings that accompany this textbook shows elevations of the kitchen cupboards. On sheet 1 you will find the elevations (south, north, east, and west) of the building.

Details and Sections

Details are large-scale drawings that are used when floor plans and elevations cannot provide sufficient detail. Sheet 8 provides details of the requirements for the installation of a swimming pool. Sheet 7 shows details of the bathroom vanities as well as of the kitchen cabinets. Sections show internal details of construction. See Section A-A on sheet 4.

Legend of Symbols

A legend of symbols provides the contractor or electrician with the information to interpret the symbols on the drawing.

Schedules

Schedules are lists of equipment. The door schedule on sheet 7 of the plans describes the size and types of doors required for the house. Electrical schedules are made for such equipment as lighting fixtures (luminaires), panelboards, raceways and cables, motors, and mechanical equipment connections.

Diagrams

One-line and riser diagrams are provided to quickly show the flow of power throughout the building. Riser diagrams are used to show vertical details while using a one-line format to show power, telephone, or fire alarm systems.

Shop Drawings

Shop drawings are used by equipment manufacturers to show details of custom-made equipment for a specific job. Installation diagrams that come with equipment could be considered as shop drawings.

SPECIFICATIONS

Working drawings are usually complex because of the amount of information they must include. To prevent confusing detail, it is standard practice to include with each set of plans a set of detailed written specifications prepared by the architect.

Specifications are written descriptions of materials and methods of construction. They provide general information for all trades involved in the construction of the building, as well as specialized information for the individual trades. Specifications include information on the sizes, type, and desired quality of the parts to be used in the structure.

Typical specifications include a section on *General Clauses and Conditions* that is applicable to all trades involved in the construction. This section is followed by detailed requirements for the various trades—excavating, masonry, carpentry, plumbing, heating, electrical, painting, and others.

The plan drawings for the residence used as an example for this text are included in the back of the text. The specifications for the electrical work indicated on the plans are given in Appendix A.

In the electrical specifications, the list of standard electrical parts and supplies frequently includes manufacturers' names and catalogue numbers of the specified items. This ensures that these items will be the correct size, type, and electrical rating, and that the quality will meet a certain standard. To allow for the possibility that the contractor may be unable to obtain the specified item, the words "or equivalent" are usually added after the manufacturer's name and catalogue number.

The specifications are also useful to the electrical contractor as all of the items needed for a specific job are grouped together and the type or size of each item is indicated. This information allows the contractor to prepare an accurate cost estimate without having to find all of the data in the plans.

REVIEW

Note: For these exercises, refer to the blueprints provided with this textbook. Also, refer to the *CEC* when necessary.

PART 1—DRAWING PLANS

1. Identify three line types shown on sheet 2.

____

____

____

2. Determine the length of the lines for the following.

Scale		Length
1:50	______________	______
1:75	______________	______
1:100	______________	______
$^1/_8'' = 1$ ft.	______________	______
$^1/_4'' = 1$ ft.	______________	______

3. What is the purpose of specifications? ______________________________

____

4. In what additional way are the specifications particularly useful to the electrical contractor? ______________________________

____

5. What is done to prevent a plan from becoming confusing because of too much detail?

____

____

6. Name three requirements contained in the specifications regarding material (Appendix A).

a. ______________________________

b. ______________________________

c. ______________________________

7. What are the two main hazards that the *CEC* is designed to prevent?

   a. ______________________ b. ______________________

8. What phrase is used when a substitution is permitted for a specific item in a specification?

   ____

   ____

9. What is the purpose of an electrical symbol? ______________________

   ____

10. What is a notation? ______________________________________

    ____

11. List five electrical notations found on the plans for the residence used as an example in this book. Refer to the blueprints provided with this textbook.

    1 ____
    2 ____
    3 ____
    4 ____
    5 ____

PART 2—STRUCTURAL FEATURES

1. To what scale is the basement plan drawn? ______________________
2. What is the size of the footing for the steel support columns in the basement?

   ____

3. To what kind of material will the front porch lighting bracket fixture be attached?

   ____

4. Give the size, spacing, and direction of the ceiling joists in the workshop.

   ____

5. What is the size of the lot on which this residence is located? ______________________
6. In what compass direction is the front of the house facing? ______________________
7. How far is the front garage wall from the curb? ______________________
8. How far is the side garage wall from the property lot line? ______________________
9. How many steel support columns are in the basement, and what size are they?

   ____

10. What is the purpose of the I-beams that rest on top of the steel support columns?

    ____

11. Is the entire garage area to have a concrete floor? ______________________

12. Where is access to the attic provided? ______________________

13. Give the thickness of the outer basement walls. ______________________

14. What material is indicated for the foundation walls? ______________________

____

15. Where are the smoke detectors located in the basement? ______________________

____

16. What is the ceiling height in the basement workshop from bottom of joists to floor?

____

17. Give the size and type of the front door.

____

18. What is the stud size for the partitions between the bathrooms in the bedroom area where substantial plumbing is to be installed? ______________________

____

____

19. Who is to furnish the range hood? ______________________

20. Who is to install the range hood? ______________________

UNIT 3

Service Entrance Calculations

OBJECTIVES

After this studying this unit, the student will be able to

- determine the total calculated load of the residence
- calculate the size of the service entrance conductors, including the size of the neutral conductors
- understand the *CEC* requirements for services, *Rule 8–200*
- fully understand special *CEC* rules for single-family dwelling service entrance conductor sizing
- perform an optional calculation for computing the required size of service entrance conductor for the residence

Before calculating the ampacity of service and service entrance conductors required for the residence, you must take an inventory of all loads in excess of 1500 watts. The calculations are based on the *CEC*. Always consult local electrical codes for any variations in requirements that may take precedence over the *CEC*.

SIZE OF SERVICE ENTRANCE CONDUCTORS AND SERVICE DISCONNECTING MEANS*

Service entrance conductors (*Rule 8–200*) and the disconnecting means shall not be smaller than

1. 60-ampere, three-wire, for a single-family dwelling where the floor area, excluding the basement floor area, is less than 80 m^2, *Rule 8–200(1)(b)(ii)*.
2. 100-ampere, three-wire, for a single-family dwelling when the floor area, excluding the basement floor area, is more than 80 m^2, *Rule 8–200(1)(b)(i)*.

The load on a residential service is a noncontinuous load, *Rule 8–200(3)*. This means that the service conductors, the service switch, and the panel are sized based on the demand amperes. To correctly calculate the demand amperes for the service, you must follow the steps listed in *Rule 8–200(1)(a)*.

Step 1. Calculate the basic load based on the living area of the house, *Rule 8–200(1)(a)(i)*.

Step 2. Calculate the electric space-heating load and the air-conditioning load. Use the larger of these loads in calculating the demand if you know that they cannot be used at the same time, *Rule 8–106(4)*. If it is possible for the electric heat and the air conditioning to operate at the same time, you must include both loads in calculating the demand. If baseboard heating is used with individual thermostats in each room or area, refer to *Rule 62–116(2)* for demand watts. If the residence has an electric furnace, the load must be included at 100% of its rating, *Rule 62–116(1)*.

* (Courtesy of CSA Group)

Step 3. Calculate the load for the electric range or the combined load for a separate cooktop and oven.

Step 4. Add the kilowatt rating of any swimming pool heaters or hot-tub and spa heaters. In this case there should be no derating, *Rule 8–200(1)(a)(v)*.

Step 5. Electric vehicle-charging equipment is loaded at 100%, *Rule 8–200(1)(a)(vi)*.

Step 6. A demand factor of 25% must be applied to any additional loads in excess of 1500 watts if an electric range is included. If there is no electric range because the residence has a gas range, the first 6-kW loads in excess of 1500 watts are added at 100%. If the load is greater than 6 kW, the remainder should be added at 25%, *Rule 8–200(1)(a)(vii)*.

For clarity, these calculations have been summarized in Tables 3–1 and 3–2. No electric vehicles are called for in the drawings, so there are no references to loading or equipment in the tables.

SERVICE CALCULATIONS FOR A SINGLE-FAMILY DWELLING, *RULE 8–200*: CALCULATING FLOOR AREA

Ground-Floor Area

To estimate the total basic load for a dwelling, you must calculate the occupied floor area of the dwelling. Note in the residence plans that the ground-floor area has an irregular shape. In this case, the simplest method of calculating the occupied floor area is to determine the total floor area using the inside dimensions of the dwelling. Then, subtract open porches, garages, and

SERVICE CALCULATION		
	Demand Watts	**Demand Watts**
Load	Line 1, Line 2	Neutral (Min.)
Basic	7 000 W	7 000 W
Heat	13 000 W	—
Range	6 820 W	6 820 W
Other—Dryer	1 425 W	1 425 W
—Water Heater	750 W	—
—Water Pump	600 W	—
	29 595 W	15 245 W
Line 1-2; I = P/E	29 595/240 = 123.3 A	
Neutral; I = P/E		15 245/240 = 63.52 A

Table 3–1 Demand watts calculation for service and neutral conductor.

MINIMUM CODE REQUIREMENTS FOR A SERVICE		
Reference	**Minimum Service Calculation**	**Panel A for Residence**
Minimum service ampacity, *Rule 8–104(1)*	123.3 A	200 A
Minimum service switch	200 A	200 A
Minimum fuse or breaker, *Table 13*	125 A	200 A
Minimum ground conductor, *Rule 10–812*	No. 6 copper	No. 6 copper
Minimum bonding jumper, *Table 41*	No. 6 copper	No. 6 copper
Minimum AWG L1, L2, *Table 2*	No. 2 RW90	No. 2/0 RW90
Minimum AWG neutral, *Table 2*	No. 6 RW90	No. 2/0 RW90
Minimum conduit size, *Tables 8, 9, 10*	27-mm	41-mm
Minimum panel ampacity	125 A	200 A
Minimum number of circuits, *Rule 8–108(1)(c)*	30	30

Table 3–2 Service requirements.

other unfinished or unused spaces from the total area if they are not adaptable for future use, *Rule 8–110*.

Many open porches, terraces, patios, and similar areas are commonly used as recreation and entertainment areas. Therefore, adequate lighting and receptacle outlets must be provided.

To simplify the calculation, the author has chosen to round off dimensions for those areas (garage, porch, and portions of the inset at the front of the house) not to be included in the computation of the general lighting load.

Fig. 3–1 shows the procedure for calculating the watts needed for the ground floor of this residence.

For practical purposes, the outside dimensions of this building could be taken as being 17 m and 11 m.

Basement Area

The basement area of the home contains the furnace, the hot water tank, and other service equipment. According to *Rule 8–110*, only 75% of the inside dimensions are to be used in calculating the living area of the basement because 25% houses the above equipment.

For our calculations, we make these assumptions:

a. Basement walls are 305 mm thick.
b. Garage is unexcavated so that additional support for the weight of vehicles is not required.

On this basis our calculations can be made as follows:

Ground-Floor Area

16.765 − (0.1 + 0.1) m = 16.565 m
10.670 − (0.1 + 0.1) m = 10.470 m

16.765 m × 10.470 m = 175.5 m^2

Less area not included:
2.135 m × 3.675 m = – 7.85 m^2
3.255 m × 3.740 m = –12.17 m^2
3.255 m × 4.775 m = –15.54 m^2

Total ground-floor area 139.9 m^2

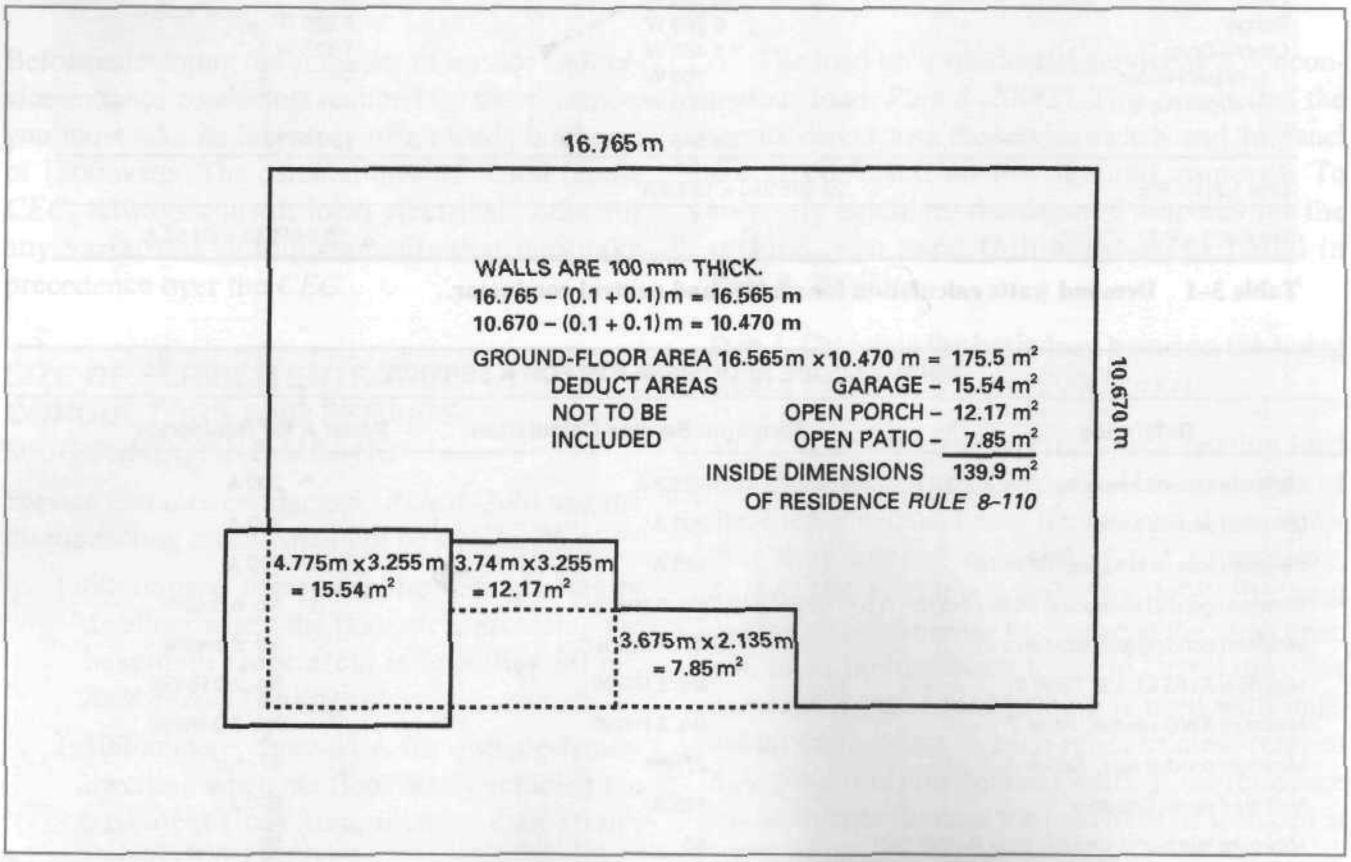


Fig. 3–1 Determining the ground-floor living area to be used to calculate basic load, *Rule 8–110*.

Basement Area

17.045 – (0.305 + 0.305) m = 16.435 m
10.945 – (0.305 + 0.305) m = 10.34 m

16.435 m × 10.34 m = 169.94 m²

Less area not included:
2.1 m × 3.75 m = – 7.88 m²
3.45 m × 3.2 m = –11.04 m²
3.2 m × 4.71 m = –15.07 m²

Total basement area 135.95 m²

Basic Load Calculations, *Rule 8–200(1)(a)(i,ii)*

For this calculation, *Rule 8–200(1)(a)(i,ii)* requires that the load be based on 100% of the living area on the ground floor plus 75% of the living area in the basement.

Area to be considered:
100% of ground floor (139.9 m²) 139.9 m²
75% of the basement area
(135.95 m²) 101.96 m²
Total area 241.86 m²

Total area = 241.86 m²
1st 90 m² = 5000 W

This leaves 151.86 m² (241.86 m² – 90 m²)

An additional 1000 W must be added for each 90 m² *or portion thereof* in excess of 90 m². Since 151.86/90 = 1.7, use 2 times.

2 × 1000 W = 2000 W

A. Basic load = 5000 W + 2000 W = 7000 W

Electric furnace and air conditioning, *Rule 8–200(1)(a)(iii)*

Since you know that the air conditioning and heating will not be used simultaneously, use whichever is the greater load in calculating the demand, *Rule 8–106(4)*. Therefore, if the air conditioner load is less than the heating load, it need not be included in the calculations. Air conditioner load is

30 amperes × 240 volts = 7200 W

This is less than the heating load.

The electric furnace for this home is applied at a demand of 100%, based on *Rule 62–116(1)*. If this home had been heated with baseboard heaters, we would have been able to derate the amount over 10 kW at a demand factor of 75%, *Rule 62–116(2)(a)*.

B. Electric furnace = 13 000 W

Electric range or wall-mounted oven and counter-mounted cooking unit combined, *Rule 8–200(1)(a)(iv)*

Wall-mounted oven = 6600 W
Counter-mounted cooking unit = 7450 W
Total = 14 050 W (14.05 kW)
For rating of 12 kW or less load = 6000 W
Add 2.05 kW × 40% = 820 W

C. Range load = 6820 W

D. Dryer 5700 W × 25% = 1425 W

E. Water heater 3000 W × 25% = 750 W

F. Pump 2400 W × 25% = 600 W

A + B + C + D + E + F = Total demand load = 29 595 W

Summary of Calculations

Step 1: Basic Load
241.86 m²
–90 m² 1st 90 m² = 5 000 W
151.86 ÷ 90
= 1.7 or 2 × 1 000 = 2 000 W
Demand watts = 7 000 W **7 000 W**

Step 2: Heat 13 000 W **13 000 W**
(electric furnace @ 100%)

Step 3: Range 1st 12 kW = 6 000 W
2.05 kW × 40% = 820 W
Demand watts = 6 820 W **6 820 W**

Step 4: Other Loads:
Dryer × 25% = 1 425 W
Water Heater × 25% = 750 W
Pump × 25% = 600 W
Demand watts = 2 775 W **2 775 W**

Total load (demand watts) **29 595 W**

Service Entrance Conductor Size

The ungrounded conductors are sized from *CEC Table 2* for copper wires and *Table 4* for aluminum. It is common to have aluminum conductors installed up to the line side of the meter base and from the load side of the meter base into the panel.

Take care in this type of installation to ensure that the aluminum conductors are installed in lugs rated and approved for the purpose, *Rule 12–118(3).*

An appropriate joint compound, for example, Pentrox™, must be used to penetrate the oxide film and prevent it from re-forming when terminating or splicing all sizes of stranded aluminum conductors, *Rule 12–118(2).*

It is important to follow the requirements of *Rule 2–130.* All conductors that are exposed to direct sunlight must be approved for the purpose. Conductors that are approved for exposure to sunlight will be surface-marked appropriately.

Neutral Conductor

According to *Rule 4–024(1),* the neutral conductor is sized according to the unbalanced load on the service. This wire shall be the larger of the bonding conductor, sized from *CEC* as specified in *Rule 10–204(2),* or the calculated ampacity as determined from the demand watts calculation shown in Table 3–1 on page 24. In this example, both methods require a minimum #6 AWG conductor.

This conductor may be run bare provided it is made of copper and is run in a raceway, *Rule 6–308(a).* Verify with your local inspection authority before proceeding.

The neutral conductor is sized by the maximum unbalanced load between line 1, line 2, and the neutral.

This means that 240-volt loads are not included in calculating the demand watts on the neutral. These may include

- central air conditioner
- electric furnace
- water pump
- water heater

Since some utilities do not allow a reduction in the size of the neutral conductor for services less than 200 amperes, check with provincial codes or the local inspection authority before proceeding with a reduced neutral installation.

Consumer Service Ampacity Rating

The minimum rating of a consumer service is based on a comparison between the overcurrent device and the ampacity of the line conductors.

Whichever is the lower value determines the ampacity rating of the service. This would also apply for branch circuits or feeders, *Rule 8–104(1).*

Main Service Switch

The main disconnect for a service is described in the *CEC* as the service box. This could be a separate switch containing fuses or a circuit breaker. In reality it is more commonly installed as a combination panel comprising the service entrance portion and the distribution portion.

The standard available sizes of disconnecting means are 30 amperes, 60 amperes, 100 amperes, 200 amperes, and 400 amperes.

Optional available sizes are 125-ampere and 225-ampere panels. However, most residential applications are now either 100 amperes or 200 amperes. Using the demand watts calculation in Table 3–1, it is determined that a 125-ampere service would be sufficient for this residence. This would, however, leave little room for future growth, such as an outbuilding for a workshop or a hot tub. For this reason, it has been decided that a 200-ampere service will be installed.

Main Service Fuse or Circuit Breaker (*Table 13*)

The size of the main fuse or circuit breaker is based on the ampacity of the line conductors, as found in *Table 2.* This ampacity is used to determine the size of the fuse or circuit breaker from *Table 13, Rule 14–104(1)(a).*

Main Service Ground (*Table 16*)

The main service ground is sized from *Table 16* (see Table 3–3), and is based on the ampacity of the line 1 and line 2 conductors, *Rule 10–206(1).*

CEC Table 16

MINIMUM SIZE CONDUCTORS FOR BONDING CONDUCTORS

(See *Rules 10–204, 10–626, 10–814, 10–816, 10–906, 12–1814, 24–104, 24–202, 30–1030, 68–058,* and *68–406.*)

Ampacity, A, of largest ungrounded conductor in the circuit or equivalent for multiple parallel conductors not exceeding	Size of bonding conductor	
	Copper wire, AWG	Aluminum wire, AWG
20	14	12
30	12	10
40	10	8
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	0
600	1	00
800	0	000
1000	00	0000
1200	000	250 kcmil
1600	0000	350 kcmil
2000	250 kcmil	400 kcmil
2500	350 kcmil	500 kcmil
3000	400 kcmil	600 kcmil
4000	500 kcmil	800 kcmil
5000	700 kcmil	1000 kcmil
6000	800 kcmil	1250 kcmil

NOTE: The ampacity of the largest ungrounded conductor, or the equivalent if multiple conductors are used, shall be determined from the appropriate Table in the *Code*, taking into consideration the number of conductors in the raceway or cable and the type of insulation.

Table 3–3 ***CEC Table 16:*** **Minimum size of conductors for bonding conductors.** (Courtesy of CSA Group)

Main Service Bonding Conductor (*Table 41*)

The bonding jumper for metallic service raceways is sized from *Table 41* and is based on the ampacity of the largest service conductor, *Rule 10–614(1)(a,b)*. This jumper connects the service raceway by means of a ground bushing to the metal enclosure. Accordingly, it provides a low impedance path for adequate bonding to prevent dangerous conditions that may result from equipment failure or lightning strikes.

Main Service Conduit Size (*Tables 8, 9, and 10*)

The minimum size conduit for the service entrance is based on 40% conduit fill (*Table 8*). The total area of the conductors is calculated using *Table 10*. Then the 40% column in *Table 9* is used to find the minimum size of the raceway. If all the conductors are the same type and size, *Table 6* may be used to size the raceway. For this service, a 41-mm conduit is adequate for the three No. 2/0 RW90 conductors.

Note that the service mast is usually 63-mm rigid metal, but the conduit from the meter base into the panel must be sized using the method described.

Main Service Panel Ampacity and Number of Circuits

The ampacity of the service panel is based on the ampacity of the main service switch, for example, a 100-ampere switch and a 100-ampere panel.

The minimum number of circuits for the panel is listed in *Rule 8–108(1)*. In this case, the 200-ampere service requires a minimum of 30 circuits, *Rule 8–108(1)(c)(ii)*. If the house had been heated with baseboard heaters, it would have required 40 circuits. The baseboard heaters would have required a number of two-pole breakers (30 amperes maximum), whereas a central furnace could be fed by a 70-ampere two-pole breaker, taking up only two positions.

Rule 8–108(2) states that two additional spaces must be left for future overcurrent devices. This is sometimes interpreted to mean that two circuits must be added to the required number in *Rule 8–108(1)*, but for the purposes of this calculation *Rule 8–108(2)* is satisfied by leaving two spaces available in the 30-circuit panel. These two spaces could be used to feed a future subpanel.

According to *Table 2*, AWG R90 XPLE (without jacket) will be the minimum size of conductor for the 29 595 watt (123.3 ampere) load.

For the service to be 200 amperes, No. 2/0 AWG RW90 (200-ampere) will be required. According to *Table 2*, the minimum size neutral is No. 6 (RW90, is good for up to 75 amperes).

The 240-volt loads are not to be included in the calculation for neutral conductors.

Calculation for Subpanel B

The calculation for the subpanel is based on the load supplied. *Rule 6–102(1)* allows for only one service to be installed to the residence. We cannot apply *Rule 8–200* to a subpanel because that rule must be applied to the whole house.

We must provide enough power at the second panel to handle the known loads. Based on the circuit schedule for Panel B in Fig. 4–13 on page 44, a 60-ampere panel would be adequate for the load. However, if the dryer, oven, and range were operated at the same time, the subpanel feeder breaker could be overloaded and trip. Therefore, the recommended feeder to Panel B is 100 amperes.

To install a 100-ampere panel, we need No. 3 R90 XLPE (without jacket). From *Table 6*, three No. 3 T90 require 27-mm conduit.

Checking the specifications and also Fig. 4–2 on page 35, we find that three No. 3 R90 XLPE (without jacket) conductors supply Panel B.

Main Disconnect

The main disconnect in the residence is a 200-ampere combination panel. Many electric utilities state that the conductors feeding this type of disconnect must have the same ampere rating as the disconnect. Some utilities also state that the neutral conductor cannot be reduced in size because it is not always possible to foresee the type of load that may be connected to the panel. As a result, it is sometimes difficult to conform to all the rules of the electric utility as well as the local electrical code. By installing three No. 2/0 RW90 conductors for the line and neutral conductors, you will satisfy most local and provincial electrical code requirements.

Grounding Electrode Conductor

The grounding electrode conductor connects the main service equipment neutral bar to the grounding electrode. The grounding electrode might be the underground metallic water piping system, a driven ground rod, or a concrete-encased ground. All of this is discussed in Unit 4.

Grounding electrode conductors are sized according to *Table 16*.

For example, a residence is supplied by No. 2/0 AWG copper service entrance conductors. Checking *CEC Rule 10–12*, we find that the minimum grounding electrode conductor must be a No. 6 AWG copper conductor.

SERVICE CALCULATIONS FOR APARTMENTS

Often, single-family homes are constructed or renovated to divide the space into two or more units. This type of building is considered to be an apartment building and requires that the services be calculated according to *Rule 8–202*.

For this example, we assume that our building is constructed with a completely independent apartment in the basement. The living area has not changed.

The heat will be changed to electric baseboard heaters with 7.5 kW located in the ground-floor unit and 5.5 kW in the basement. The floor plans will be modified so that all loads previously allocated to the service will be connected to the ground-floor unit service. The basement unit will have a 3-kW water heater and a 12-kW range. Laundry facilities will not be available in the basement unit.

The service calculation for an apartment unit is almost identical to that of a single dwelling. The only difference is in the basic load calculation.

Ground-Floor Unit

Basic load based on a floor area of 139.9 m^2

First 45 m^2	3500 watts	
Next 45 m^2	1500 watts	
Next 90 m^2 or portion	1000 watts	
Total Range	6000 watts	6 000 watts

First 12 kW	6000 watts	
Remaining 2.05 kW × 40%	820 watts	
Total	6820 watts	6 820 watts
Other loads		
Dryer × 25%	1425 watts	
Water heater × 25%	750 watts	
Pump × 25%	600 watts	
Total	2775 watts	2 775 watts
Subtotal		15 595 watts
Electric heat		7 500 watts
Grand total		23 095 watts

Basement Unit

Basic load based on a floor area of 180.98 m^2

First 45 m^2	3500 watts	
Next 45 m^2	1500 watts	
Next 90 m^2 or portion	1000 watts	
Total Range	6000 watts	6 000 watts
First 12 kW	6000 watts	6 000 watts
Other loads		
Water heater × 25%	750 watts	750 watts
Subtotal		*12 750 watts*
Electric heat × 100%		5 500 watts
Grand total		18 250 watts

To determine the ampacity of the service for the ground floor:

$$\frac{\text{Demand watts}}{\text{System voltage}} = \frac{23\,095 \text{ watts}}{240 \text{ volts}} = 96.2 \text{ amperes}$$

Therefore, a 100-ampere service would be acceptable. However, the installer may wish to increase the service to 125 amperes to allow for future growth.

To determine the ampacity of the basement unit service:

$$\frac{\text{Demand watts}}{\text{System voltage}} = \frac{18\,250 \text{ watts}}{240 \text{ volts}} = 76 \text{ amperes}$$

Therefore a 100-ampere service would be installed.

This type of service installation usually is in the form of a single consumer service, divided into several parts in a multigang meter socket and terminating in separate service boxes. The ampacity of the consumer service conductors is not the sum of the individual services, but a calculation based on the individual demand loads and *Rule 8–202(3)*. To perform this calculation, we must begin with the demand of each unit, without any electric heat or air-conditioning loads.

The calculation is

100% of the largest unit = 15 595 × 100% =	15 595 watts
65% of the next largest unit = 12 750 × 65% =	8 287.5 watts
Subtotal	23 882.5 watts

Add the electric heat as outlined in *Rule 62–116(2)*

Total installed electric heat =	7.5 kW + 5.5 kW = 13 kW
100% of the first 10 kW = 10 kW × 100% =	10 000 watts
75% of the remaining 3 kW = 3 kW × 75% =	2 250 watts
Subtotal	12 250 watts
Grand total	36 132.5 watts

Minimum Service Ampacity

$$\frac{\text{Calculated demand}}{\text{System voltage}} = \frac{36\,132.5 \text{ watts}}{240 \text{ volts}} = 150.6 \text{ amperes}$$

The minimum consumer service ampacity is considerably less than the sum of the individual services. For this application, the installer would normally install a 200-ampere service to allow for future growth.

REVIEW

Note: Refer to the *CEC* or the the blueprints provided with this textbook when necessary.

1. When a service entrance calculation results in a value of 15 kW or more, what is the minimum size service required by the *CEC*? ______________________

2. a. What is the demand load per 90 m^2 for the general lighting load of a residence?

   b. What are the demand factors for the baseboard heating load in dwellings?

3. a. What is the ampere rating of the circuits that are provided for the lighting and power loads? ______________________

   b. What is the maximum number of outlets permitted on a 15-ampere branch circuit by the *CEC*? ______________________

   c. How many 15-ampere circuits are included in this residence? ______________________

4. Why is the air-conditioning load for this residence omitted in the service calculations? What is the rule number? ______________________

5. What demand factor may be applied to loads greater than 1500 watts, such as a clothes dryer and water heater, in addition to an electric range, *Rule 8–200(1)(a)(vi).*

6. What load may be used for an electric range rated at not over 12 kW?

7. What is the load for an electric range rated at 16 kW, *Rule 8–200(1)(a)(v)*? Show calculations.

8. What is the computed load when fixed electric heating is used in a residence? (*Rule 62–116*) ______________________

9. On what basis is the neutral conductor of a service entrance determined? ___________

____

____

____

10. Why is it permissible to omit an electric space heater, water heater, and certain other 240-volt equipment when calculating the size of the neutral service entrance conductor for a residence? ___________

____

____

____

11. Calculate the minimum size of service entrance conductors required for a residence containing the following: floor area 8 m × 12 m; 12-kW electric range; 5-kW dryer 120/240-volt; 2200-watt sauna heater, 120-volt; 12 kW of baseboard heaters with individual thermostat control, 240-volts; two 3-kW, 240-volt air conditioners; 3-kW, 240-volt water heater.

Determine the sizes of the ungrounded conductors and the neutral conductor. Use type RW90 copper conductors.

Two No. ________ RW90 ungrounded conductors

One No. ________ RW90 neutral (or bare neutral if permitted)

One No. ________ AWG system grounding conductor to water meter

STUDENT CALCULATIONS

Minimum service ampacity

Minimum switch

Minimum fuse or circuit breaker

Minimum bonding jumper

Minimum conduit size

Minimum panel ampacity

Minimum number of circuits in panel

UNIT 4

Service Entrance Equipment

OBJECTIVES

After studying this unit, the student will be able to

- define *electric service, supply service, consumer's service, overhead service,* and *underground service*
- list the various *CEC* rules covering the installation of a mast-type overhead service and an underground service
- discuss the *CEC* requirements for disconnecting the electric service using a main panel and load centres
- discuss the grounding of interior alternating current systems and the bonding of all service entrance equipment
- describe the various types of fuses
- select the proper fuse for a particular installation
- explain the operation of fuses and circuit breakers
- explain the term *interrupting rating*
- determine available short-circuit current using a simple formula
- perform cost-of-energy calculations
- understand how to read a watt-hour meter

An electric service is required for all buildings containing an electrical system and receiving electrical energy from a utility company. The *CEC* describes the term *service* in two ways: *consumer's service* and *supply service*.

A consumer's service is considered to be all of the wiring from the service box to the point where the utility makes connection. A service box is a main switch and fuses or the main breaker in a combination panel.

Section 0 defines a supply service as the single set of conductors run by the utility from its mains to the consumer's service. On an overhead service, this is usually from the transformer on the pole to the point of attachment on the service mast. With an underground service, this may be from the transformer to the line side of the meter base. If the electric utility defines the point of connection as the transformer, the wires that are run from the transformer to the meter base form part of the consumer's service. Always check with your local utility for the specific bylaws and requirements that pertain to services.

In general, watt-hour meters are located on the exterior of a building. Local codes may permit the watt-hour meter to be mounted inside the building. In some cases, all of the service entrance equipment may be mounted outside the building. This includes the watt-hour meter and the disconnecting means, *Rule 6–408.*

The electric utility generally must be contacted to determine the location of the meter, *Rule 6–408.* This will usually be within 1 m from the front of the house and 1.8 m above grade to the centre of the socket.

OVERHEAD SERVICE

An overhead supply service consists of the overhead service conductors (including any splices) that are connected from the mains of the supply authority to the service entrance conductors at the mast for the consumer's service.

A combination panel has two sections, the service box (service entrance portion) and the panelboard (the distribution portion); see Fig. 4–1.

In Fig. 4–1 there is a dashed line between the two portions of the combination panel. The panelboard (distribution portion of the combination panel) is not considered to be part of the service entrance wiring. Therefore, it is very important that all of the service entrance wiring enters only the service entrance portion of the panel.

Fig. 4–1 shows how a pad-mounted transformer feeds the service in the residence, which in turn feeds Panel B. Fig. 4–2 illustrates the *CEC* terms for the various components of a service entrance.

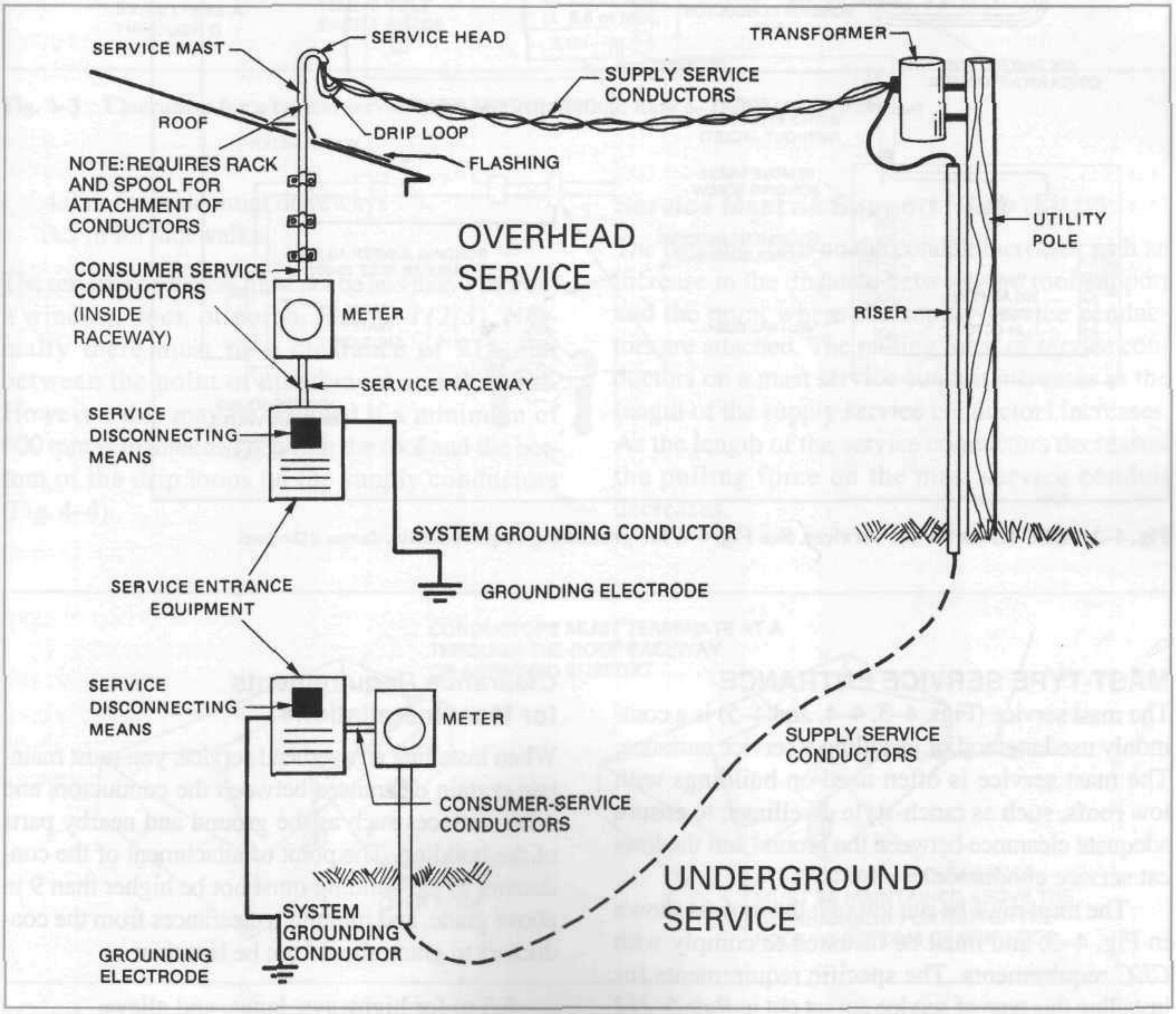


Fig. 4–1 Service entrance, main panel, subpanel, and grounding for the service in this residence. The metal water pipe from a public water main provides the best ground for a service, *Rule 10–700(1)(c).* (Courtesy of CSA Group)

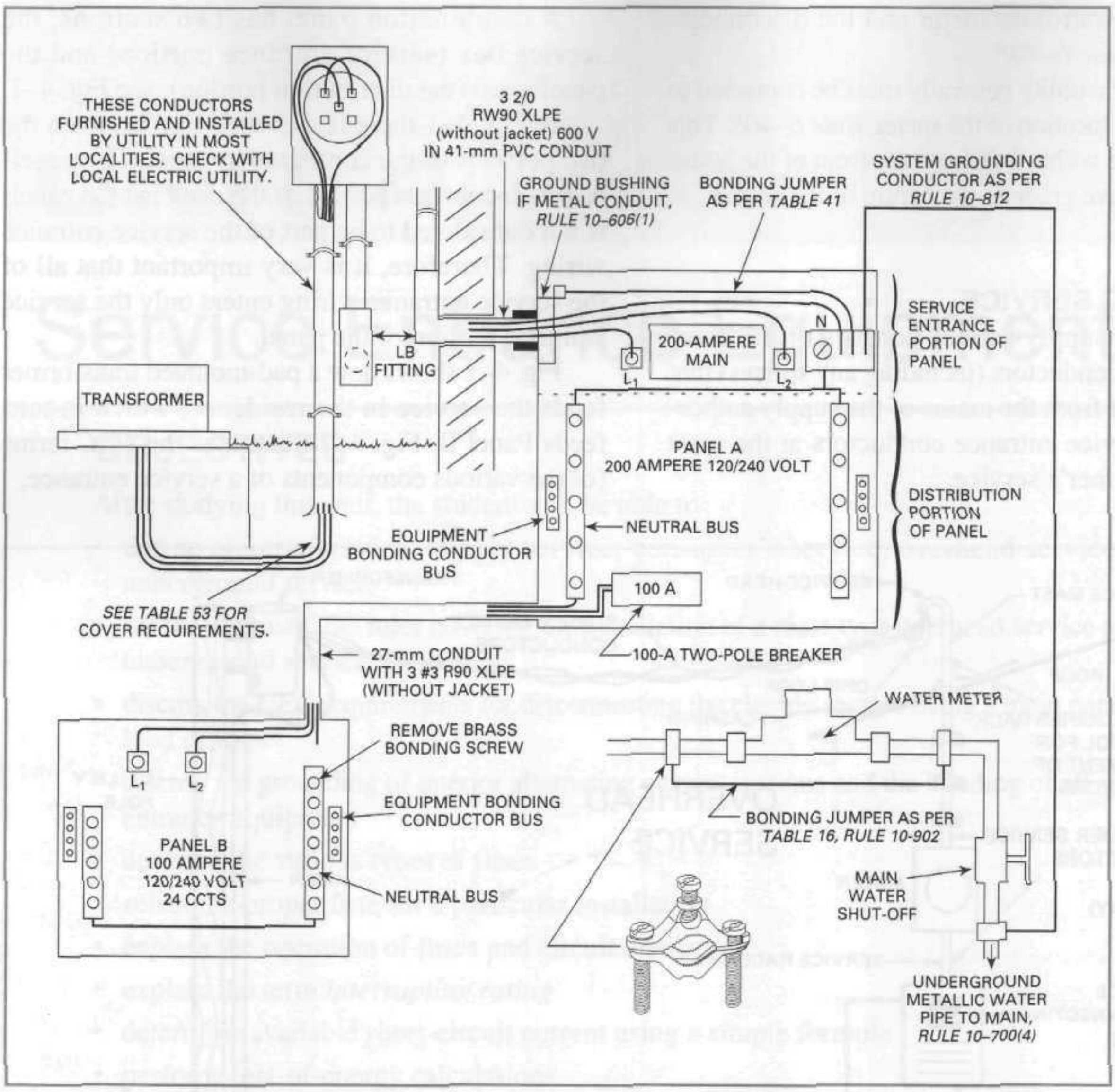


Fig. 4–2 ***CEC*** **terms for the services. See Fig. 4–6 for grounding requirements.** (Courtesy of CSA Group)

MAST-TYPE SERVICE ENTRANCE

The mast service (Figs. 4–3, 4–4, and 4–5) is a commonly used method of installing a service entrance. The mast service is often used on buildings with low roofs, such as ranch-style dwellings, to ensure adequate clearance between the ground and the lowest service conductor.

The mast must be run through the roof, as shown in Fig. 4–3, and must be fastened to comply with *CEC* requirements. The specific requirements for installing this type of service are set out in *Rule 6–112* and *Appendix B.*

Clearance Requirements for Mast Installations

When installing an overhead service, you must maintain certain clearances between the conductors and other surfaces such as the ground and nearby parts of the building. The point of attachment of the conductors to the building must not be higher than 9 m above grade, and minimum clearances from the conductors to grade should not be less than

5.5 m for highways, lanes, and alleys
5.0 m commercial and industrial driveways

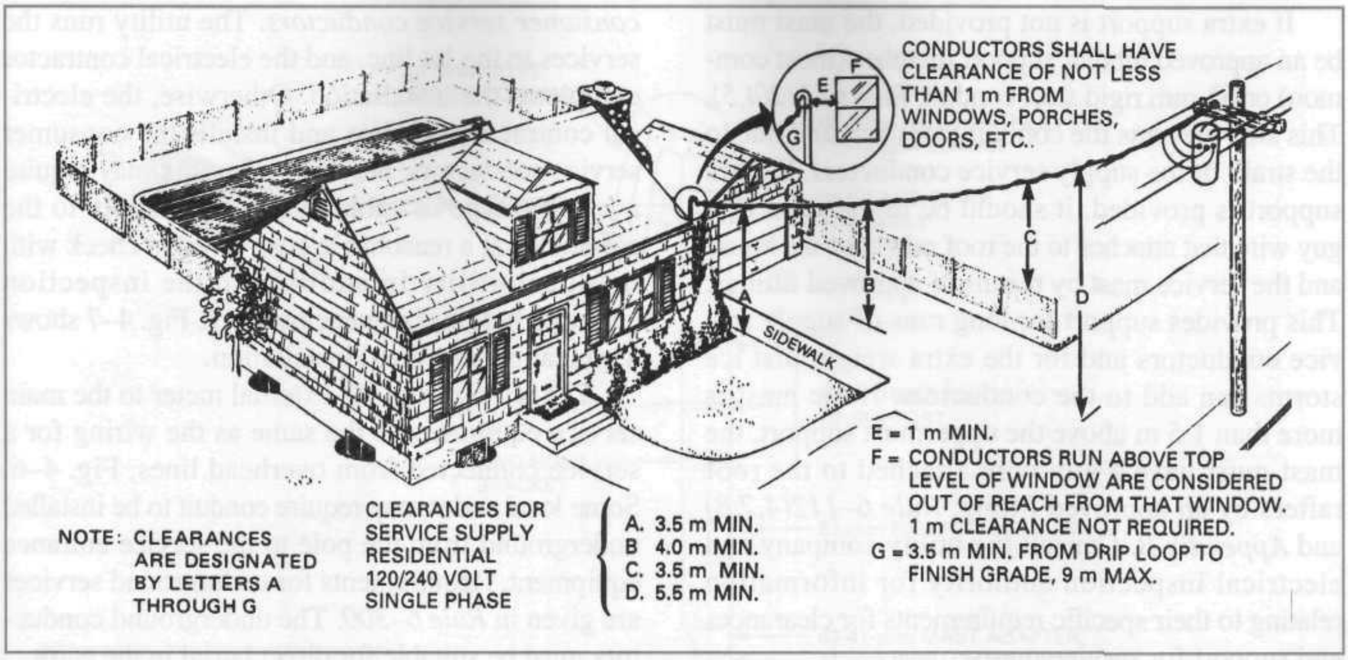


Fig. 4–3 Clearances for a typical service entrance installation, *Rule 6–112(2)*. (Courtesy of CSA Group)

4.0 m for residential driveways
3.5 m for sidewalks

The service conductors must not be less than 1 m from a window, door, or porch, *Rule 6–112(3)*. Normally there must be a clearance of 915 mm between the point of attachment and the roof. However, this may be reduced if a minimum of 600 mm is maintained between the roof and the bottom of the drip loops on the supply conductors (Fig. 4–4).

Service Mast as Support (*Rule 6–112*)

The bending force on the conduit increases with an increase in the distance between the roof support and the point where the supply service conductors are attached. The pulling force of service conductors on a mast service conduit increases as the length of the supply service conductors increases. As the length of the service conductors decreases, the pulling force on the mast service conduit decreases.

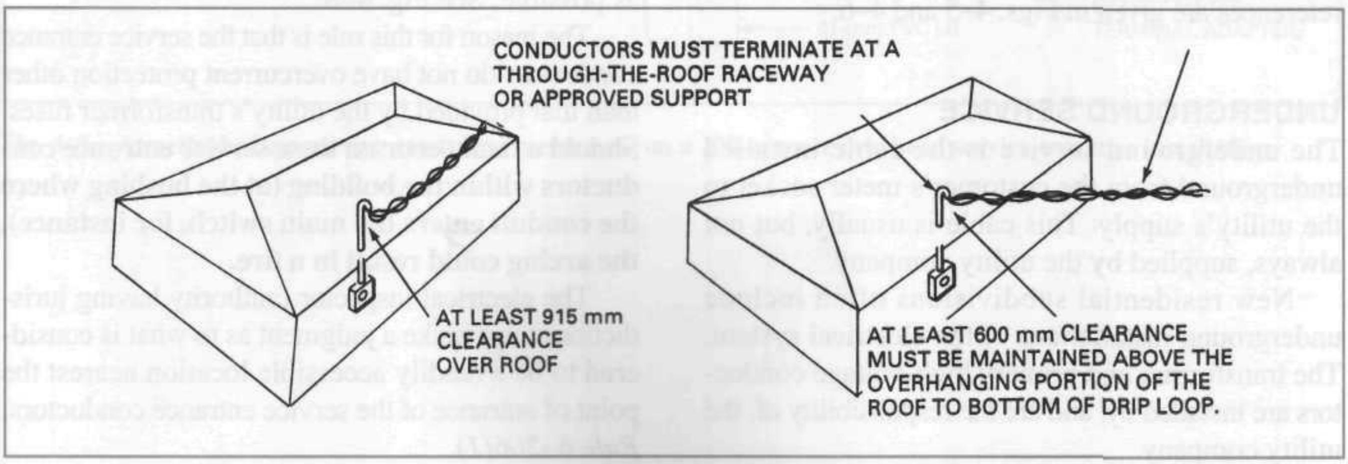


Fig. 4–4 Clearance requirements for consumer's service conductors passing over residential roofs, *Rule 6–112* and *Appendix B*, where voltage between conductors does not exceed 300 volts. (Courtesy of CSA Group)

If extra support is not provided, the mast must be an approved tubular support member (most common) or 63-mm rigid steel conduit, *Rule 6–112(4,5)*. This size prevents the conduit from bending due to the strain of the supply service conductors. If extra support is provided, it should be in the form of a guy wire that attaches to the roof rafters of the house and the service mast by means of approved fittings. This provides support for long runs of supply service conductors and for the extra weight that ice storms can add to the conductors. If the mast is more than 1.5 m above the uppermost support, the mast must have a guy wire attached to the roof rafters by an approved fitting, *Rule 6–112(4,7,8)* and *Appendix B*. Consult the utility company and electrical inspection authority for information relating to their specific requirements for clearances and support for service masts.

The *CEC* rules for installation and clearances apply to the supply service and consumer service conductors. For example, the service conductors must be insulated, except where the provisions of *Rule 6–308* are met and approved for exposure to direct sunlight as required by *Rule 2–130*. In this case, the grounded neutral conductors are not required to have insulation.

Rule 6–112 and *Appendix B* give clearance allowances for the supply service passing over the roof of a dwelling, Fig. 4–4.

The installation requirements for a typical service entrance are shown in Figs. 4–5 and 4–6. Fig. 4–3 shows the required clearances above the ground. The wiring connections, grounding requirements, and *CEC* references are given in Figs. 4–5 and 4–6.

UNDERGROUND SERVICE

The underground service is the cable installed underground from the customer's meter socket to the utility's supply. This cable is usually, but not always, supplied by the utility company.

New residential subdivisions often include underground installations of the electrical system. The transformer and primary high-voltage conductors are installed by, and are the responsibility of, the utility company.

The conductors installed between the pad-mounted transformers and the meter are called *consumer service conductors*. The utility runs the services to the lot line, and the electrical contractor completes the installation. Otherwise, the electrical contractor supplies and installs the consumer service conductors, but the local utility may require a specific type of cable that it may supply to the contractor at a reasonable cost. Always check with the local utility in addition to the inspection authority before commencing work. Fig. 4–7 shows a typical underground installation.

The wiring from the external meter to the main service equipment is the same as the wiring for a service connected from overhead lines, Fig. 4–6. Some local codes may require conduit to be installed underground from the pole to the service entrance equipment. Requirements for underground services are given in *Rule 6–300*. The underground conductors must be suitable for direct burial in the earth.

If the electric utility installs the underground service conductors, the work must comply with the rules established by the utility, *Section 0, Scope*. These rules may not be the same as *Rule 6–300*.

When the underground conductors are installed by the electrician, *Rule 6–300* applies. This rule deals with the protection of conductors against damage and sealing of underground conduits where they enter a building.

MAIN SERVICE DISCONNECT LOCATION

The main service disconnect means shall be installed at a readily accessible location so that the service entrance conductors within the building are as short as possible. See Fig. 4–8.

The reason for this rule is that the service entrance conductors do not have overcurrent protection other than that provided by the utility's transformer fuses. **Should a fault occur on these service entrance conductors within the building (at the bushing where the conduit enters the main switch, for instance), the arcing could result in a fire.**

The electrical inspector (authority having jurisdiction) must make a judgment as to what is considered to be a readily accessible location nearest the point of entrance of the service entrance conductors, *Rule 6–206(1)*.

Rule 2–100(3)(a) states that all panels must have a legible circuit directory indicating what the

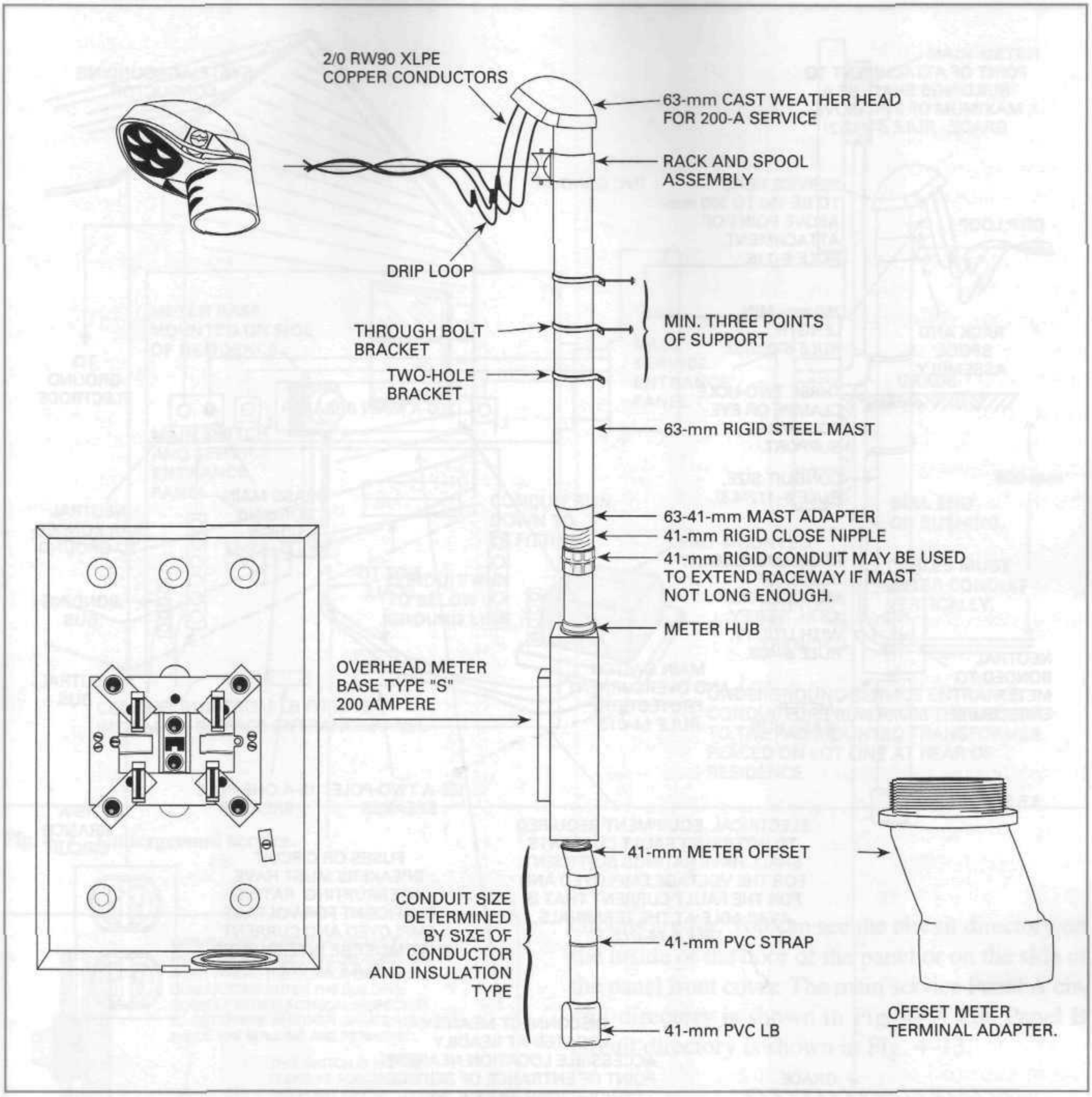


Fig. 4–5 A method of connecting conduit to meter base on a 200-ampere overhead service entrance installation.

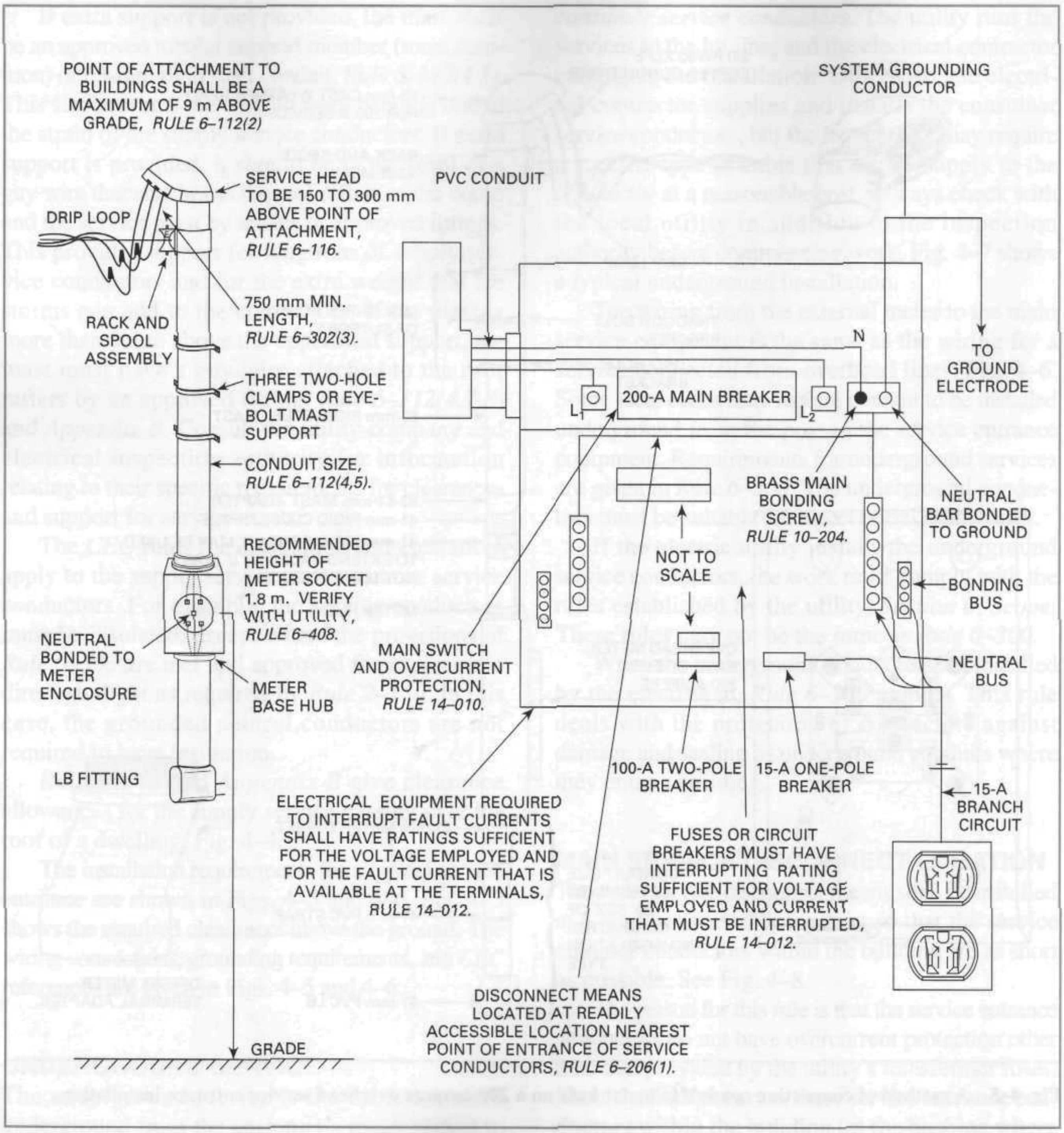


Fig. 4–6 The wiring of a typical overhead service entrance installation. (Courtesy of CSA Group)

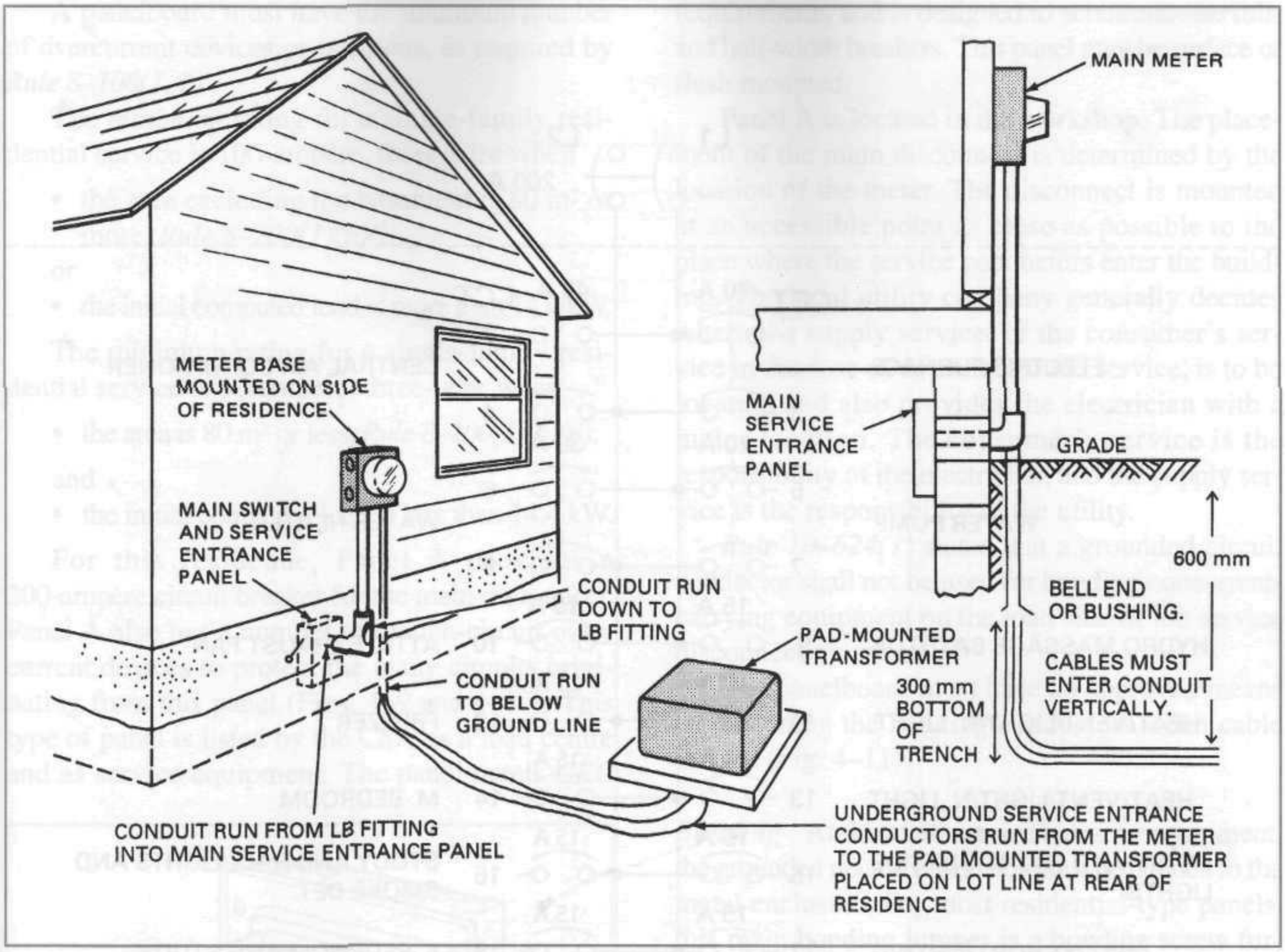


Fig. 4–7 Underground service.

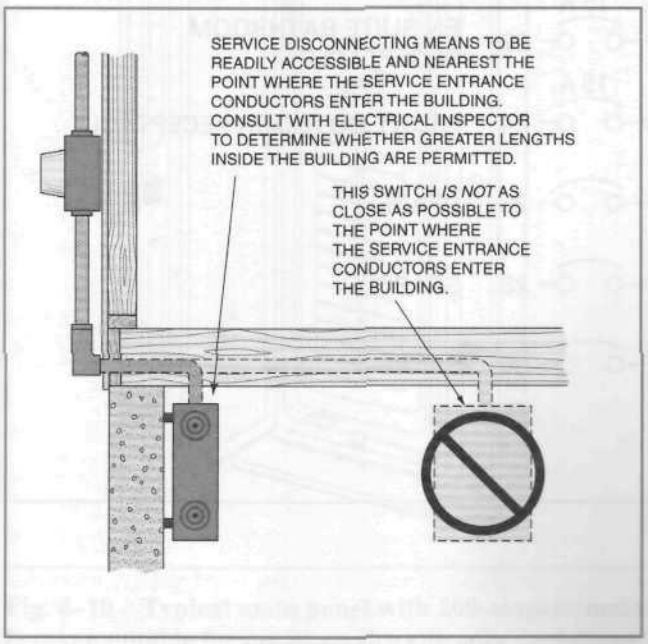


Fig. 4–8 Main service disconnect location, *Rule 6–206(1)(b)*. (Delmar/Cengage)

circuits are for. You can see the circuit directory on the inside of the door of the panel or on the side of the panel front cover. The main service Panel A circuit directory is shown in Fig. 4–9. The Panel B circuit directory is shown in Fig. 4–13.

Disconnect Means (Panel A)

The requirements for disconnecting the electric services are covered in *Rule 6–200*. *Rule 6–200(1)* requires that each consumer's service be provided with a single service box.

However, *Subrule (2)* sets out the circumstances in which more than one service box is permitted:

- The subdivision is made at the meter base.
- Maximum rating is 600 amperes and 150 volts to ground.
- The meter base is located outdoors.

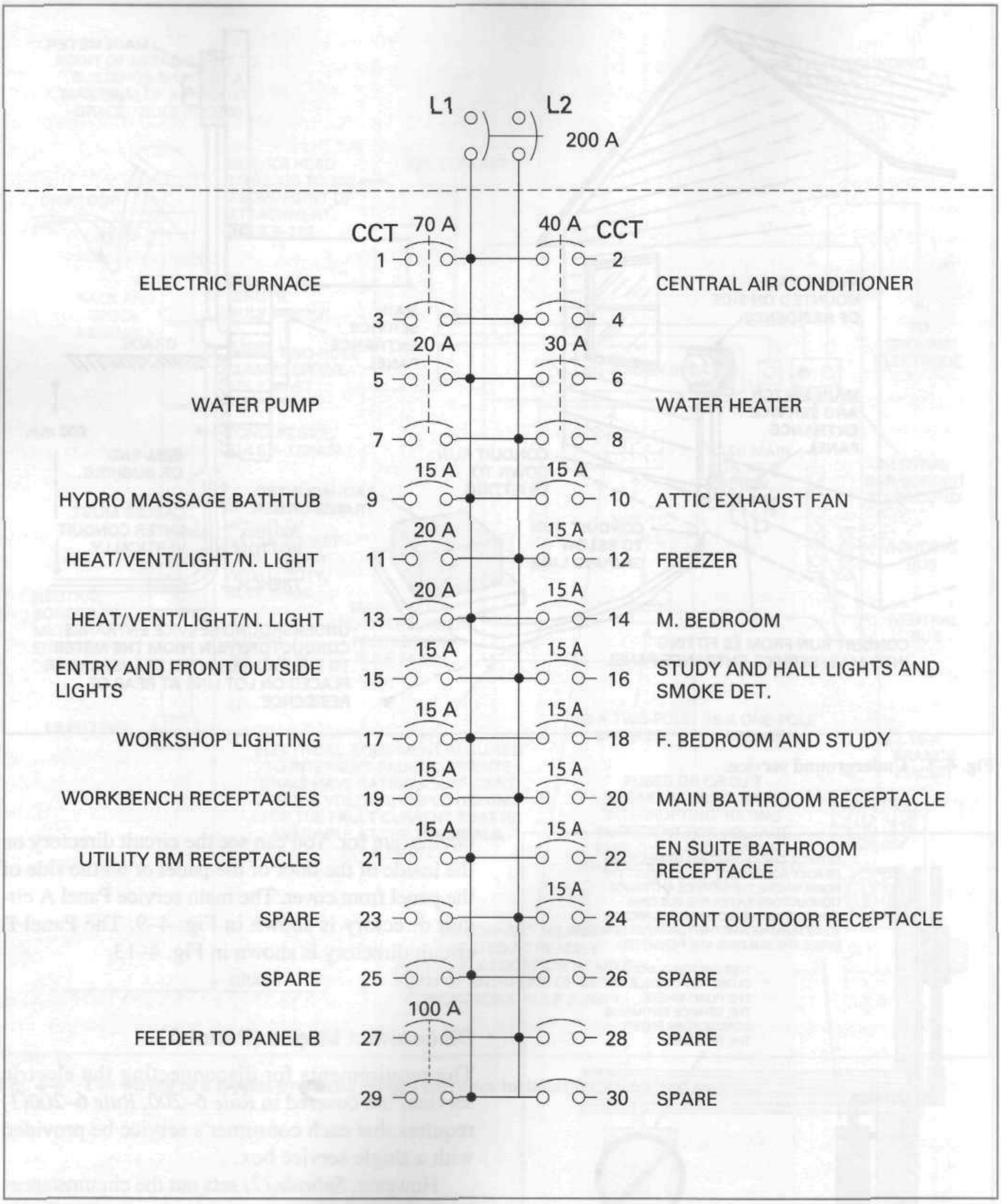


Fig. 4–9 Circuit schedule of main service Panel A.

A panelboard must have the minimum number of overcurrent devices or positions, as required by *Rule 8–108(1, 2).*

The *minimum* rating for a single-family residential service is 100-ampere, three-wire when

- the area excluding the basement is 80 m^2 or more, *Rule 8–200(1)(b)(i)*;

or

- the initial computed load is more than 14.4 kW.

The minimum rating for a single-family residential service is 60-ampere, three-wire when

- the area is 80 m^2 or less, *Rule 8–200(1)(b)(ii)*;

and

- the initial computed load is less than 14.4 kW.

For this residence, Panel A provides a 200-ampere circuit breaker for the main disconnect. Panel A also has a number of branch-circuit overcurrent devices to protect the many circuits originating from this panel (Figs. 4–9 and 4–10). This type of panel is listed by the CSA as a load centre and as service equipment. The panel meets *CEC* requirements and is designed to accommodate full- and half-width breakers. This panel may be surface or flush mounted.

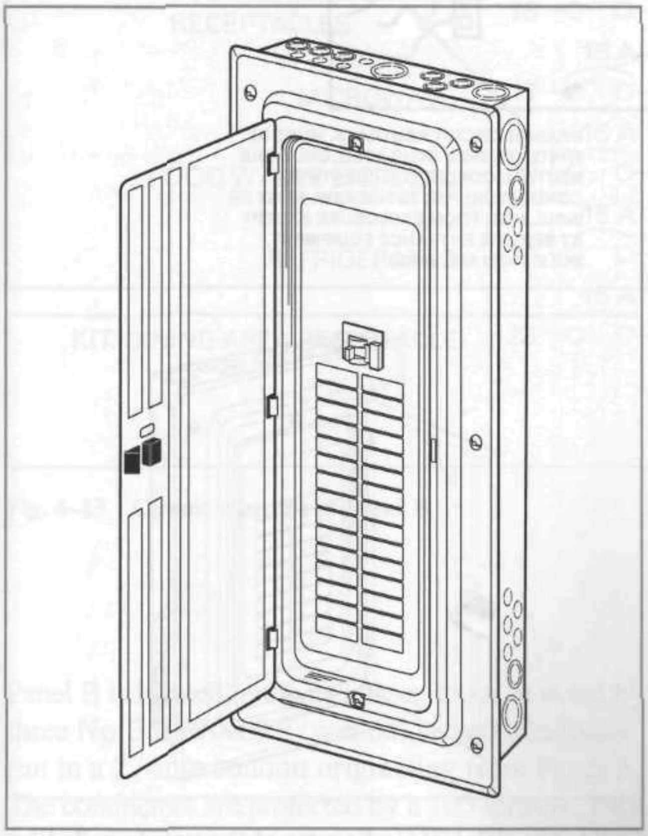


Fig. 4–10 Typical main panel with 200-ampere main breaker suitable for use as service entrance equipment, *Rule 6–200(1).* (Courtesy of Siemens Energy and Automation)

Panel A is located in the workshop. The placement of the main disconnect is determined by the location of the meter. The disconnect is mounted at an accessible point as close as possible to the place where the service conductors enter the building. The local utility company generally decides where the supply service, or the consumer's service in the case of an underground service, is to be located, and also provides the electrician with a meter location. The consumer's service is the responsibility of the electrician, and the supply service is the responsibility of the utility.

Rule 10–624(1) states that a grounded circuit conductor shall not be used for bonding noncurrent-carrying equipment on the load side of the service disconnecting means.

The panelboard must have an approved means for attaching the bonding conductors when cable is used (Fig. 4–11).

Bonding At the main service entrance equipment, the grounded neutral conductor must be bonded to the metal enclosure. For most residential-type panels, this main bonding jumper is a bonding screw furnished with the panel. This bonding screw is inserted through the neutral bar into a threaded hole in the back of the panel itself. The bonding screw will be brass or green in colour and must be clearly visible after it is in place.

As previously mentioned, *Rule 10–624(1)* prohibits bonding the grounded neutral of a system to any equipment on the load side of the main service disconnect. Therefore, the brass or green main-bonding jumper screw furnished with residential-type panels will be inserted at the main service panel *only*. This screw must be removed at subpanels, such as Panel B in the recreation room of the residence, *Rule 10–204(1)(c)*. See Fig. 4–11.

Load Centre (Panel B)

When the main service panel is located some distance from areas having many circuits and/or a heavy load concentration such as the kitchen or laundry of this residence, it is recommended that load centres be installed near these concentrations

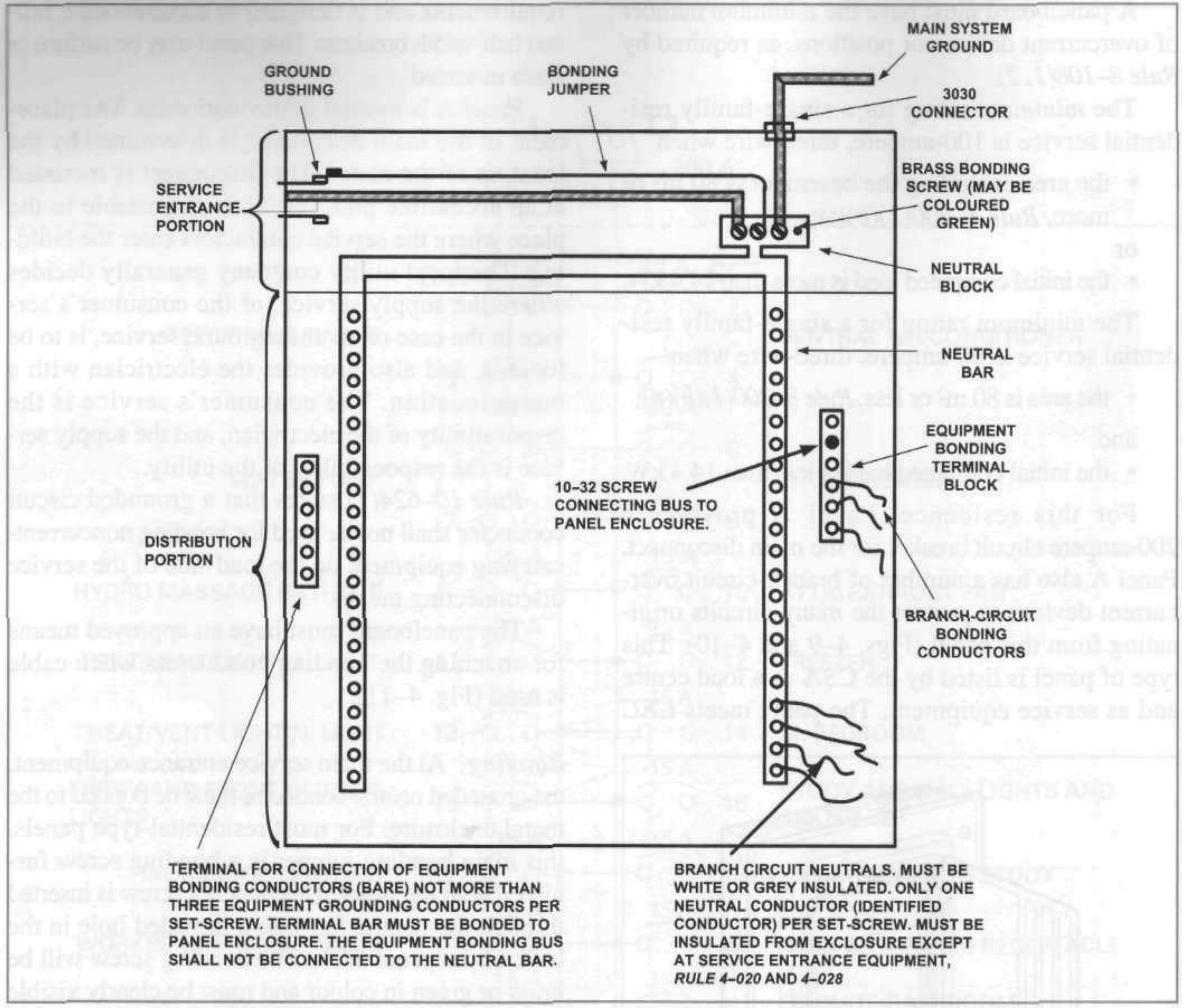


Fig. 4–11 Connections of service neutral, branch-circuit neutral, and equipment bonding conductors at main panel boards, *Rule 10–210(1)(b).*

of load. The individual branch-circuit conductors are run to the load centre, not back to the main panel. Thus, the branch-circuit runs are short, and line losses (voltage and wattage) are less than if the circuits had been run all the way back to the main panel.

To determine if there is a cost or benefit and if the lower line losses justify installing an extra load centre, the cost of material and labour to install the extra load centre should be compared to the cost of many branch circuits run back to the main panel.

A typical load centre is shown in Fig. 4–12.

The circuit schedule for Panel B, the load centre of the residence, is shown in Fig. 4–13.

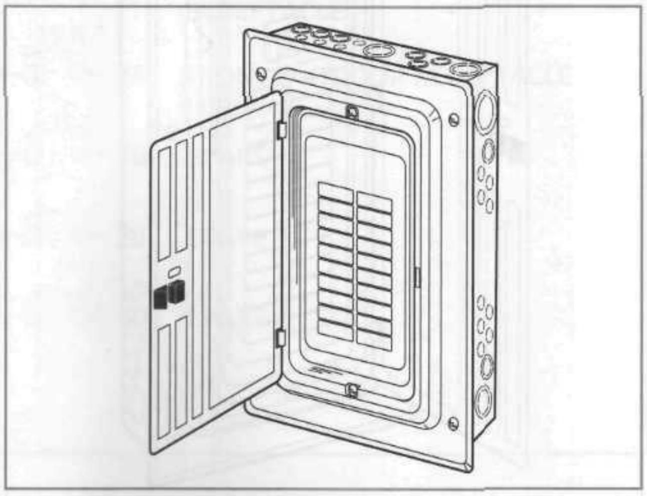


Fig. 4–12 Typical load centre of the type installed for Panel B in this residence. The bonding screw will be removed from the neutral block, *Rule 10–204(1)(c).* (Courtesy of Siemens Energy and Automation)

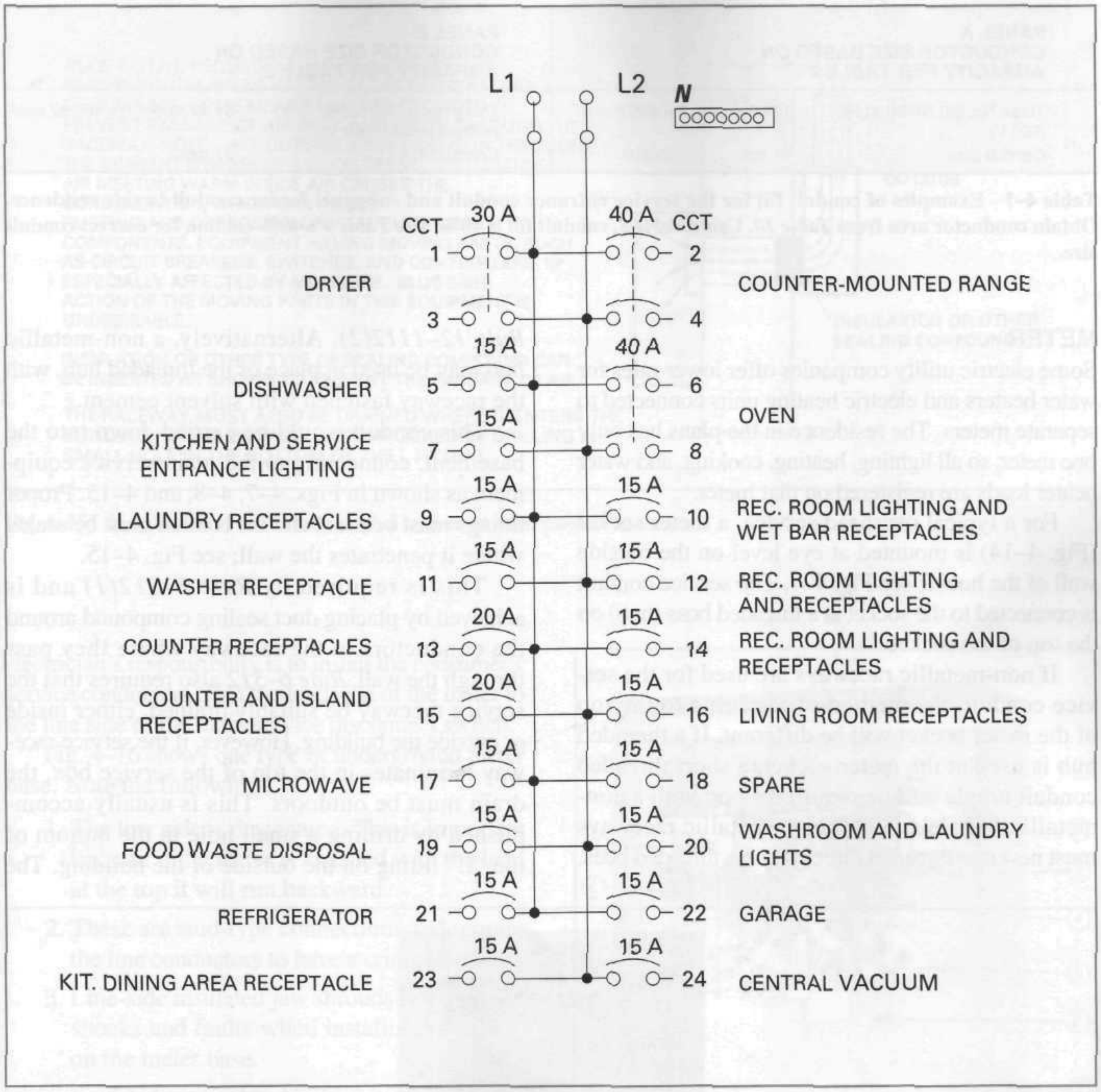


Fig. 4–13 Circuit schedule of Panel B.

Panel B is located in the recreation room. It is fed by three No. 3 R90 XLPE (without jacket) conductors run in a 27-mm conduit originating from Panel A. The conductors are protected by a 100-ampere, 240-volt, two-pole overcurrent device in Panel A. The overcurrent protection can be fuses or circuit breakers. This is discussed later in this unit.

SERVICE ENTRANCE CONDUIT SIZING

To determine the proper size of conduit, the conduit fill is calculated using the same method as outlined in Unit 3.

Look up the necessary data in *Tables 8, 9,* and *10* (see Table 4–1). If all the wires in the conduit are the same size, *Table 6* may be used for sizing the conduit.

PANEL A CONDUCTOR SIZE BASED ON AMPACITY PER *TABLE 2*		PANEL B CONDUCTOR SIZE BASED ON AMPACITY PER *TABLE 2*	
Three No. 2/0 RW90 XLPE (600 V)	141.9 mm^2 × 3 = 425.7 mm^2	Three No. 3 R90 XLPE (without jacket) (600 V)	61.99 mm^2 × 3 = 485.97 mm^2
Conduit Size	*41 mm*	*Conduit Size*	*27 mm*

Table 4–1 Examples of conduit fill for the service entrance conduit and subpanel feeder conduit in this residence. Obtain conductor area from *Table 10*. Using *Table 8*, conduit fill is 40%. Use *Table 9*'s 40% column for correct conduit size.

METER

Some electric utility companies offer lower rates for water heaters and electric heating units connected to separate meters. The residence in the plans has only one meter, so all lighting, heating, cooking, and water heater loads are registered on that meter.

For a typical overhead service, a meter socket (Fig. 4–14) is mounted at eye level on the outside wall of the house; see Fig. 4–7. The service conduit is connected to the socket at a threaded boss (hub) on the top of the socket.

If non-metallic raceways are used for the service conduit, the method of fastening to the top of the meter socket will be different. If a threaded hub is used at the meter socket, a short threaded conduit nipple will be required along with a non-metallic female adapter. Non-metallic raceways must never be threaded directly into a threaded boss, *Rule 12–1112(2)*. Alternatively, a non-metallic hub may be used in place of the threaded hub, with the raceway fastened with solvent cement.

This conduit would be carried down into the basement, connecting to the main service equipment as shown in Figs. 4–7, 4–8, and 4–15. Proper fittings must be used, and the conduit must be sealed where it penetrates the wall; see Fig. 4–15.

This is required by *Rule 6–312(1)* and is achieved by placing duct sealing compound around the conductors in the raceway where they pass through the wall. *Rule 6–312* also requires that the service raceway be suitably drained, either inside or outside the building. However, if the service raceway terminates in the top of the service box, the drain must be outdoors. This is usually accomplished by drilling a small hole in the bottom of the "L" fitting on the outside of the building. The

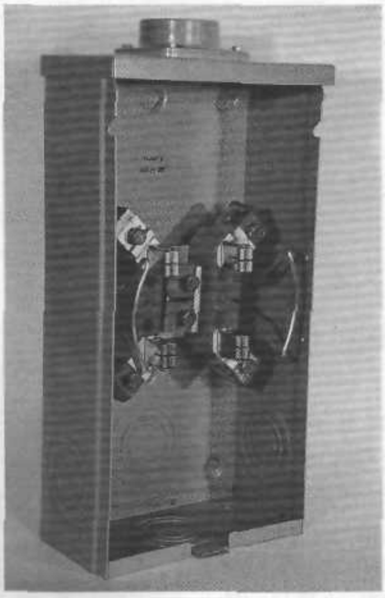


Fig. 4–14 Typical meter socket. (Courtesy of Schneider Electric)

RULE 6–312(1) REQUIRES THAT WHEN RACEWAYS PASS THROUGH AREAS HAVING GREAT TEMPERATURE DIFFERENCES, SOME MEANS MUST BE PROVIDED TO PREVENT PASSAGE OF AIR BACK AND FORTH THROUGH THE RACEWAY. NOTE THAT OUTSIDE AIR IS DRAWN IN THROUGH THE CONDUIT WHENEVER A DOOR OPENS. COLD OUTSIDE AIR MEETING WARM INSIDE AIR CAUSES THE CONDENSATION, WHICH CAN CAUSE RUSTING AND CORROSION OF VITAL ELECTRICAL COMPONENTS. EQUIPMENT HAVING MOVING PARTS, SUCH AS CIRCUIT BREAKERS, SWITCHES, AND CONTROLLERS, IS ESPECIALLY AFFECTED BY MOISTURE. SLUGGISH ACTION OF THE MOVING PARTS IN THIS EQUIPMENT IS UNDESIRABLE.

INSULATION OR OTHER TYPE OF SEALING COMPOUND CAN BE INSERTED AS SHOWN TO PREVENT THE PASSAGE OF AIR.

THE RACEWAY MUST ALSO BE DRAINED WHERE IT ENTERS THE BUILDING. THIS IS USUALLY ACCOMPLISHED BY DRILLING A SMALL HOLE IN THE BOTTOM OF THE L FITTING.

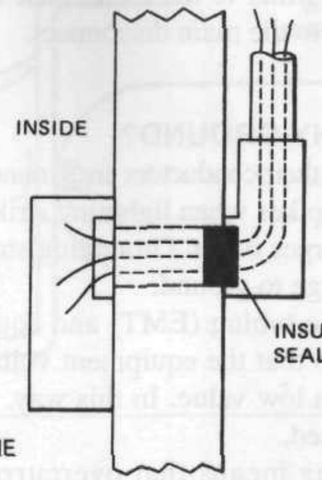


Fig. 4–15 Installation of conduit through a basement wall. (Courtesy of CSA Group)

electrician's responsibility is to install the consumer's service conductors from the load side of the meter to the line side of the main service disconnect switch.

Fig. 4–16 shows one type of underground meter base. Note the following:

1. The line side is designated. This is important because if the meter is installed with the load at the top it will run backward.
2. These are stud-type connections and require the line conductors to have a crimped-on lug.
3. Line-side insulated jaw shrouds help prevent shocks and faults when installing the cover on the meter base.
4. Insulated support blocks also provide a location for a flat-rate water heater lug, which can be bolted on at the three o'clock position.
5. Load-side lugs are angled for ease of connection without too much cable bending.
6. Two-position ground lug. This is not normally used because the meter base is bonded through the grounded service conductor (neutral), *Rule 10–624(1)*.
7. The enclosure is 450 × 300 × 112.5 mm, which gives plenty of room for pulling in conductors and terminating the lugs.

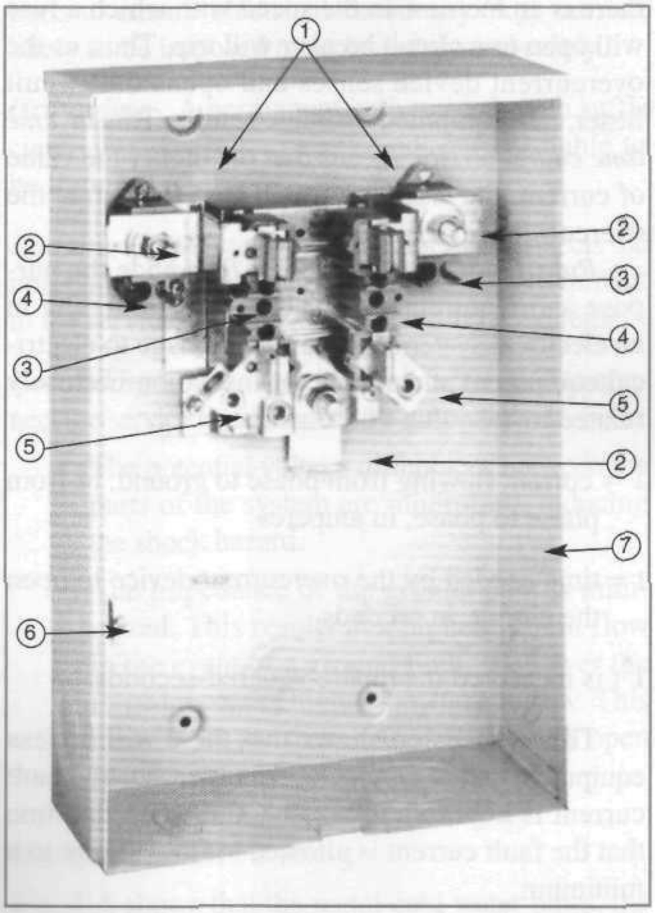


Fig. 4–16 An underground type of meter base with studs for utility connection of line conductors. (Courtesy of Thomas & Betts Incorporated)

8. The knockouts are provided for the conduit from the transformer to the meter base and for the conduit to the main disconnect.

GROUNDING—WHY GROUND?

Electrical systems and their conductors are grounded to minimize voltage spikes when lightning strikes, or when other line surges occur. Grounding stabilizes the normal voltage to ground.

Electrical metallic tubing (EMT) and equipment are grounded so that the equipment voltage to ground is kept to a low value. In this way, the shock hazard is reduced.

Proper grounding means that overcurrent devices can operate faster when responding to ground faults. Effective grounding occurs when a low-impedance (opposition to AC current flow) ground path is provided. A low-impedance ground path means that there is a high value of ground-fault current. As the ground-fault current increases, there is an increase in the speed with which a fuse will open or a circuit breaker will trip. Thus, as the overcurrent device senses and opens the circuit faster, less equipment damage results. This *inverse time characteristic* means that the higher the value of current, the less time it will take to operate the overcurrent device.

Rule 10–500 and *Appendix B* provide the purpose and requirements for effective grounding in an electrical system. The arcing damage to electrical equipment and conductor insulation is closely related to the value of I^2t, where

I = *current flowing from phase to ground, or from* phase to phase, in amperes

t = time needed by the overcurrent device to open the circuit, in seconds

I^2t is measured in ampere-squared-seconds.

This expression shows that there will be less equipment and/or conductor damage when the fault current is kept to a low value and when the time that the fault current is allowed to flow is kept to a minimum.

Grounding electrode conductors and equipment-grounding conductors carry an insignificant amount of current under normal conditions. However, when a ground fault occurs, these grounding conductors must be capable of carrying whatever value of fault current might flow for the time it takes the overcurrent protective device to clear the fault.

GROUNDING ELECTRODE SYSTEMS

In the grounding electrode system, rather than grounding a single item such as the neutral conductor, the electrician must be concerned with grounding and bonding together an entire system. The term *system* means the service neutral conductor, the grounding electrode, cold water pipes, gas pipes, service entrance equipment, and jumpers installed around meters. If any of these system parts become disconnected or open, the integrity of the grounding system is maintained through other paths. This means that all parts of the system must be tied (bonded) together.

Fig. 4–17 and the following steps illustrate what can happen if an entire system is not grounded:

1. A live wire contacts the gas pipe. The bonding jumper (A) is not installed originally.
2. The gas pipe now has 120 volts with respect to ground. The pipe is hot.
3. The insulating joint in the gas pipe results in a poor path to ground; assume the resistance is 8 ohms.
4. The 20-ampere overcurrent device does not open:

$$I = \frac{E}{R} = \frac{120}{8} \text{ amperes} = 15 \text{ amperes}$$

5. If a person touches the hot gas pipe and the water pipe at the same time, current flows through the person's body. If the body resistance is 12 000 ohms, the current is

$$I = \frac{E}{R} = \frac{120}{12\,000} \text{ amperes} = 0.01 \text{ amperes}$$

This value of current passing through a human body can cause death.

6. The overcurrent device is "seeing" (15 + 0.01) amperes = 15.01 amperes; however, it still does not open.

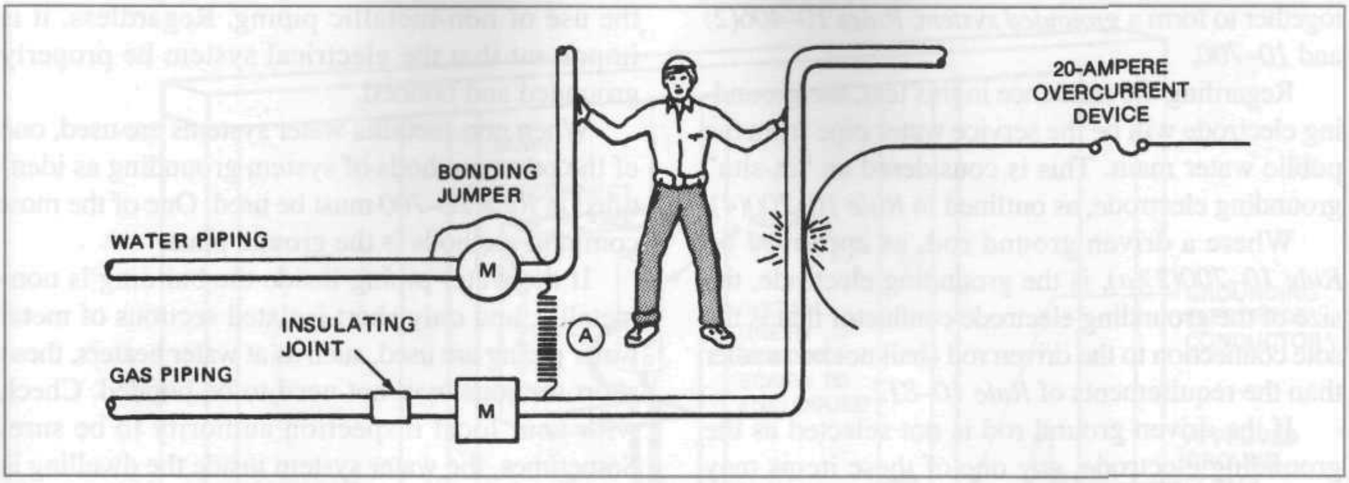


Fig. 4–17 System grounding. See text for explanation.

7. If the *system grounding* concept had been used, bonding jumper A would have kept the voltage difference between the water pipe and the gas pipe at zero, *Rule 10–406(2)(a)* and *(4)*. Thus, the overcurrent device would open. If 3.05 m of No. 6 AWG copper wire is used as the jumper, the resistance of the jumper is 0.003 95 ohms. The current is

$$I = \frac{E}{R} = \frac{120}{0.003\,95} \text{ amperes} = 30\,380 \text{ amperes}$$

(In an actual system, the impedance of all parts of the circuit is much higher, resulting in a much lower current. The current, however, would be high enough to cause the overcurrent device to open.)

Advantages of System Grounding*

To appreciate the concepts of proper grounding, let us review some important *CEC* rules.

Rule 10–002 sets out the objectives of grounding and bonding, summarized as follows:

- to protect life from the danger of electric shock
- to limit the voltage on a circuit
- to facilitate the operation of electrical apparatus and systems
- to limit voltage on a circuit when exposed to lightning
- to limit AC circuit voltages to ground to 150 volts or less on circuits supplying interior wiring systems.

* (Courtesy of CSA Group)

Section 0 provides definitions for the terms associated with grounding and bonding electrical systems.

Bonding A low impedance path obtained by permanently joining all non-current-carrying metal parts to ensure electrical continuity. Any current likely to be imposed must be conducted safely.

Grounding A permanent path to earth with sufficient ampacity to carry any fault current liable to be imposed on it.

Bonding Conductor A conductor that connects the non-current-carrying parts of electrical equipment to the service equipment or grounding conductor.

Grounding Conductor The conductor used to connect the service equipment to the grounding electrode.

- The potential voltage differences between the parts of the system are minimized, reducing the shock hazard.
- The impedance of the ground path is minimized. This results in a higher current flow in the event of a ground fault: the lower the impedance, the higher the current flow. This means that the overcurrent device will open faster under fault conditions.

Methods of Grounding

Fig. 4–6 shows that the metal cold water pipes, the service raceways, the metal enclosures, the service switch, and the neutral conductor are bonded together to form a *grounded system, Rules 10–406(2)* and *10–700.*

Regarding the residence in this text, the grounding electrode will be the service water pipe from the public water main. This is considered an "in-situ" grounding electrode, as outlined in *Rule 10–700(4).*

Where a driven ground rod, as approved by *Rule 10–700(2)(a),* is the grounding electrode, the size of the grounding electrode conductor that is the sole connection to the driven rod shall not be smaller than the requirements of *Rule 10–812.*

If the driven ground rod is not selected as the grounding electrode, any one of these items may be used: at least 6 m of bare copper conductor not smaller than No. 4 AWG (*Table 43*) or an approved manufactured ground plate; see Fig. 4–18. Both of these may be encased in concrete at least 50 mm thick and in direct contact with the earth, such as near the bottom of a foundation or footing.

Either a bare copper conductor or a ground plate may be used when buried directly in the ground to a minimum depth of 600 mm below finished grade.

There is little doubt that this concept of a grounded system gives rise to many interpretations of the *CEC.* The electrician must check with the local inspection authority to determine the local interpretation.

Refer to Fig. 4–19.

GROUNDING THE SERVICE WHEN NON-METALLIC WATER PIPE IS USED

It is quite common to find the main water supply to a residence installed with plastic (PVC) piping. Even interior water piping systems may be non-metallic piping. Some local building codes prohibit the use of non-metallic piping. Regardless, it is important that the electrical system be properly grounded and bonded.

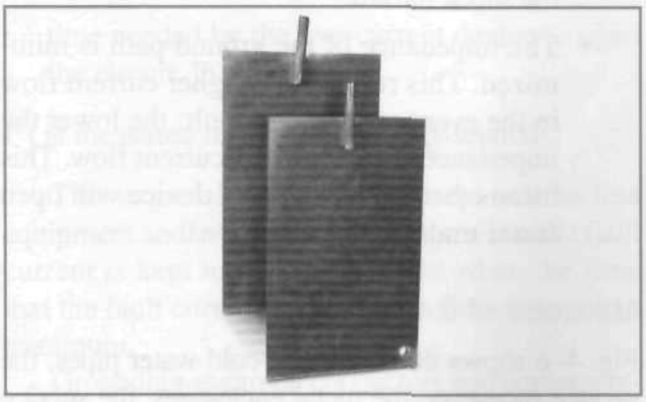


Fig. 4–18 Ground plates. (Courtesy of Thomas & Betts Incorporated)

When non-metallic water systems are used, one of the other methods of system grounding as identified in *Rule 10–700* must be used. One of the most common methods is the ground plate.

If the water piping inside the building is non-metallic, and only short isolated sections of metal water piping are used, such as at water heaters, these short sections may not need to be bonded. Check with your local inspection authority to be sure. Sometimes, the water system inside the dwelling is metallic, even though the water service to the street is non-metallic. With this large amount of metal water piping present, it must now be bonded to ground.

SUMMARY—SERVICE ENTRANCE EQUIPMENT GROUNDING

When grounding service entrance equipment, Fig. 4–20, you must observe these *CEC* rules*:

- The system must be grounded when the maximum voltage to ground does not exceed 150 volts, *Rule 10–106(1)(a).*
- The system must be grounded if it incorporates a neutral conductor, *Rule 10–106(1)(b).*
- All grounding schemes shall be installed so that no objectionable currents will flow over the grounding conductors and other grounding paths, *Rule 10–200(1,2).*
- The ground electrode conductor must be connected to the supply side of the service-disconnecting means. It must not be connected to any grounded circuit conductor on the load side of the service disconnect, *Rule 10–204(1)(b)(d).*
- The neutral conductor must be grounded, *Rule 10–210(1).*
- All electrical equipment must be bonded together. See *Rule 10–400.*
- The grounding electrode conductor used to connect the grounded neutral conductor to the grounding electrode must not be spliced, except with thermit welding or compression connectors. *Rule 10–806(1).*

* (Courtesy of CSA Group)

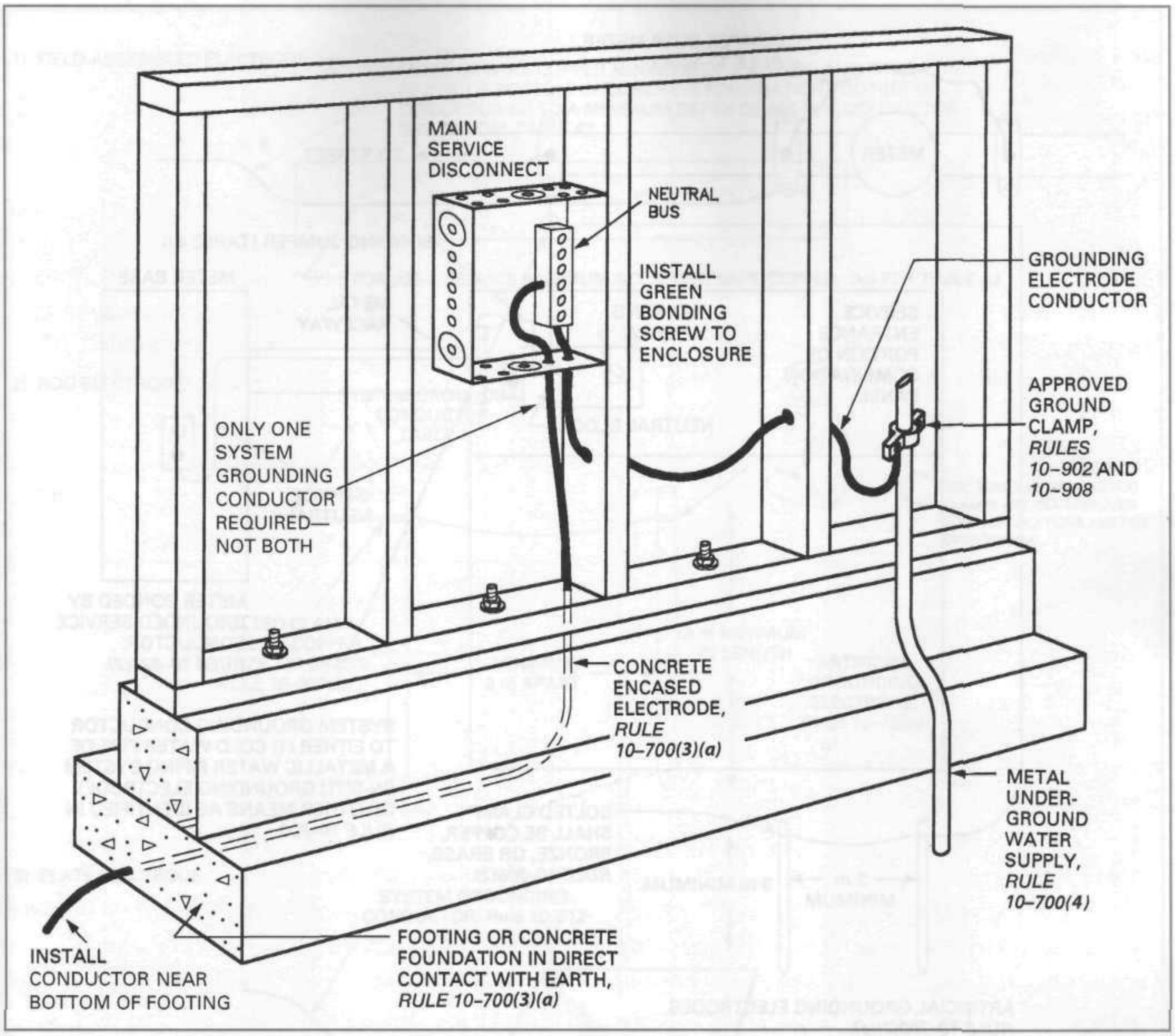


Fig. 4–19 ***Rule 10–700*** **lists many options for a system grounding electrode. Here a concrete-encased No. 3 AWG bare copper conductor is laid near the bottom of the footing, encased by at least 50 mm of concrete. The *minimum* length of the conductor is 6 m. See *Rule 10–700(3)(a)* and *Table 43*. *Note:* The *CEC* requires that if more than one ground electrode connection exists, they must be bonded together, *Rule 10–702*.** (Courtesy of CSA Group)

- The grounding electrode conductor must be sized according to *Rule 10–812*.
- The minimum conductor size for concrete-encased electrodes is found in *Table 43* and *Rule 10–700(3)*.
- The metal water supply system shall be bonded to the grounding conductor of the electrical system, *Rule 10–406(2)* and *Appendix B*.
- When more than one grounding means exist, they must be bonded together, *Rule 10–702*.
- The grounding electrode conductor must be a minimum of No. 6 AWG copper if the run is exposed and without metal covering or protection. This wire must be free from exposure to mechanical injury, *Rule 10–806(2)*.
- The grounding electrode conductor shall be copper, and may be insulated or bare, *Rule 10–802*.
- Bonding shall be provided around all insulating joints or sections of the metal water

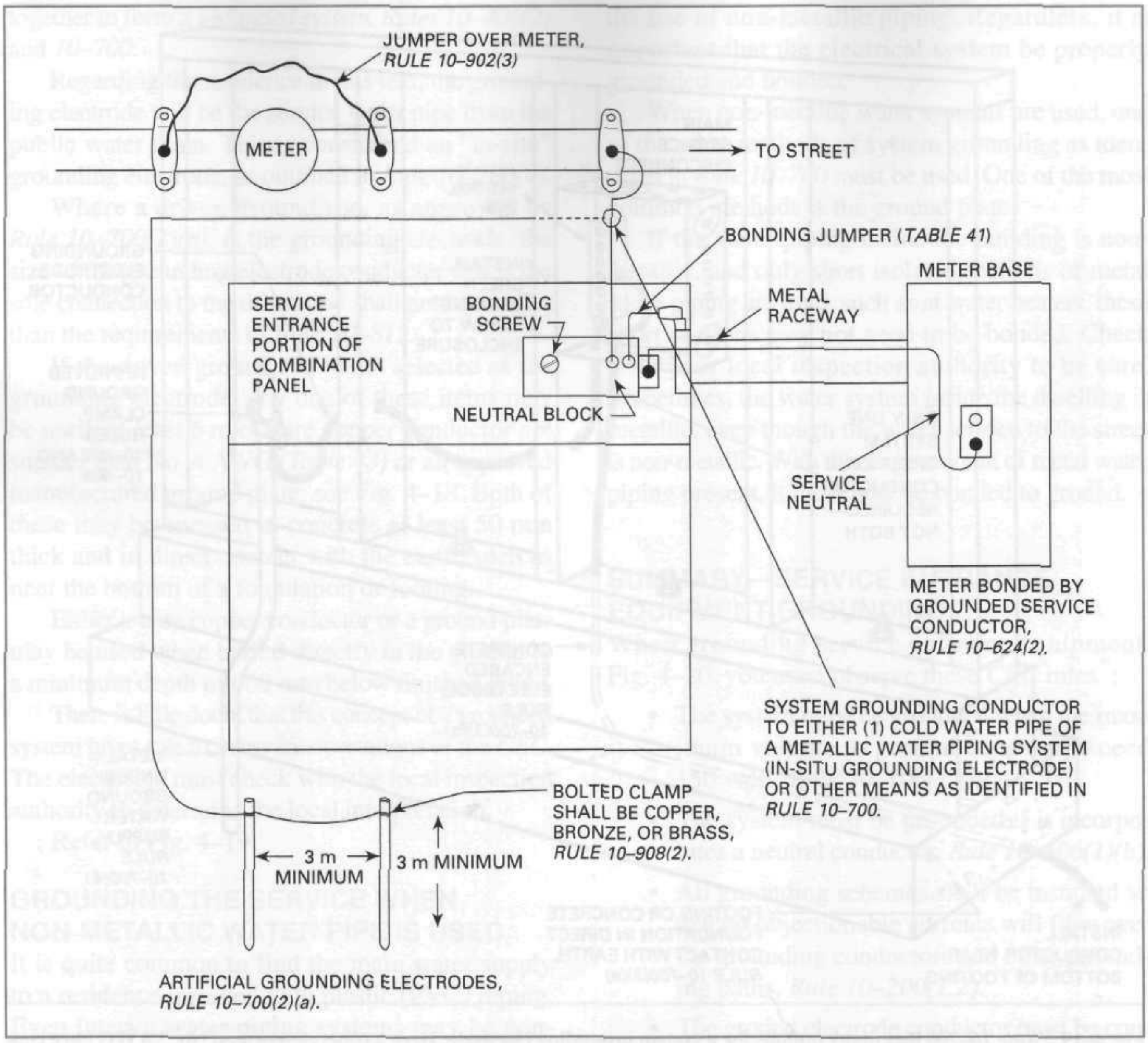


Fig. 4–20 One method that may be used to provide proper grounding and bonding of service entrance equipment for a typical single-family residence.

piping system that may be disconnected, *Rule 10–902(3)*.

- The connection to the grounding electrode must be accessible, *Rule 10–902(2)*.
- The grounding conductor must be connected tightly using the proper lugs, connectors, clamps, or other approved means, *Rule 10–908(1)*.

Fig. 4–21 illustrates three common types of ground electrodes. These are connected to the neutral in the main service disconnect.

This residence is supplied by three No. 2/0 RW90 XLPE service entrance conductors. According to *Rule 10–812*, a No. 6 AWG grounding electrode conductor is required. This conductor may be run in conduit or cable armour, or it may be run exposed if it is not subjected to severe physical damage.

BONDING

Bonding must be done at service entrance equipment. *Rule 10–606* lists the methods approved for bonding this equipment. Grounding bushings (Fig. 4–22) and

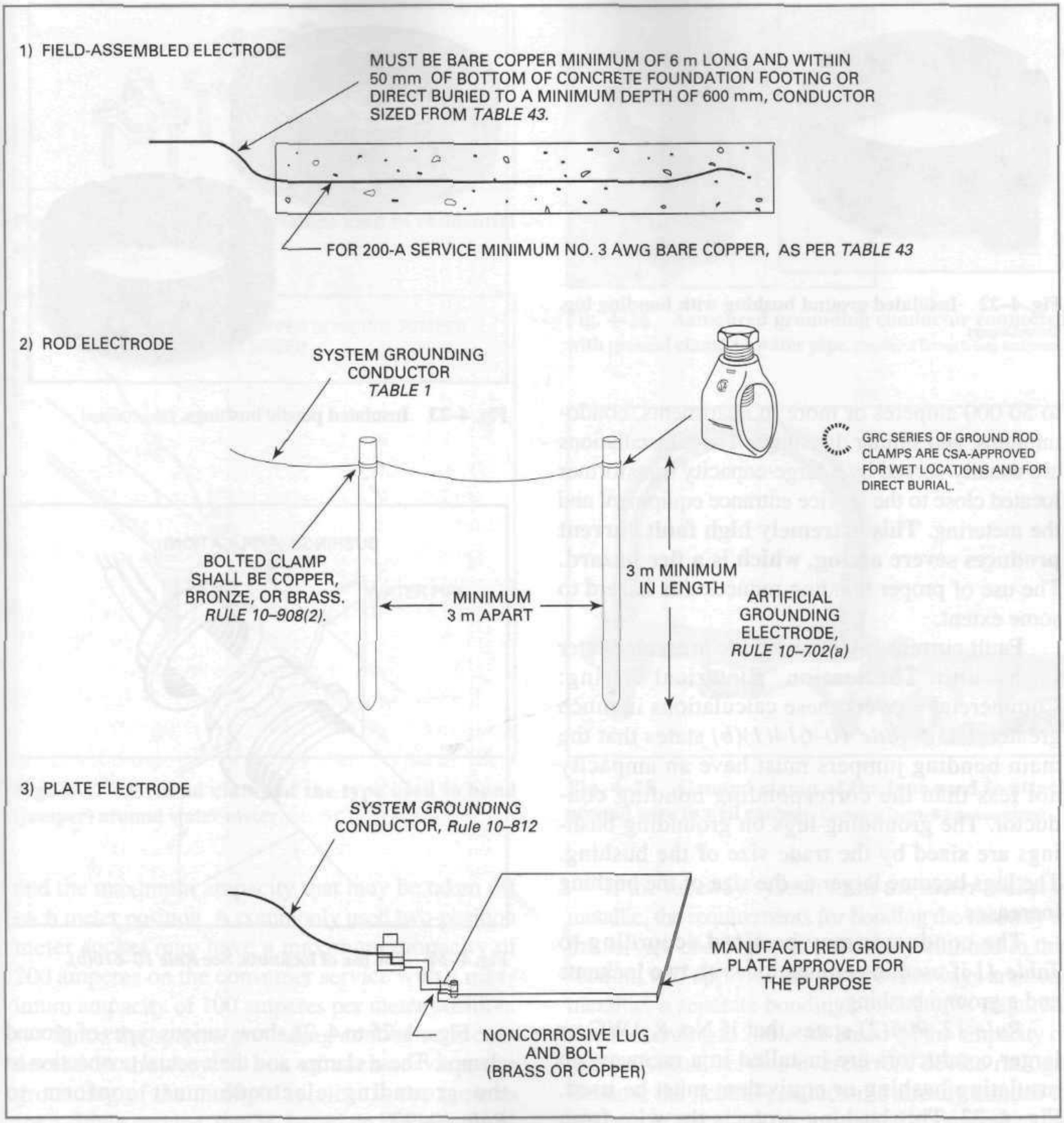


Fig. 4–21 Three common types of grounding electrodes: (1) a field-assembled grounding electrode, (2) two rod electrodes, and (3) a plate electrode. In many instances, the grounding electrode is better than the service water pipe (in-situ) ground electrode, particularly since the advent of non-metallic (PVC) water piping systems.

bonding jumpers are installed on metallic service *conduits at service entrance equipment to ensure a* low-impedance path to ground if a fault occurs on any of the service entrance conductors, *Rule 10–606*. Service entrance conductors are not fused at the service head. Thus, the short-circuit current on these conductors is limited only by the capacity of the *transformer or transformers supplying the service* equipment, and the distance between the service equipment and the transformers. The short-circuit current can easily reach 20 000 amperes or more in dwellings. Fault currents can easily reach 40 000

Fig. 4–22 **Insulated ground bushing with bonding lug.** (Delmar/Cengage)

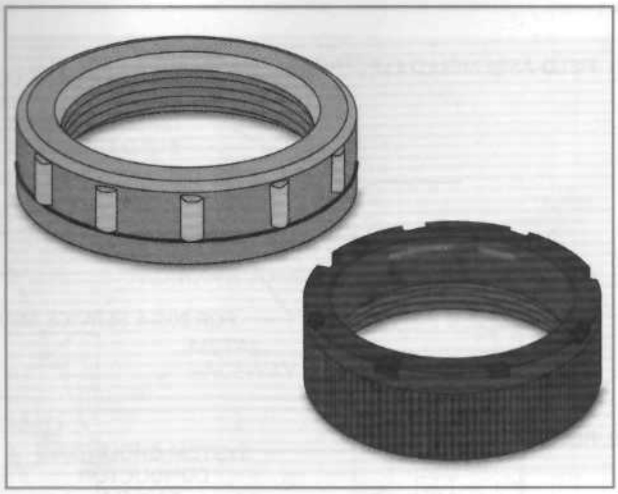


Fig. 4–23 **Insulated plastic bushings.** (Delmar/Cengage)

to 50 000 amperes or more in apartments, condominiums, and similar dwellings. These installations are usually served by a large-capacity transformer located close to the service entrance equipment and the metering. **This extremely high fault current produces severe arcing, which is a fire hazard.** The use of proper bonding reduces this hazard to some extent.

Fault current calculations are presented later in this unit. The section "Electrical Wiring: Commercial" covers these calculations in much greater detail. *Rule 10–614(1)(b)* states that the main bonding jumpers must have an ampacity not less than the corresponding bonding conductor. The grounding lugs on grounding bushings are sized by the trade size of the bushing. The lugs become larger as the size of the bushing increases.

The conductor may be sized according to *Table 41* if used in conjunction with two locknuts and a ground bushing.

Rule 12–906(2) states that if No. 8 AWG or larger conductors are installed in a raceway, an insulating bushing or equivalent must be used, Fig. 4–23. This bushing protects the wire from shorting or grounding itself as it passes through the metal bushing. Combination bushings can be used. These bushings are metallic (for mechanical strength) and have plastic insulation. When conductors are installed in EMT, they can be protected at the fittings by the use of connectors with insulated throats.

If the conduit bushing is made of insulating material only, as in Fig. 4–23, two locknuts must be used; see Fig. 4–24 and *Rule 10–610(b)*.

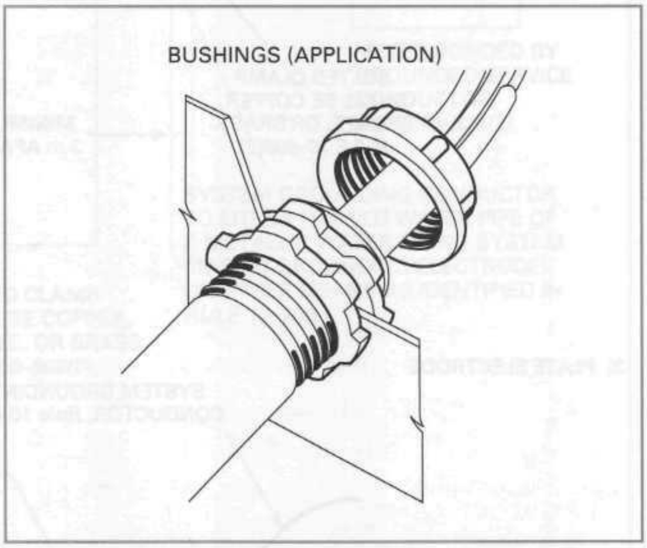


Fig. 4–24 The use of locknuts. See *Rule 10–610(b)*.

Figs. 4–25 to 4–28 show various types of ground clamps. These clamps and their actual connection to the grounding electrode must conform to *Rule 10–908*.

MULTIPLE METER INSTALLATIONS

If multiple meter sockets are required, as in a multifamily dwelling or a water heater metered at a different rate, a multigang meter socket is used. This is a single enclosure that is capable of holding more than one meter. The meter socket is rated in two ways: the maximum ampacity of the consumer service conductors feeding the enclosures

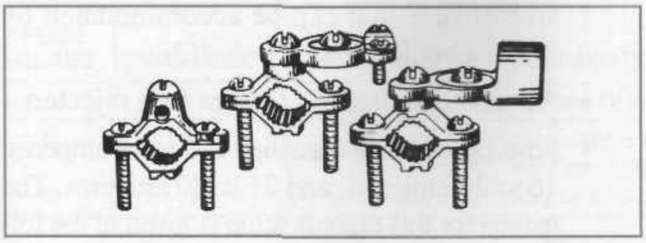


Fig. 4–25 Typical ground clamps used in residential systems.

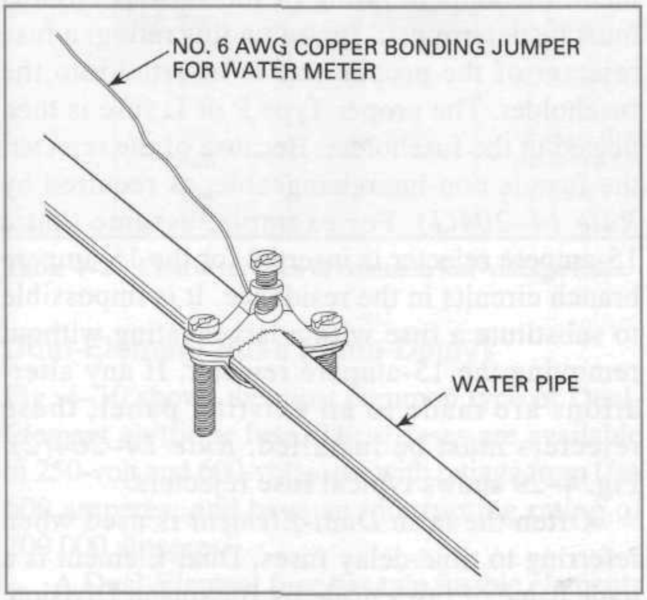


Fig. 4–27 Ground clamp of the type used to bond (jumper) around water meter.

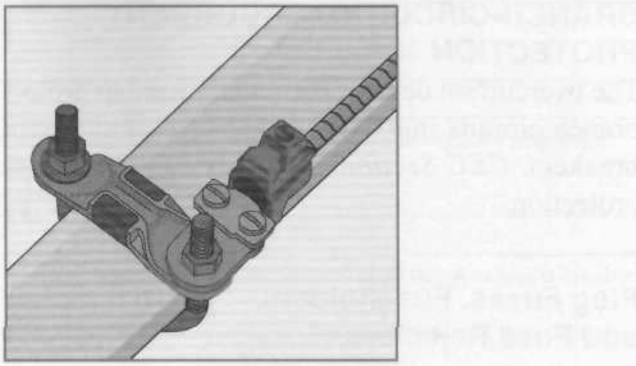


Fig. 4–26 Armoured grounding conductor connected with ground clamp to water pipe. (Courtesy of Thomas & Betts Incorporated)

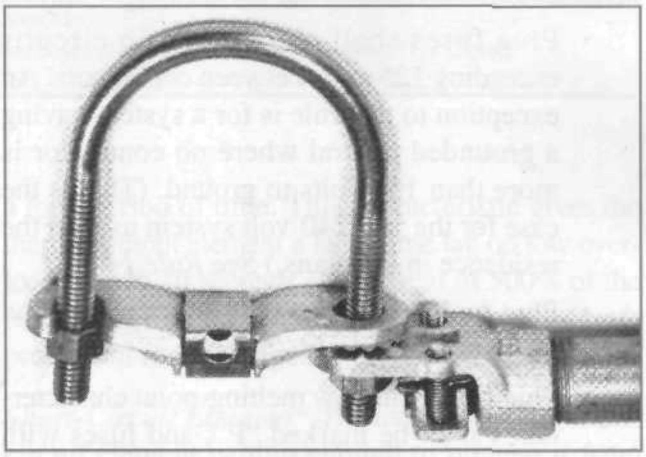


Fig. 4–28 Ground clamp of the type used to attach ground wire to well casings. (Courtesy of Thomas & Betts Incorporated)

and the maximum ampacity that may be taken off each meter position. A commonly used two-position meter socket may have a maximum ampacity of 200 amperes on the consumer service with a maximum ampacity of 100 amperes per meter position.

Since the system grounding conductor is connected in the service box of each service, the grounding of the multiple services is the same as for a single service, that is, based on the individual service ampacity and *Rule 10–812*. However, *Rule 10–204(1)(b)* states that the system grounding connection may be made in other service equipment located on the supply side of the service disconnects. The service can therefore be grounded at the multigang meter socket by connecting the neutral conductor to the grounding electrode using a conductor sized according to *Rule 10–812,* based on the ampacity of the consumer service conductors feeding the meter socket.

If the raceway system from the meter socket is metallic, the requirements for bonding the raceway to the service enclosure, as previously outlined in this section, will apply. If the service raceways are nonmetallic, a separate bonding conductor is required, sized according to *Table 16,* based on the ampacity of the individual service overcurrent device ratings. Because the neutral conductor is already bonded to the case of the meter enclosure and connected to the grounding electrode from this location, you must apply *Rule 10–204(1)(c)*. This rule requires that the neutral not be connected to the enclosure in the service box of the individual services. Therefore, the brass or green bonding screw must be removed from the neutral bar in the individual services.

The neutral must be bonded to only non-current-carrying components in one location, that location being at the point at which the neutral is connected to the system-grounding electrode.

BRANCH-CIRCUIT OVERCURRENT PROTECTION

The overcurrent devices commonly used to protect branch circuits in dwellings are fuses and circuit breakers. *CEC Section 14* discusses overcurrent protection.

Plug Fuses, Fuseholders, and Fuse Rejecters

Fuses are a reliable and economical form of overcurrent protection. *Rules 14–200* through *14–212* give the requirements for plug fuses, fuseholders, and fuse rejecters, including*

- Plug fuses shall not be used in circuits exceeding 125 volts between conductors. An exception to this rule is for a system having a grounded neutral where no conductor is more than 150 volts to ground. (This is the case for the 120/240-volt system used in the residence in the plans.) See *Rule 14–202*.
- Plug fuses shall have ratings between 0 and 30 amperes, *Rule 14–208(1)*.
- Plug fuses with low melting-point characteristics shall be marked "P", and fuses with time delay shall be marked "D", *Rule 14–200.*
- The screw shell of the fuseholder must be connected to the load side of the circuit.
- Where there is an alteration to a fuse panel, the fuse panel is required to be equipped with fuse rejecters that are designed to limit the size of fuse that can be accommodated by the fuseholder, *Rule 14–204(2)*.
- All new installations require fuse rejecters.
- Fuse rejecters are classified at 0 to 15 amperes, 16 to 20 amperes, and 21 to 30 amperes. The reason for this classification is given in the following paragraph.

When the electrician installs fusible equipment, the ampere rating of the various circuits must be determined. Based on this rating, a fuse rejecter of the proper size is inserted into the fuseholder. The proper Type P or D fuse is then placed in the fuseholder. Because of the rejecter, the fuse is non-interchangeable, as required by *Rule 14–204(1)*. For example, assume that a 15-ampere rejecter is inserted for the 15-ampere branch circuits in the residence. It is impossible to substitute a fuse with a larger rating without removing the 15-ampere rejecter. If any alterations are made to an existing panel, these rejecters must be installed, *Rule 14–204(2)*. Fig. 4–29 shows typical fuse rejecters.

Often the term *Dual-Element* is used when referring to time-delay fuses. Dual-Element is a trade name of fuses made by Bussmann Division, Cooper Industries. The term is used in much the same manner as *Romex* is used for type NMD90 cable and *BX* is used for armoured cable.

CSA has classified fuses according to their size and operating characteristics. Table 4–2 provides information on common low-voltage fuses.

* (Courtesy of CSA Group)

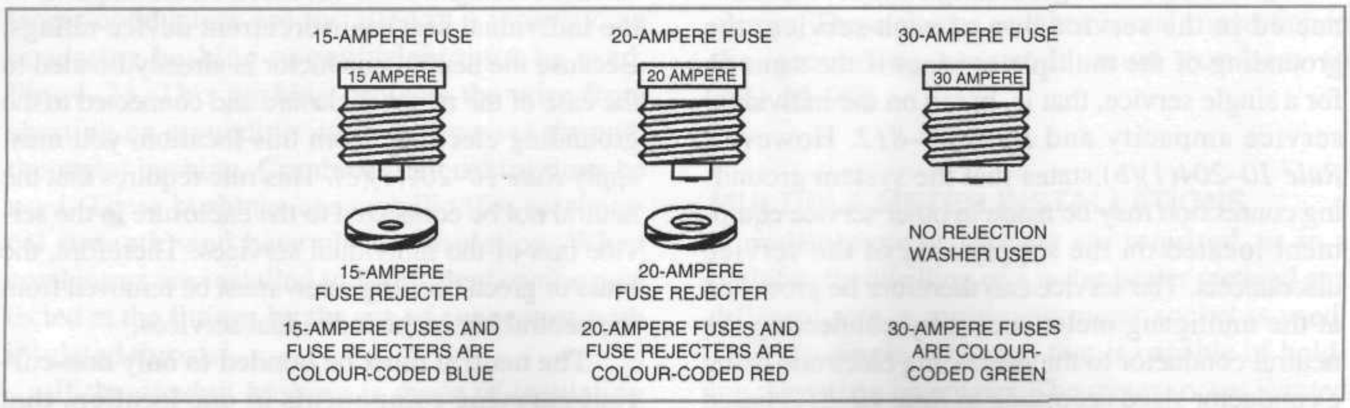


Fig. 4–29 Type C fuses and rejection washers are designed to prevent overfusing in panelboards that use plug fuses. Rejection washers can be added to any existing panelboard that uses plug fuses.

FUSE CLASS	VOLTAGE	CURRENT	COMMENTS
			Plug Fuses
C	125	0 – 30	Has rejection feature when used with rejection washers; low melting-point plug fuses are Type P nontime-delay and Type D time-delay
S	125	0 – 30	May be time-delay or nontime-delay
			Cartridge Fuses
H	250 600	0 – 600	Standard fuse used in circuits where interrupting capacity of 10 000 A or less is required
J	250 600	0 – 600	UL class J: 200 000-A interrupting capacity, smaller physical dimensions than Class H fuses
K	250 600	0 – 600	UL class K: will be found on equipment imported from the United States
L	250 600	601 – 6000	UL class L: high temperature fuses
R	250 600	0 – 600	UL class R: rejection fuse may be placed in a standard fuseholder, but standard fuses will not fit in a Class R fuseholder
T	250 600	0 – 600	UL class T: has smaller physical dimensions than either Class H or Class J

Table 4–2 Characteristics of common low-voltage fuses.

Dual-Element Fuse (Time-Delay)

Fig. 4–30 shows the most common type of Dual-Element cartridge fuse. These fuses are available in 250-volt and 600-volt sizes with ratings from 0 to 600 amperes, and have an interrupting rating of 200 000 amperes.

A Dual-Element fuse has two fusible elements connected in series: the overload element and the short-circuit element. When an excessive current flows, one of the elements opens. The amount of excess current determines which element opens.

The electrical characteristics of these two elements are very different. Thus, a Dual-Element fuse has a greater range of protection than the single-element fuse. The overload element opens circuits on current in the low overload range (up to 500% of the fuse rating). The short-circuit element handles only short circuits and heavy overload currents (above 500% of the fuse rating).

Overload Element The overload element opens when excessive heat is developed in the element. This heat may be the result of a loose connection or poor contact in the fuseholder or excessive current. When the temperature reaches 138°C, a fusible alloy melts and the element opens. Any excessive current produces heat in the element. However, the mass of the element absorbs a great deal of heat before the cutout opens. A small excess of current will cause this element to open if it continues for a long period of time. This characteristic gives the thermal cutout element a large time lag on low overloads (up to 10 seconds at a current of 500% of the fuse rating). In addition, it provides very accurate protection for prolonged overloads.

Short-Circuit Element The capacity of the short-circuit element is high enough to prevent it from opening on low overloads. This element is designed to clear the circuit quickly of short circuits or heavy overloads above 500% of the fuse ratings.

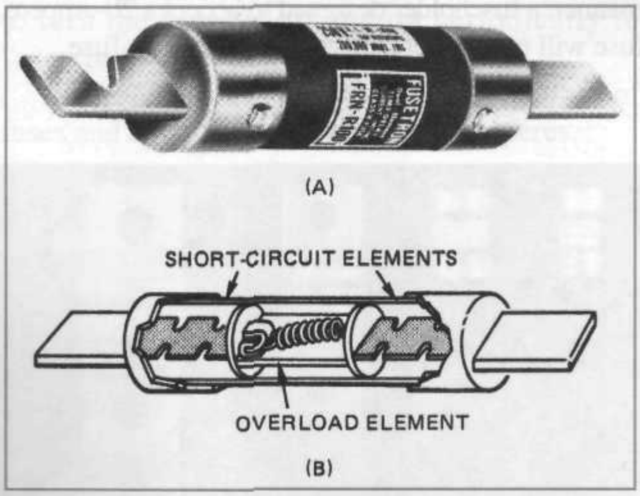


Fig. 4–30 Cartridge-type Dual-Element fuse (A) is a 250-volt, 100-ampere fuse. The cutaway view in (B) shows the internal parts of the fuse. (Courtesy of Cooper Industries)

Dual-element fuses are used on motor and appliance circuits where the time-lag characteristic of the fuse is required. Single-element fuses do not have this time lag. Such fuses blow as soon as an overcurrent condition occurs. The homeowner may be tempted to install a fuse with a higher rating. The fuseholder adapter, however, prevents the use of such a fuse. Thus, the dual-element fuse is recommended for this type of situation.

The standard plug fuse can be used only to replace blown fuses on existing installations. A Type P or D fuse is required on all new installations. The cartridge fuse is a dual-element fuse that is available in both ferrule and knife blade styles.

Cartridge Fuses

Fig. 4–31 shows another style of small-dimension cartridge fuse.

A type of cartridge fuse that is also in use is rated at not over 60 amperes for circuits of 300 volts or less to ground. The physical size of this fuse is smaller than that of standard cartridge fuses. The time-delay characteristics of this fuse mean that it can handle harmless current surges or momentary overloads without blowing. However, these fuses open very rapidly under short-circuit conditions.

These fuses prevent over-fusing since they are size-limiting for their ampere ratings. For example, a fuseholder designed to accept a 15-ampere fuse will not accept a 20-ampere cartridge fuse. In the same manner, a fuseholder designed to accept a 20-ampere fuse will not accept a 30-ampere cartridge fuse.

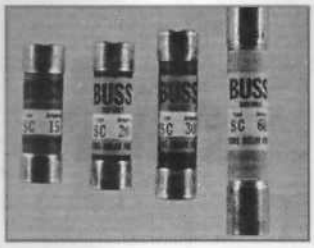


Fig. 4–31 Cartridge-type fuses. (Courtesy of Cooper Industries)

Class J Fuses

Another type of physically small fuse is the Class J fuse; see Fig. 4–32. This has a high-interrupting rating in sizes from 0 to 600 amperes in both 300-volt and 600-volt ratings. Such fuses are used as the main fuses in a panel having circuit-breaker branches; see Fig. 4–33. In this case, the Class J fuses protect the low-interrupting capacity breakers against high-level short-circuit currents.

Most manufacturers list service equipment, metering equipment, and disconnect switches that make use of Class J fuses. This allows the safe installation of this equipment where fault currents exceed 10 000 amperes, such as on large services, and any service equipment located close to pad-mounted transformers, such as are found in apartments, condominiums, shopping centres, and similar locations.

The standard ratings for fuses range from 1 ampere to 6000 amperes.

Circuit Breakers

Installations in dwellings normally use thermal-magnetic circuit breakers. On a continuous overload, a bimetallic element in such a breaker moves until it

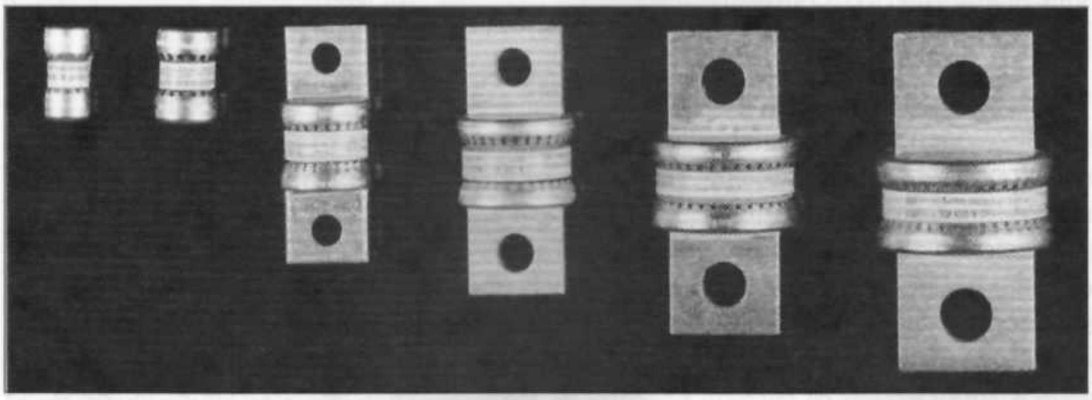


Fig. 4–32 Class J fuses rated at 30, 60, 100, 200, 400, and 600 amperes, 300 volts. (Courtesy of Cooper Industries)

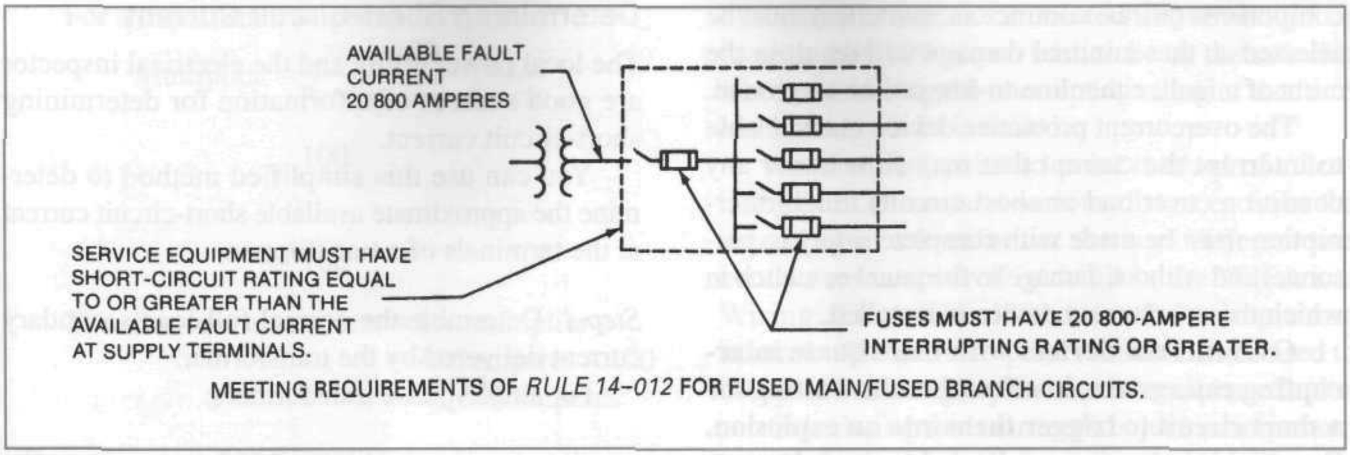


Fig. 4–33 Fused main/fused branch circuits. (Courtesy of CSA Group)

unlatches the inner tripping mechanism of the breaker. Momentary small overloads do not cause the element to trip the breaker. If the overload is heavy or if there is a short circuit, a magnetic coil in the breaker causes it to interrupt the branch circuit instantly.

Rules 14–300 to *14–308* give the requirements for circuit breakers, including*

- Circuit breakers shall be trip-free so that the internal mechanism will trip to the OFF position even if the handle is held in the ON position (which can be achieved using a lock-on device), *Rule 14–300(1)*.
- Breakers shall indicate clearly whether they are on or off, *Rule 14–300(2)*.
- A breaker shall be non-tamperable so that it cannot be readjusted (trip point changed) *without dismantling the breaker or breaking* the seal.
- The rating shall be durably marked on the breaker. For small breakers rated at 100 amperes or less and 600 volts or less, the rating must be moulded, stamped, or etched on the handle (or on another part of the breaker that will be visible after the cover of the panel is installed).
- Every breaker with an interrupting rating other than 5000 amperes shall have this rating marked on the breaker. Most have a 10 000-ampere mimimum rating.
- Circuit breakers rated at 120 volts and 347 volts and used for fluorescent loads shall not be used as switches unless marked "SWD", *Section 30–710(3)(b)*.

* (Courtesy of CSA Group)

Most circuit breakers are ambient temperature compensated. This means that the tripping point of the breaker is not affected by an increase in the surrounding temperature. An ambient-compensated breaker has two elements. One element heats up due to the current passing through it and the heat in the surrounding area. The other element heats up because of the surrounding air only. The actions of these elements oppose each other. Thus, as the tripping element tends to lower its tripping point because of external heat, the second element opposes the tripping element and stabilizes the tripping point. As a result, the current through the tripping element is the only factor that causes the element to open the circuit. It is a good practice to turn the breaker off and on periodically to "exercise" its moving parts.

Table 13 gives the standard ampere ratings of fuses and circuit breakers up to 600 amperes.

INTERRUPTING RATINGS FOR FUSES AND CIRCUIT BREAKERS*

Rule 14–012(a) states that all fuses, circuit breakers, and other electrical devices that break current shall have an interrupting capacity sufficient for the voltage employed and for the current that must be interrupted.

According to *Rule 14–012(a)* and *Appendix B*, all overcurrent devices, the total circuit impedance, and the withstand capability of all circuit

* (Courtesy of CSA Group)

components (wires, contractors, switches) must be selected so that minimal damage will result in the event of a fault, either line-to-line or line-to-ground.

The overcurrent protective device must be able to interrupt the current that may flow under any condition (overload or short circuit). Such interruption must be made with complete safety to personnel and without damage to the panel or switch in which the overcurrent device is installed.

Overcurrent devices with inadequate interrupting ratings are, in effect, bombs waiting for a short circuit to trigger them into an explosion. Personal injury may result, and serious damage will be done to the electrical equipment.

Cartridge-type fuses have a maximum interrupting rating of 10 000 amperes root mean square (RMS) symmetrical. Plug fuses can interrupt no more than 10 000 amperes RMS symmetrical. Cartridge dual-element fuses (Fig. 4–30) and Class J fuses (Fig. 4–32) have interrupting ratings of 200 000 amperes RMS symmetrical. These interrupting ratings are described in *CSA Standard C22.2 No. 59.1-M1987*. The interrupting rating of a fuse is marked on its label when the rating is other than 10 000 amperes.

Short-Circuit Currents

This text does not cover in detail the methods of calculating short-circuit currents (see the "Electrical Wiring: Commercial" section later in this unit). The ratings required to determine the maximum available short-circuit current delivered by a transformer are the kilovolt-ampere (kVA) and impedance values of the transformer. The size and length of wire installed between the transformer and the overcurrent device must be considered as well.

The transformers used in modern electrical installations are efficient and have very low impedance values. A low-impedance transformer having a given kVA rating delivers more short-circuit current than a transformer with the same kVA rating and a higher impedance. When an electric service is connected to a low-impedance transformer, the problem of available short-circuit current is very serious. The possible situations are shown in Fig. 4–33.

The examples given in Fig. 4–33 show that the available short-circuit current at the transformer secondary terminal is 20 800 amperes.

Determining Short-Circuit Current

The local power utility and the electrical inspector are good sources of information for determining short-circuit current.

You can use this simplified method to determine the approximate available short-circuit current at the terminals of a transformer.

Step 1. Determine the normal full-load secondary current delivered by the transformer.

For single-phase transformers:

$$I = \frac{kVA \times 1000}{E}$$

For three-phase transformers:

$$I = \frac{kVA \times 1000}{E \times 1.73}$$

I = current, in amperes
kVA = kilovolt-amperes (transformer nameplate rating)
E = secondary line-to-line voltage (transformer nameplate rating)

Step 2. Using the impedance value given on the transformer nameplate, find the multiplier to determine the short-circuit current.

$$\text{Multiplier} = \frac{100}{\text{Percent impedance}}$$

Step 3. The short-circuit current = normal full-load secondary current × multiplier.

EXAMPLE: A transformer is rated at 100 kVA and 120/240 volts. It is a single-phase transformer with an impedance of 1% (from the transformer nameplate). Find the short-circuit current.

For a single-phase transformer:

$$I = \frac{kVA \times 1000}{E}$$

$$= \frac{100 \times 1000}{240} \text{ amperes}$$

$$= 417 \text{ amperes, full-load current}$$

For a transformer impedance of 1%:

$$\text{Multiplier} = \frac{100}{\text{Percent impedance}}$$

$$= \frac{100}{1}$$

$$= 100$$

$$\text{The short-circuit current} = \text{I} \times \text{multiplier}$$
$$= 416 \text{ amperes} \times 100$$
$$= 41\,600 \text{ amperes}$$

Thus, the available short-circuit current at the terminals of the transformer is 41 600 amperes.

This value decreases as the distance from the transformer increases. If the transformer impedance is 1.5%,

$$\text{Multiplier} = \frac{100}{1.5} = 66.6$$

$$\text{The short-circuit current} = 416 \times 66.6 \text{ amperes}$$
$$= 27\,706 \text{ amperes}$$

If the transformer impedance is 2%:

$$\text{Multiplier} = \frac{100}{2} = 50$$

$$\text{The short-circuit current} = 416 \times 50 \text{ amperes}$$
$$= 20\,800 \text{ amperes}$$

Note: A short-circuit current of 20 800 amperes is used in Figs. 4–33, 4–34, 4–35, and 4–36.

CAUTION: The line-to-neutral short-circuit current at the secondary of a single-phase transformer is about 1.5 times greater than the line-to-line short-circuit current. For the previous example,

Line-to-line short-circuit current = 20 800 amperes

Line-to-neutral short-circuit current
= 20 800 × 1.5 amperes = 31 200 amperes

Note that *CSA Standard C22.2 No. 47* allows the marked impedance on the nameplate of a transformer to vary plus or minus (±) 10% from the actual impedance value of the transformer. Thus, for a transformer marked "2%Z", the actual impedance could be as low as 1.8%Z or as much as 2.2%Z. Therefore, the available short-circuit current at the secondary of a transformer as calculated above should be increased by 10% if you wish to be on the safe side when considering the interrupting rating of the fuses and breakers to be installed.

An excellent point-to-point method of calculating fault currents at various distances from the secondary of a transformer that uses different size conductors is covered in detail in the "Electrical Wiring: Commercial" section. It is simple and accurate. The point-to-point method can be used to compute both single-phase and three-phase faults.

Calculating fault currents is just as important as calculating load currents. Overloads will cause conductors and equipment to run hot, will shorten their life, and will eventually destroy them. Fault currents that exceed the interrupting rating of the overcurrent protective devices can cause violent electrical explosions of equipment with the potential of serious injury to personnel standing near it. Fire hazard is also present.

PANELS AND LOAD CENTRES

Fused Main/Fused Branches (Fig. 4–33)

- Fused main/fused branch circuits must be listed as suitable for use as service equipment.
- They must be sized to satisfy the required ampacity as determined by service entrance calculations and/or local codes.
- All fuses must have interrupting rating adequate for the available fault current. Panel must have short-circuit rating adequate for the available fault current.
- For overload conditions on a branch, only the branch-circuit fuse(s) will open. All other circuits remain energized. System is selective.*
- For short circuits (line-to-line or line-to-neutral) and for ground faults (line-to-ground), only the fuse protecting the faulted circuit opens. All other circuits remain energized. System is selective.*

* See boldfaced note on page 62.

Fused Main/Breaker Branches (Fig. 4–34)

- Fused main/breaker branches must be listed as suitable for use as service equipment.

- They must be sized to satisfy the required ampacity as determined by service entrance calculations and/or local codes.
- Main fuses must have interrupting rating adequate for the available fault circuit.
- Panel must have short-circuit rating adequate for the available fault current.
- Main fuses must be current limiting, such as Class J fuses, so that if a fault exceeding the branch-circuit breaker's interrupting rating (ampere interrupting rating, AIR) occurs, the fuse will limit the let-through fault current to a value less than the maximum interrupting rating of the branch-circuit breaker. Branch-circuit breakers generally have 10 000 amperes interrupting rating.
- For branch-circuit faults (L-N or L-G) exceeding the branch-circuit breaker's interrupting rating, one fuse opens, de-energizing one-half of the panel. The system is nonselective.*
- For branch-circuit faults (L-L) exceeding the branch-circuit breaker's interrupting rating, both main fuses open, de-energizing the entire panel. The system is non-selective.*
- Check time–current curves of fuses and breakers and check the unlatching time of breakers to determine at what point in "time" and "current" the breakers are slower than the current-limiting fuses.
- For normal overloads and low-level faults, this system is selective.

* See boldfaced note on page 62.

Breaker Main/Breaker Branches (Fig. 4–35) (All Standard Plastic-Case Breakers)

- These breaker main/breaker branches must be listed as suitable for use as service equipment.
- They must be sized to satisfy the required ampacity as determined by service entrance calculations and/or local codes.
- Main and branch breakers must have interrupting rating adequate for the available fault current.
- Panel must have short-circuit rating adequate for the available fault current.
- For overload conditions and low-level faults on a branch circuit, only the branch-circuit breaker will trip off. All other circuits remain energized. The system is selective.*
- For branch-circuit faults (short circuits or ground faults) that exceed the instant trip setting of the main breaker (usually five times the breaker's ampere rating), both the branch-circuit breaker and main breaker trip off. For instance, for a branch fault of 700 amperes, a 100-ampere main breaker also trips because the main will trip instantly for faults of 500 (100×5) amperes or more. Entire panel is de-energized. System is nonselective.*
- Check manufacturer's data for time–current characteristic curves and unlatching times of the breakers.

* See boldfaced note on page 62.

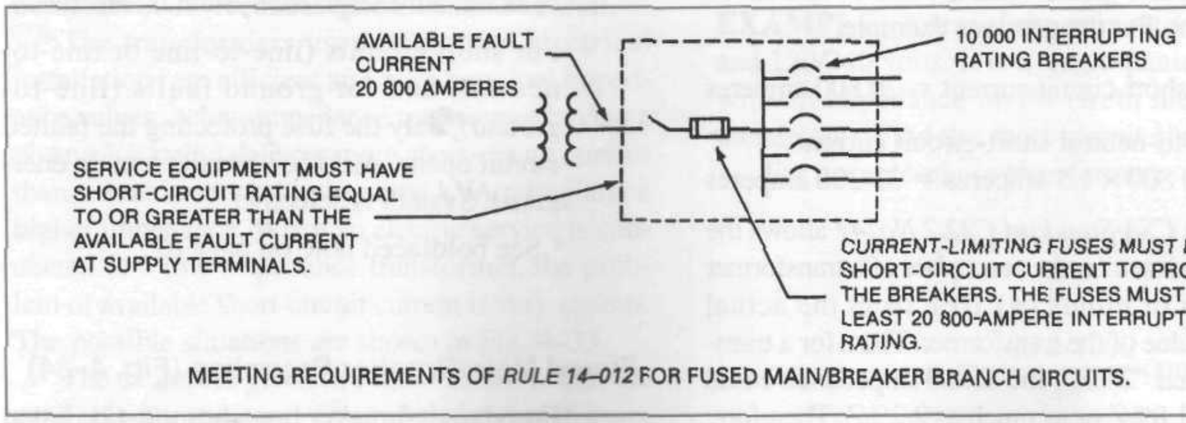


Fig. 4–34 Fused main/breaker branch circuits. (Courtesy of CSA Group)

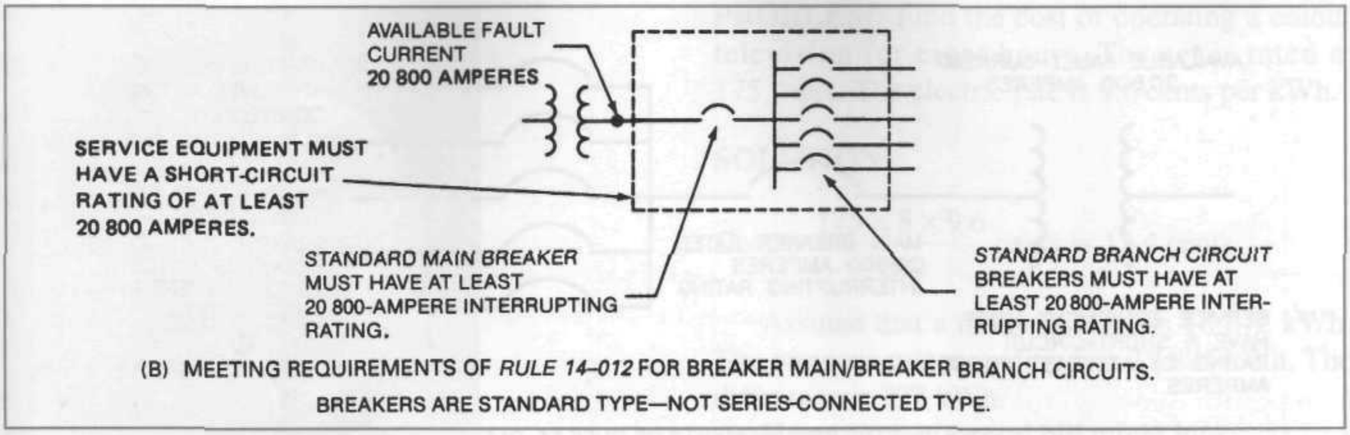


Fig. 4–35 Breaker main/breaker branch circuits. (Courtesy of CSA Group)

Breaker Main/Breaker Branches (Fig. 4–36) (Series Connected—Sometimes Called *Series Rated, Rule 14–014*)

- These breaker main/breaker branches must be listed as suitable for use as service equipment.
- They must be sized to satisfy the required ampacity as determined by service entrance calculations and/or local codes.
- They must be listed as series connected.

Note: **The terms and theory behind selective and nonselective systems are covered in detail in the *Electrical Wiring: Commercial* volume. In all instances, you should check the time–current curves of fuses and circuit breakers to be installed. Also check the circuit breaker manufacturer's unlatching time data, as these will help determine at what values of current the system will be selective or nonselective.**

Fault current calculations are covered in the *Electrical Wiring: Commercial* volume.

- Main breaker will have interrupting rating higher than the branch breaker. For example: main breaker has a 22 000-ampere interrupting rating, whereas branch breaker has a 10 000-ampere interrupting rating.
- Panel must be listed and marked with its maximum fault current rating.
- For branch-circuit faults (L-L, L-N, L-G) above the instant trip factory setting (i.e., 200-ampere main breaker with 5 × setting: $200 \times 5 = 1000$ amperes), both branch and main breakers will trip. The system is nonselective.
- For overload conditions and low-level faults on a branch, only the branch breaker will trip. The system is selective.
- Obtain time–current curves and unlatching time data from the manufacturer.
- The panel's integral rating is attained because when a heavy fault occurs, both main and branch breakers open. The two arcs in series add impedance; thus the fault current is reduced to a level less than the 10 000 AIR rating of the branch-circuit breaker.
- For series-rated panelboards where the available fault current exceeds the interrupting rating of the branch-circuit breakers, the equipment must be marked by the manufacturer as having a series combination interrupting rating at least equal to the maximum available fault current, *Rule 14–014(d)*.
- When panels containing low interrupting rating circuit breakers are separated from the equipment in which the higher interrupting rating circuit breakers protecting the panel are installed, the system becomes a field-installed *series-rated system.* This panel must be field-marked (by the installer) and this marking must be readily visible, *Rule 14–014(e). This marking calls attention to the fact that the actual available fault*

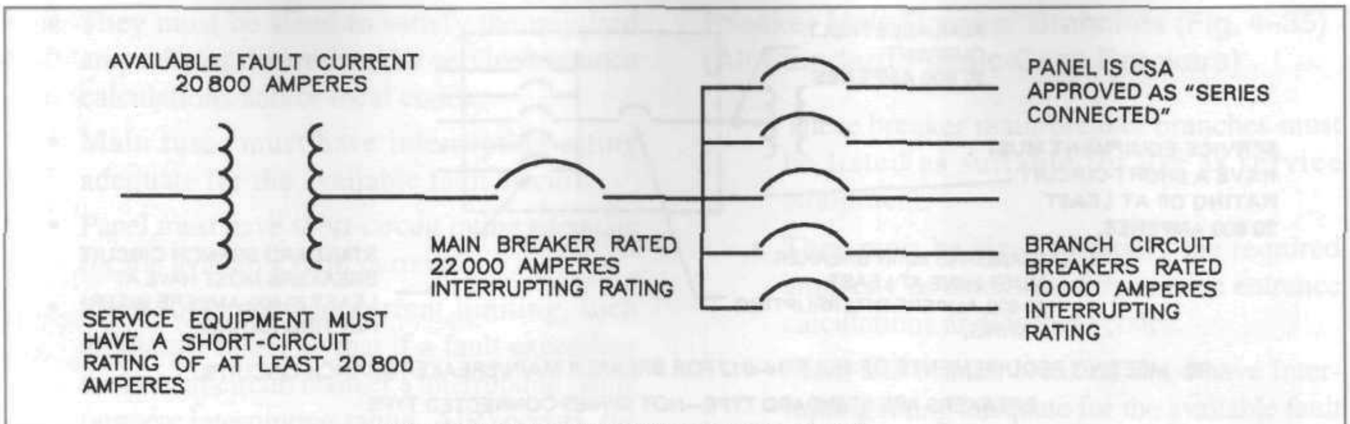


Fig. 4–36 Breaker main/breaker branch circuits (series-connected plastic-case type). (Courtesy of CSA Group)

current exceeds the interrupting rating of the breakers in the panel, and that the panel is protected by properly selected circuit breakers back at the main equipment. The label will appear on panelboards and enclosed panelboards and may appear as follows:

When protected by ___ A maximum HRC ___ fuse or (manufacturer's name and type designation) circuit breaker rated not more than ___ A, this panelboard is suitable for use on a circuit capable of delivering not more than ___ A RMS symmetrical, ___ V maximum.

CAUTION

SERIES-RATED SYSTEM

CAUTION: Closely check the manufacturer's catalogue numbers to be sure that the circuit-breaker combination you are intending to install *in series* is recognized by the CSA for that purpose. This is extremely important because many circuit breakers have the same physical size and dimensions, yet have different interrupting and voltage ratings, and have not been tested as *series-rated* devices. To install these as a series combination constitutes a violation of *Rules 14–012* and *14–014*, which could be dangerous.

READING THE METER

Fig. 4–37 shows a typical single-phase watt-hour meter with five dials. From left to right, the dials represent tens of thousands, thousands, hundreds, tens, and units of kilowatt-hours.

Starting with the first dial (on the left), record the last number the pointer has passed. Continue doing this with each dial until the full reading is obtained. The reading on the five-dial meter in Fig. 4–38 is 18 672 kWh.

If the meter reads 18 975 one month later (Fig. 4–39) by subtracting the previous reading of 18 672, it is found that 303 kWh were used during the month.

The number is multiplied by the rate per kilowatt-hour, and the power company bills the consumer for the energy used. The utility may also add a fuel adjustment charge.

COST OF USING ELECTRICAL ENERGY

A watt-hour meter is always connected into some part of the service entrance equipment. In residential metering, a watt-hour meter is normally installed as part of the service entrance.

All electrical energy consumed is metered so that the utility can bill the customer on a monthly or bimonthly basis.

The kilowatt (kW) is a convenient unit of electrical power. One thousand watts (W) is equal to one kilowatt (kW). The watt-hour meter measures

Fig. 4–37 Typical single-phase watt-hour meter.
(Courtesy of Landis+Gyr)

both wattage and time. As the dials of the meter turn, the kilowatt-hour (kWh) consumption is continually recorded.

Utility rates are based on so many cents per kilowatt-hour.

EXAMPLE: One kWh will light a 100-watt light bulb for ten hours. One kWh will operate a 1000-watt electric heater for one hour. Therefore, if the electric rate is 8 cents per kilowatt-hour, the use of a 100-watt bulb for ten hours would cost 8 cents. A 1000-watt electric heater could be used for one hour at a cost of 8 cents.

$$\text{kWh} = \frac{\text{Watts} \times \text{hours}}{1000} = \frac{100 \times 10}{1000}\ \text{kWh} = 1\ \text{kWh}$$

The cost of the energy used by an appliance is:

$$\text{Cost} = \frac{\text{Watts} \times \text{Hours used} \times \text{Cost per kWh}}{1000}$$

PROBLEM: Find the cost of operating a colour television for eight hours. The set is rated at 175 watts. The electric rate is 9.6 cents per kWh.

SOLUTION:

$$\text{Cost} = \frac{175 \times 8 \times 9.6}{1000}\ \text{cents} = 13.4\ \text{cents}$$

Assume that a meter now reads 18 672 kWh. The previous meter reading was 17 895 kWh. The difference is 777 kWh.

Here is how a typical bill might look:

GENERIC ELECTRIC COMPANY			
Days of Service 33	from 01–28–12	to 03–01–12	Due Date 03–25–12
Present reading			18 672
Last reading			17 895
Kilowatt-hours			777
Rate/kWh			0.08
Amount			$62.16
Total			$62.16 + applicable taxes

Some utilities apply a fuel adjustment charge that may increase or decrease the electric bill. These charges, on a "per kWh" basis, enable the electric utility to recover from the consumer extra expenses it might incur for fuel costs used in generating electricity. These charges can vary each time the utility prepares the bill, without it having to apply to the regulatory agency for a rate change.

Some utilities increase their rates during the summer months when people turn on their air conditioners. This air-conditioning load taxes the utility's generating capabilities during the peak summer months. The higher rate structure also gives people

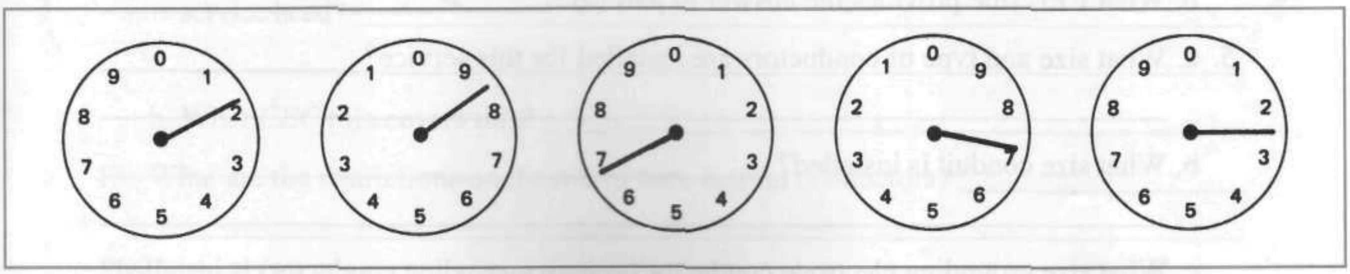


Fig. 4–38 The reading of this five-dial meter is 18 672 kWh.

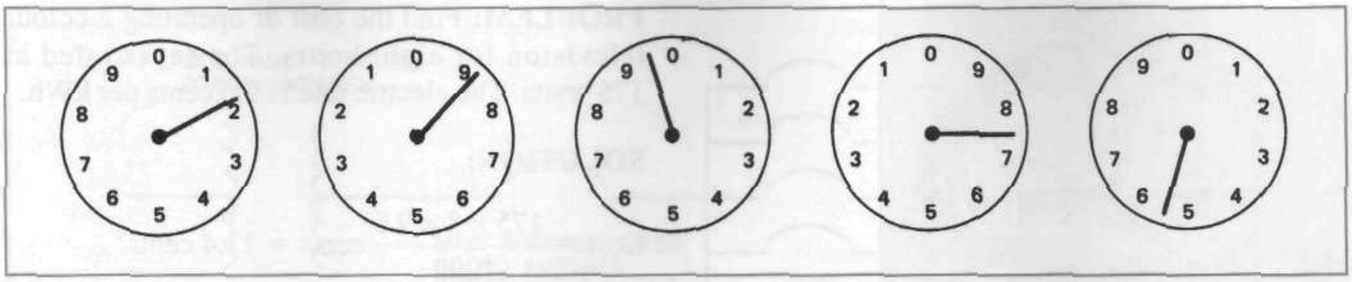


Fig. 4–39 One month later, the meter reads 18 975 kilowatt-hours, indicating that 303 kilowatt-hours were used during the month.

an incentive to not set their thermostats too low, thus saving energy.

To encourage customers to conserve energy, a utility company might offer the following rate structure:

First 500 kWh @ 6.12 cents per kWh
Over 500 kWh @ 10.64 cents per kWh (summer rate)
Over 500 kWh @ 8.64 cents per kWh (winter rate)

REVIEW

Note: Refer to the *CEC* or the blueprints provided with this textbook when necessary.

1. Where does a consumer's service start and end? ______

2. What are supply service conductors? ______

3. Who is responsible for determining the service location? ______

4. a. [Circle one.] The service head must be located (above) (below) the point where the supply service conductors are spliced to the consumer's service conductors.

   b. What *CEC* rule provides the answer to part (a)? ______

5. a. What size and type of conductors are installed for this service? ______

   b. What size conduit is installed? ______

   c. What size grounding electrode conductor (system grounding conductor) is installed? (Not neutral) ______

d. Is the grounding electrode conductor insulated, armoured, or bare? ______

______

6. How and where is the grounding electrode conductor attached to the water pipe? ______

______

______

7. When a service mast is extended through a roof, must it be guyed? ______

______

8. What are the minimum distances or clearances for the following?

   a. Supply service conductors, clearance over private driveway ______

   b. Supply service conductors, clearance over private sidewalks ______

   c. Supply service conductors, clearance over alleys ______

   d. Supply service conductors, clearance over a roof having a roof pitch that may be walked on. (Voltage between conductors does not exceed 300 volts.) ______

   e. Supply service conductors, horizontal clearance from a porch ______

   f. Supply service conductors, clearance from a window or door ______

9. What size ungrounded conductors are installed for each of the following residential services? (Use type RW90 XLPE copper conductors.)

   a. 60-ampere service No. _____ RW90 XLPE copper

   b. 100-ampere service No. _____ RW90 XLPE copper

   c. 200-ampere service No. _____ RW90 XLPE copper

10. What size grounding electrode conductors are installed for the services listed in Question 9? (*Rule 10–812*)

   a. 60-ampere service No. _____ AWG grounding conductor

   b. 100-ampere service No. _____ AWG grounding conductor

   c. 200-ampere service No. _____ AWG grounding conductor

11. What is the recommended height of a meter socket from the ground?

______

12. a. What is the minimum length of conductor that must be left extending out of the service head? ______

______

   b. What *CEC* rule covers this? ______

13. What are the restrictions on the use of bare neutral conductors? ______

______

______

______

14. How far must mechanical protection be provided when underground service conductors are carried up a pole? ______________________________

15. What is the maximum number of consumer's services allowed without special permission? Quote the *CEC* rule. ______________________________

16. Complete the following table by filling in the columns with the appropriate information.

	CIRCUIT NUMBER	AMPERE RATING	POLES	VOLTS	WIRE SIZE
A. LIVING ROOM RECEPTACLE OUTLETS					
B. WORKBENCH RECEPTACLE OUTLETS					
C. WATER PUMP					
D. ATTIC EXHAUST FAN					
E. KITCHEN LIGHTING					
F. HYDROMASSAGE TUB					
G. ATTIC LIGHTING					
H. COUNTER-MOUNTED COOKING UNIT					
I. ELECTRIC FURNACE					

17. a. What size conductors supply Panel B? ______________________________

b. What size conduit? ______________________________

c. Is this raceway run in the form of EMT or rigid conduit? ______________________________

d. What size overcurrent device protects the feeders to Panel B? ______________________________

18. How many electric meters are provided for this residence? ______________________________

19. According to the *CEC*, is it permissible to ground rural service entrance systems and equipment to driven ground rods when a metallic water system is not available? ______________________________

20. What table of the *CEC* lists the sizes of grounding electrode conductors to be used for service entrances of various sizes similar to the type found in the residence discussed in this text? ______________________________

21. Do the following conductors require mechanical protection?
    a. No. 8 grounding conductor
    b. No. 6 grounding conductor
    c. No. 4 grounding conductor
22. Why is bonding service entrance equipment necessary?
23. What special types of bushings are required on service entrances when metallic raceways are used?
24. When No. 8 AWG conductors or larger are installed, what additional provision is required on the conduit ends?
25. What minimum size copper bonding jumpers must be installed to properly bond the electric service for the residence discussed in this text?
26. a. What is a Type D fuse?

    b. Where could a Type D fuse be installed?
27. a. What is the maximum voltage permitted between conductors when using plug fuses?

b. May plug fuses be installed in a switch that disconnects a 120/240-volt clothes dryer? ______

c. Give a reason for the answer to (b). ______

28. What part of a circuit breaker causes the breaker to trip

a. on an overload? ______ b. on a short circuit? ______

29. List the standard sizes of circuit breakers up to and including 100 amperes. ______

30. Using the method shown in this unit, what is the approximate short-circuit current available at the terminals of a 50-kVA single-phase transformer rated 120/240 volts? The transformer impedance is 1%.

a. line-to-line? ______

b. line-to-neutral? ______

31. Where is the service for this residence located? ______

32. a. On what type of wall is Panel A fastened? ______

b. On what type of wall is Panel B fastened? ______

33. When conduits pass through the wall from outside to inside, the conduit must be ______ to prevent air circulation through the conduit.

34. Briefly explain why electrical systems and equipment are grounded. ______

35. What *CEC* rule states that all overcurrent devices must have adequate interrupting ratings for the current to be interrupted? ____________________

36. All electrical components have some sort of "withstand rating," which indicates the ability of the component to withstand fault currents for the time required by the overcurrent device to open the circuit. What *CEC* rule refers to withstand ratings with reference to fault current protection? ____________________

37. Arcing fault damage is closely related to the value of ____________________.

38. In general, systems are grounded so that the maximum voltage to ground does not exceed [circle one]

    a. 120 volts   b. 150 volts   c. 300 volts

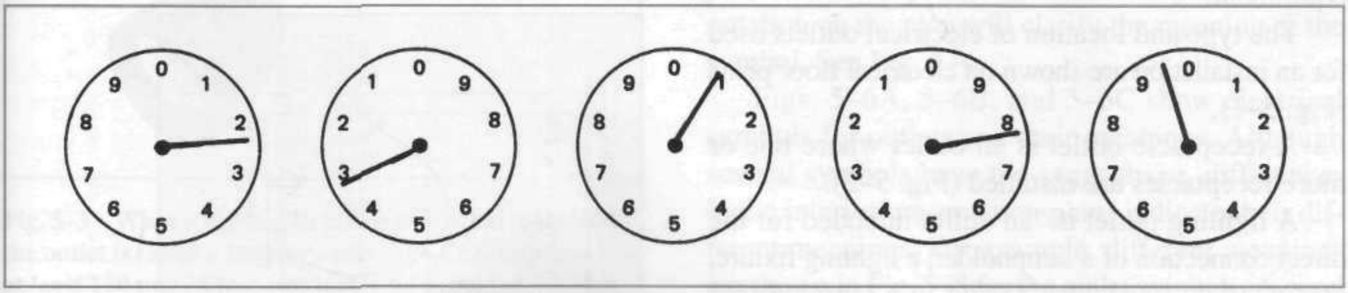
39. An electric clothes dryer is rated at 5700 watts. The electric rate is 10.091 cents per kWh. The dryer is used continuously for three hours. Find the cost of operation, assuming that the heating element is on continuously. ____________________

40. *Rule 14–012* requires that the service equipment (breakers, fuses, and the panel itself) be rated [circle one]

    a. equal to or greater than the current it must interrupt

    b. equal to or greater than the available voltage and the fault current that is available at the terminals

41. Read the meter below. Last month's reading was 22 796. How many kilowatt-hours of electricity were used for the current month? ____________________



UNIT 5

Electrical Outlets

OBJECTIVES

After studying this unit, the student will be able to

- identify and explain the electrical outlet symbols used in the plans of the single-family dwelling
- discuss the types of outlets, boxes, fixtures, and switches used in the residence
- explain the methods of mounting the various electrical devices used in the residence
- understand the meaning of the terms *receptacle outlet* and *lighting outlet*
- *understand the preferred way to position receptacles in wall boxes*
- position wall boxes in relation to finished wall surfaces
- make surface extensions from concealed wiring
- *determine the number of wires permitted in a given size box*

ELECTRICAL OUTLETS

The *CEC* defines an *outlet* as a point on a wiring system where current is taken to supply utilization equipment.

The type and location of electrical outlets used for an installation are shown on electrical floor plans (Fig. 5–1).

A receptacle outlet is an outlet where one or more receptacles are installed (Fig. 5–2).

A lighting outlet is "an outlet intended for the direct connection of a lampholder, a lighting fixture, or a pendant cord terminating in a lampholder" (Fig. 5–3).

A toggle switch is *not* an outlet; however, the term *outlet* is used broadly by electricians to include noncurrent-consuming switches and similar control devices in a wiring system when estimating the cost of the installation. Each type of outlet is represented on the plans as a symbol.

Fig 5–1 shows the outlets by the symbols ⊖ and -○-. Standard electrical symbols are shown in Fig. 2–9E on page 17.

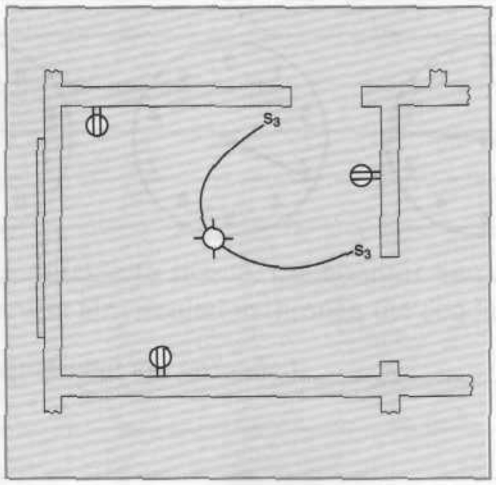


Fig. 5–1 Use of electrical symbols and notations on a floor plan.

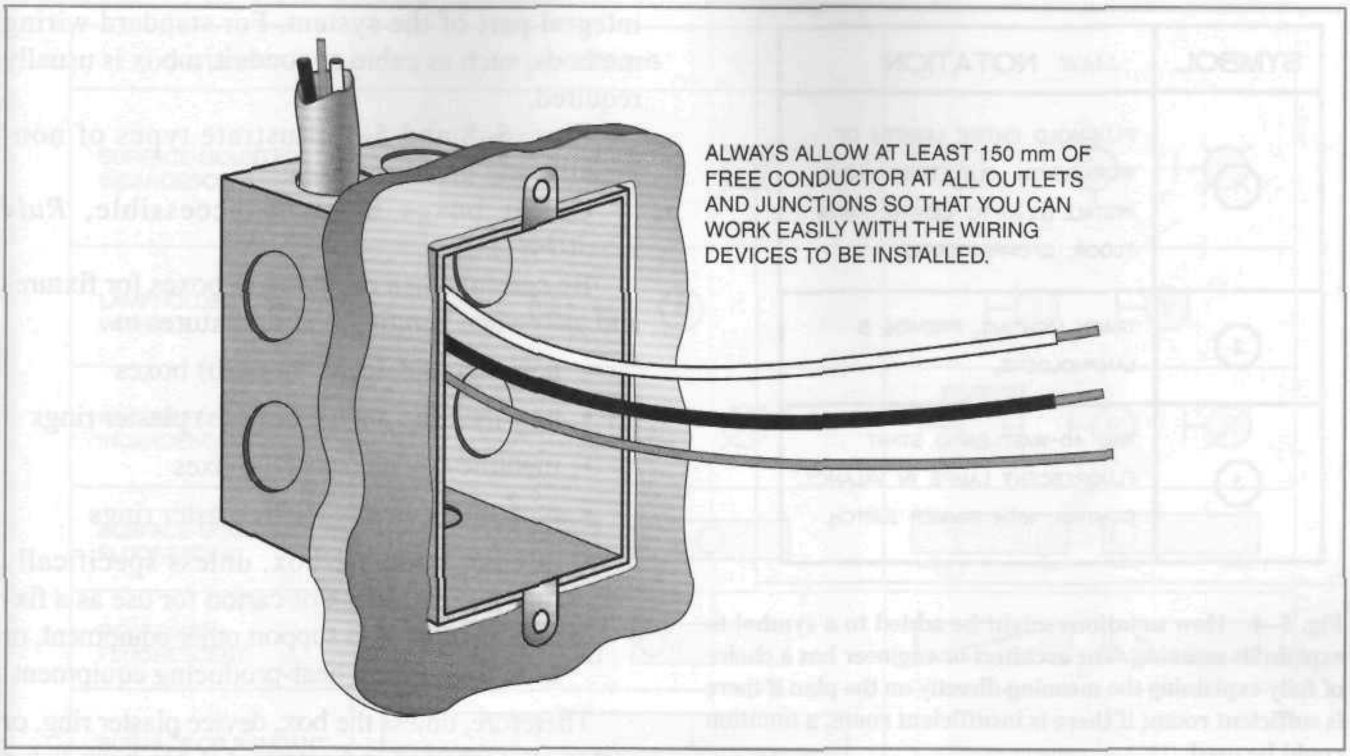


Fig. 5–2 When a receptacle is connected to the wires, the outlet is called a *receptacle outlet*. For ease in working with wiring devices, *CEC Rule 12–3000(6)* requires that at least 150 mm of free conductor be provided.

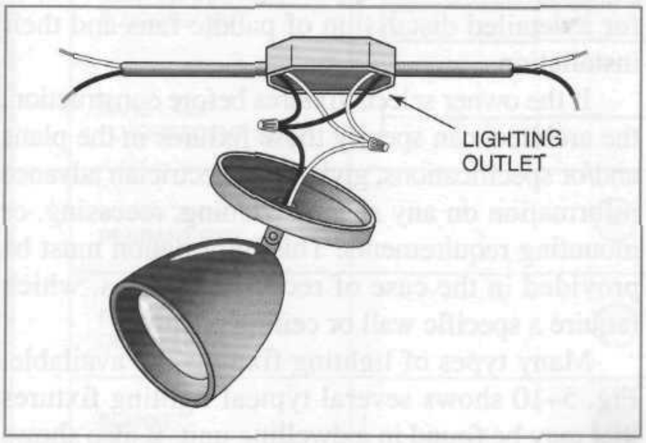


Fig. 5–3 When a lighting fixture is connected to the wires, the outlet is called a *lighting outlet*. The *CEC* requires that at least 150 mm of free conductor be provided.

The curved lines in Fig. 5–1 run from the outlet to the switch or switches that control the outlet. These lines are usually curved so that they cannot be mistaken for hidden edge lines. Outlets shown on the plan without curved lines are independent and have no switch control.

When preparing electrical plans, most architects, designers, and electrical engineers use symbols approved by the Standards Council of Canada (SCC) whenever possible. However, plans may contain symbols that are not found in these standards. When unlisted (non-standard) symbols are used, the electrician must refer to a legend that interprets these symbols. The legend may be included on the plans or in the specifications. In many instances, a notation on the plan will clarify the meaning of the symbol. See Fig. 5–4.

Figs. 5–6A, 5–6B, and 5–6C show electrical symbols for outlets and their meanings. Although several symbols have the same shape, differences in the interior presentation plans indicate their different meanings. For example, different meanings are shown in Fig. 5–5 for the outlet symbols. A good practice in studying symbols is to learn the basic forms first and then add the supplemental information to obtain different meanings.

LIGHTING FIXTURES AND OUTLETS

Architects often include in the specifications an amount of money to purchase electrical fixtures. The electrical contractor includes this amount in

SYMBOL	NOTATION
1	PLUGMOLD ENTIRE LENGTH OF WORKBENCH. OUTLETS 90 cm O.C. INSTALL 122 cm TO CENTRE FROM FLOOR. GFCI-PROTECTED.
2	TRACK LIGHTING. PROVIDE 5 LAMPHOLDERS.
3	TWO 40-WATT RAPID START FLUORESCENT LAMPS IN VALANCE. CONTROL WITH DIMMER SWITCH.

Fig. 5–4 How notations might be added to a symbol to explain its meaning. The architect or engineer has a choice of fully explaining the meaning directly on the plan if there is sufficient room; if there is insufficient room, a notation could be used.

Fig. 5–5 Variations in outlet symbols.

the bid, and the choice of fixtures is then left to the homeowner. If the owner selects fixtures whose total cost exceeds the fixture allowance, the owner is expected to pay the difference between the actual cost and the specification allowance. If the fixtures are not selected before the roughing-in stage of wiring of the house, the electrician usually installs outlet boxes having standard fixture mounting studs.

Most modern surface-mount lighting fixtures can be fastened to an octagon box (Figs. 5–7A and 5–7B) or an outlet box with a plaster ring using appropriate No. 8–32 metal screws and mounting strap furnished with the fixture.

A box must be installed at each outlet or switch location, *Rule 12–3000(1)*. There are exceptions to this rule, but in general they relate to special manufactured wiring systems where the "box" is an integral part of the system. For standard wiring methods, such as cable or conduit, a box is usually required.

Figs. 5–8 and 5–9 illustrate types of non-metallic and metallic boxes.

Outlet boxes must be accessible, *Rule 12–3014(1)*.

Be careful when roughing in boxes for fixtures and also when hanging ceiling fixtures to

- non-metallic device (switch) boxes
- non-metallic device (switch) plaster rings
- metallic device (switch) boxes
- metallic device (switch) plaster rings
- any non-metallic box, unless specifically marked on the box or carton for use as a fixture support, or to support other equipment, or to accommodate heat-producing equipment

Therefore, unless the box, device plaster ring, or carton is marked to indicate that it has been listed by the CSA for the support of fixtures, do not use where fixtures are to be hung. Refer to *Rule 12–1110*.

Be careful when installing a ceiling outlet box for the purpose of supporting a fan. See Unit 11 for a detailed discussion of paddle fans and their installation.

If the owner selects fixtures before construction, the architect can specify these fixtures in the plans and/or specifications, giving the electrician advance information on any special framing, recessing, or mounting requirements. This information must be provided in the case of recessed fixtures, which require a specific wall or ceiling opening.

Many types of lighting fixtures are available. Fig. 5–10 shows several typical lighting fixtures that may be found in a dwelling unit. It also shows the electrical symbols used on plans to designate these fixtures and the type of outlet boxes or switch boxes on which the lighting fixtures can be mounted. A standard receptacle outlet is shown as well. These switch boxes are made of steel; they may also be made of plastic, as shown in Fig. 5–8.

When mounting an outlet box in a wall or ceiling that is to be insulated and covered with a vapour barrier, you must make special provision to maintain the integrity of the vapour barrier. A polyethylene boot covers the outlet box and is sealed to the 6-mm polyethylene vapour barrier.

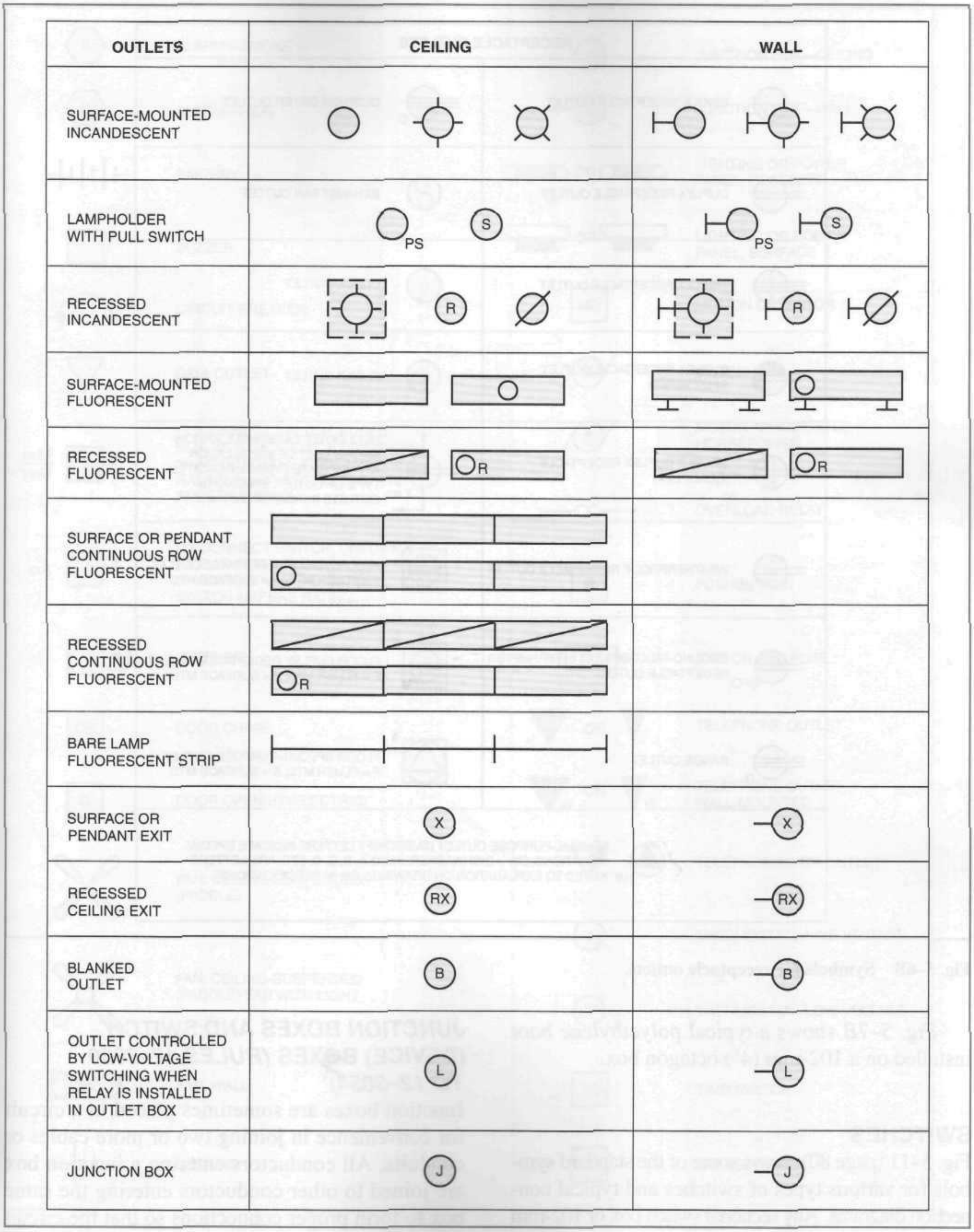


Fig. 5–6A Symbols for different types of lighting outlets.

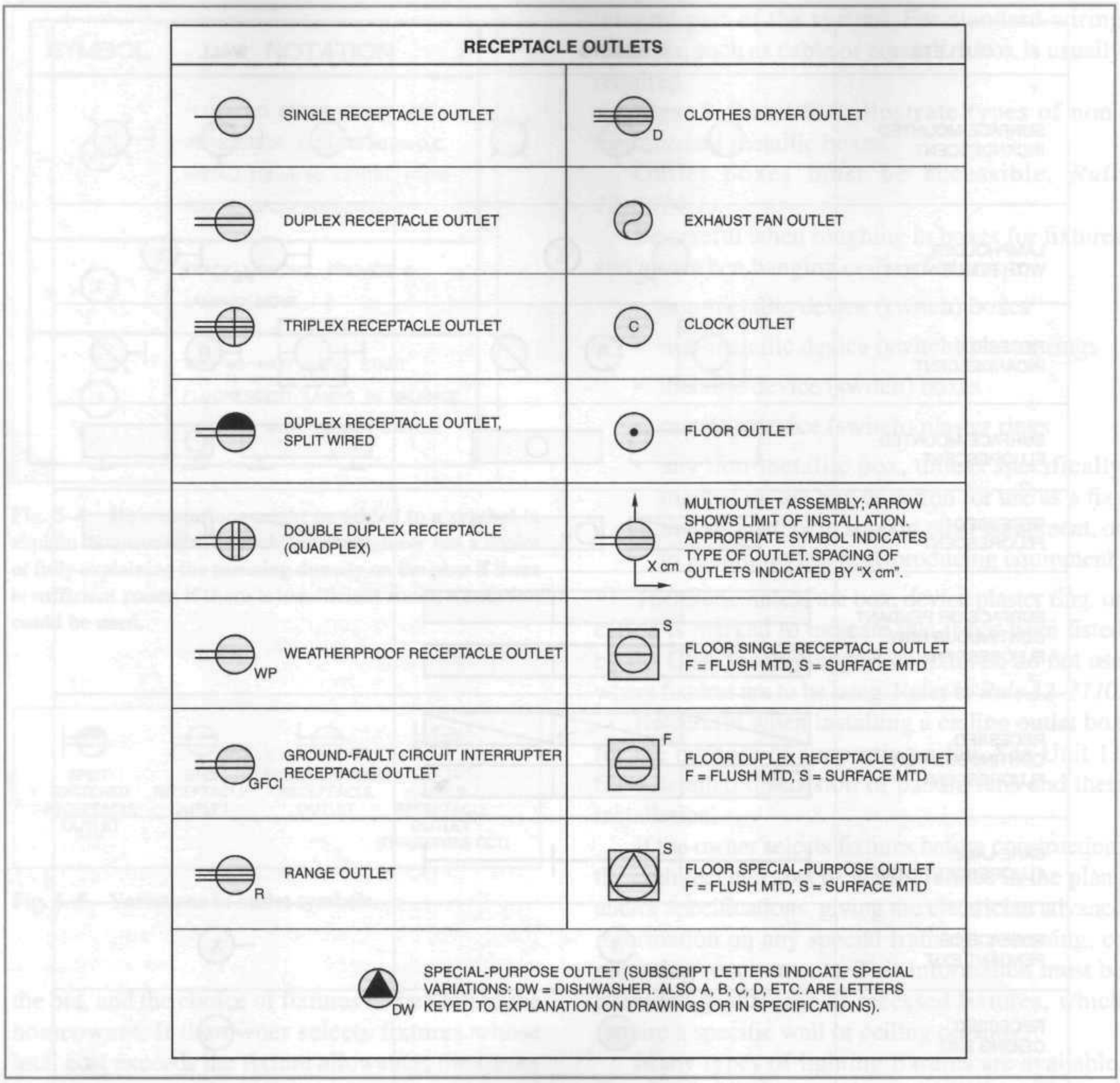


Fig. 5–6B Symbols for receptacle outlets.

Fig. 5–7B shows a typical polyethylene boot installed on a 102-mm (4″) octagon box.

SWITCHES

Fig. 5–11 (page 80) shows some of the standard symbols for various types of switches and typical connection diagrams. Any sectional switch box or 102-mm (4-in.) square box with a side-mounting bracket and raised switch cover can be used to install these switches (Fig. 5–10).

JUNCTION BOXES AND SWITCH (DEVICE) BOXES *(RULES 12–3000 TO 12–3034)*

Junction boxes are sometimes placed in a circuit for convenience in joining two or more cables or conduits. All conductors entering a junction box are joined to other conductors entering the same box to form proper connections so that the circuit will operate in its intended manner.

All electrical installations must conform to the *CEC* standards requiring that junction boxes be

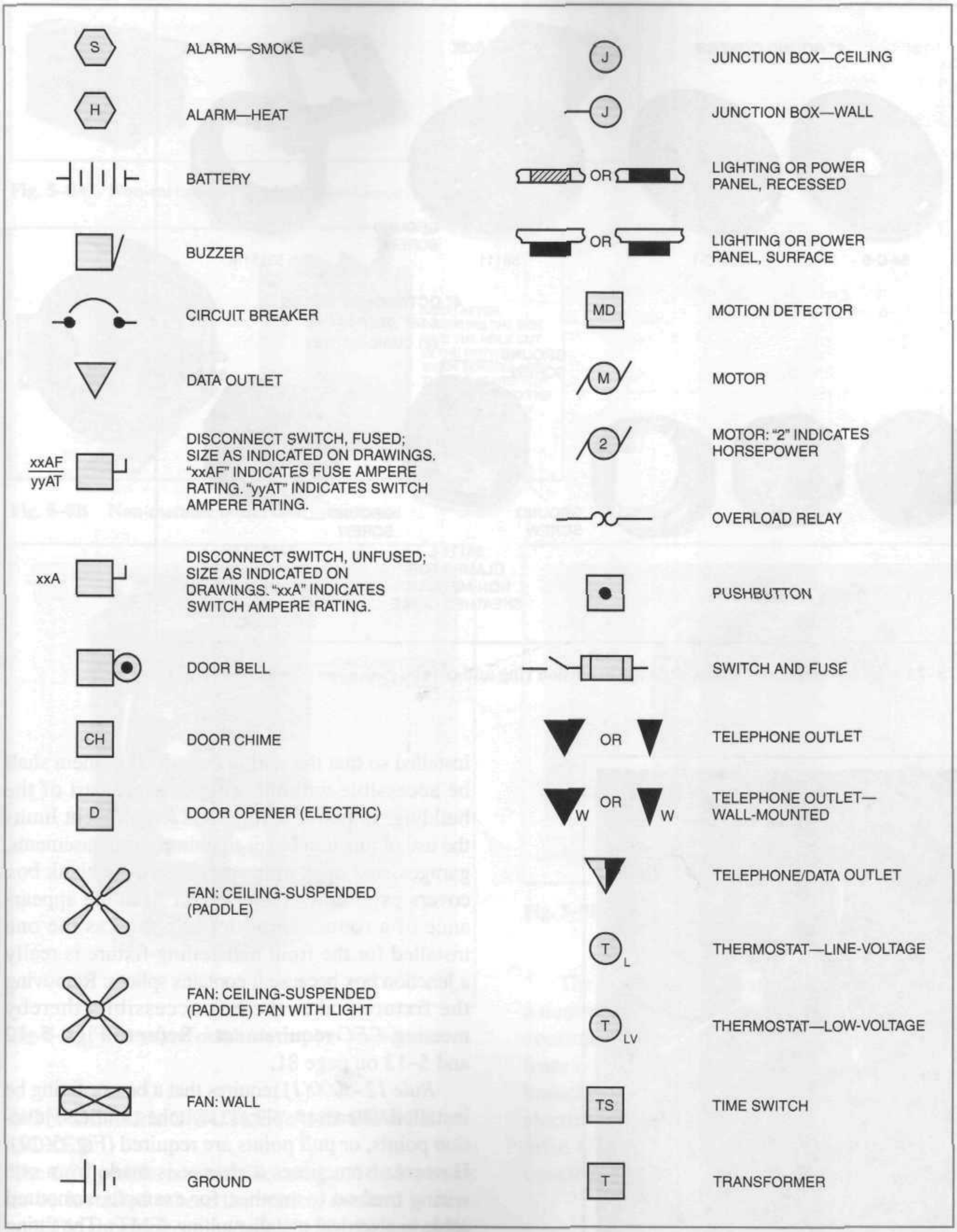


Fig. 5–6C Miscellaneous symbols.

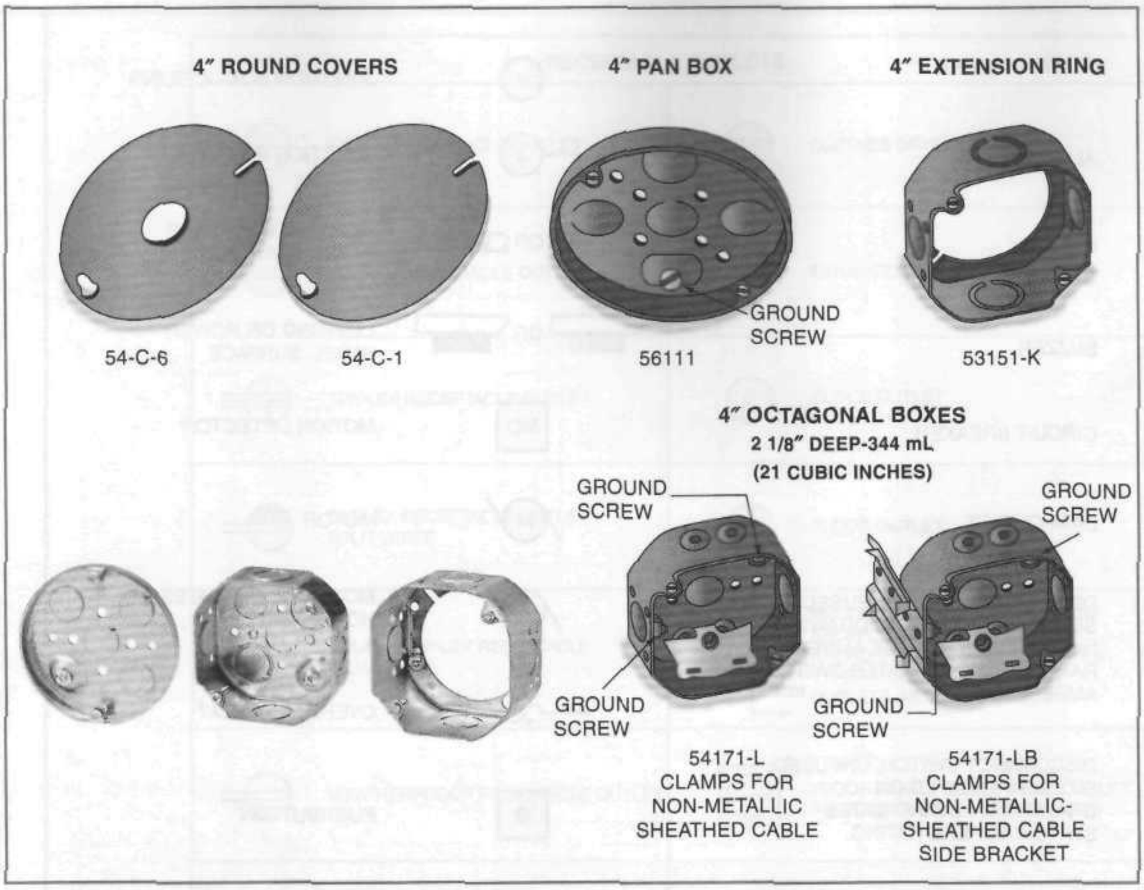


Fig. 5–7A Octagonal outlet boxes, showing extension ring and covers. (Photos courtesy of Thomas & Betts Incorporated)

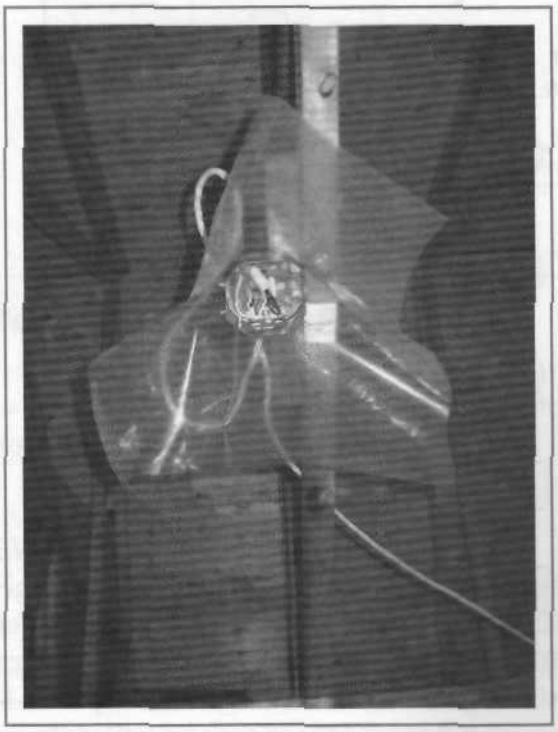


Fig. 5–7B Outlet box complete with vapour boot.
(© www.cottageontheedge.com)

installed so that the wiring contained in them shall be accessible without removing any part of the building. In house wiring, this requirement limits the use of junction boxes to unimproved basements, garages, and open attic spaces because blank box covers exposed to view detract from the appearance of a room. An outlet box such as the one installed for the front hall ceiling fixture is really a junction box because it contains splices. Removing the fixture makes the box accessible, thereby meeting *CEC* requirements. Refer to Figs. 5–12 and 5–13 on page 81.

Rule 12–3000(1) requires that a box or fitting be installed wherever splices, switches, outlets, junction points, or pull points are required (Fig. 5–12). However, sometimes a change is made from one wiring method to another, for example, armoured cable to electrical metallic tubing (EMT). The fitting where the change is made must be accessible after installation; see Fig. 5–14.

Boxes shall be rigidly and securely mounted, Rule 12–3010(1).

Fig. 5–8A Non-metallic outlet box. (Delmar/Cengage)

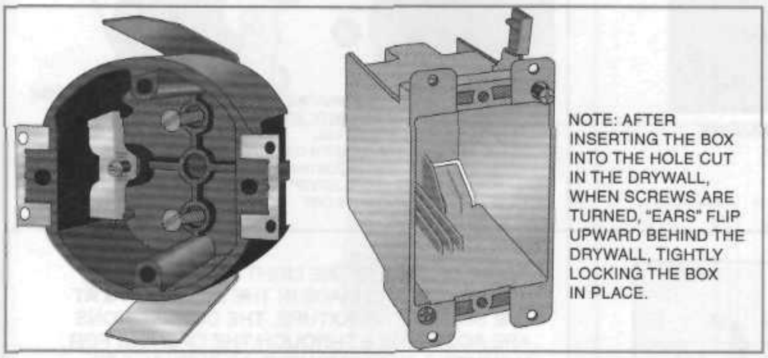


Fig. 5–8B Non-metallic outlet box. (Delmar/Cengage)

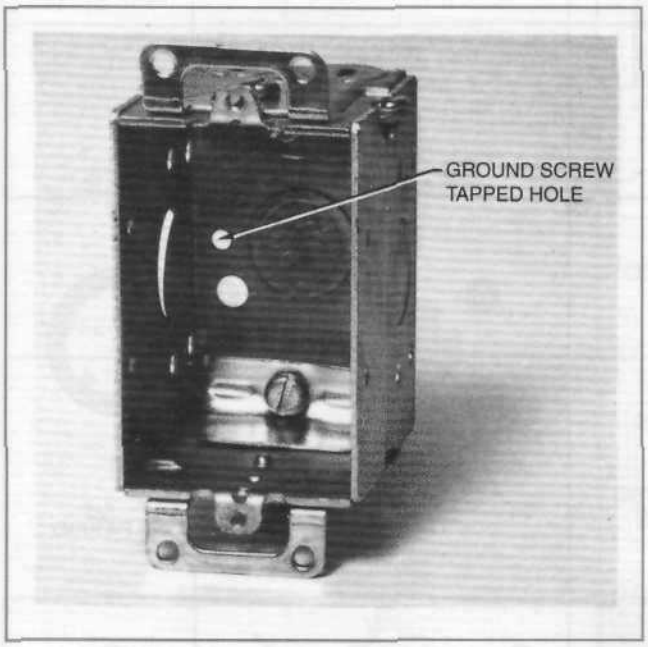


Fig. 5–9A Gang-type switch (device) box. (Delmar/Cengage)

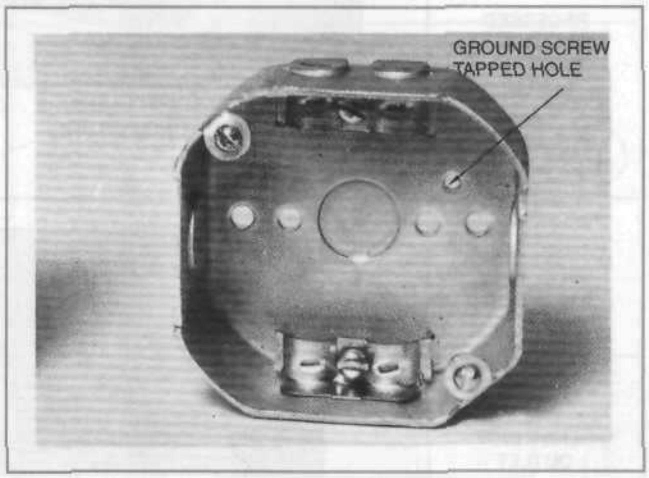


Fig. 5–9B Octagon box. (Delmar/Cengage)

NON-METALLIC OUTLET AND DEVICE BOXES

The *CEC* permits non-metallic outlet and device boxes to be installed where the wiring method is non-metallic sheathed cable, *Rule 12–524*. Non-metallic boxes may be used with armoured cable or metal raceways, but only if a proper means is provided inside the boxes to bond any and all metal raceways and/or armoured cables together, *Rule 12–3000(2)*.

The house wiring system is usually formed by a number of specific circuits, each consisting of a continuous run of cable from outlet to outlet or from box to box. The residence plans show many branch circuits for general lighting, appliances, electric heating, and other requirements. The specific *CEC* rules for each of these circuits are covered in later units.

GANGED SWITCH (DEVICE) BOXES

A flush switch or receptacle outlet for residential use fits into a standard $3 \times 2 \times 2\frac{1}{2}$-in. sectional switch box (sometimes called a *device box*). When two or

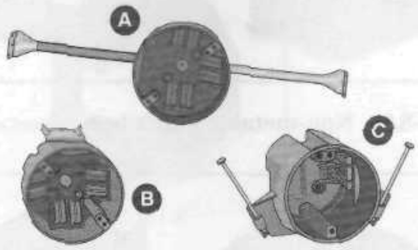
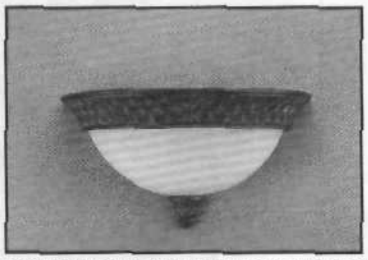
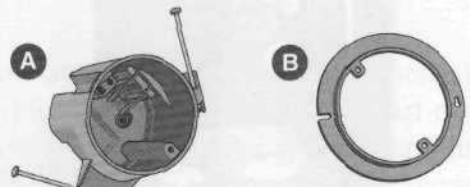
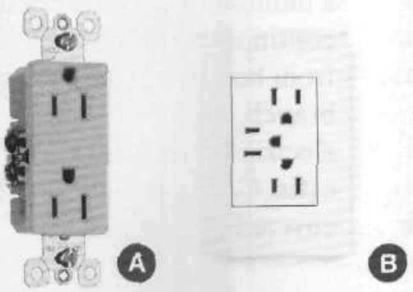
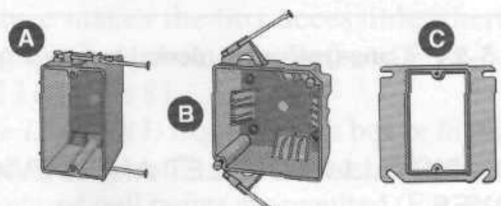
SYMBOL	TYPE OF LUMINAIRE (LIGHTING FIXTURE) OR OUTLET	BOXES THAT MAY BE USED
 CEILING *LIGHTING* OUTLET	1.  SURFACE-MOUNTED LUMINAIRE (LIGHTING FIXTURE)	 (A) ADJUSTABLE BRACKET WITH OUTLET BOX. (B) OUTLET BOX WITH BRACKET FOR JOIST MOUNTING. (C) OUTLET BOX WITH CAPTIVE NAILS/BRACKET FOR JOIST MOUNTING. BOXES ARE "LISTED" FOR LUMINAIRE (LIGHTING FIXTURE) SUPPORT
 RECESSED CEILING LIGHTING OUTLET	2.  RECESSED LUMINAIRE (LIGHTING FIXTURE)	CONNECTIONS TO THE LIGHT FIXTURE (LUMINAIRE) ARE MADE IN THE BOX SHOWN AT THE SIDE OF THE FIXTURE. THE CONNECTIONS ARE ACCESSIBLE THROUGH THE OPENING FOR MOUNTING THE LUMINAIRE, AS SHOWN. *CEC RULE 30-910.*
 WALL LIGHTING OUTLET	3.  WALL-MOUNTED LUMINAIRE (LIGHTING FIXTURE) ALSO CALLED A "SCONCE"	 (A) OUTLET BOX WITH CAPTIVE NAILS/BRACKET FOR STUD MOUNTING. (B) ADAPTER RING FOR OUTLET BOX. BOX "LISTED" FOR LUMINAIRE (LIGHTING FIXTURE) SUPPORT.
 DUPLEX RECEPTACLE OUTLET  *TRIPLEX* RECEPTACLE OUTLET	4. 	 (A) SINGLE-GANG SWITCH (DEVICE) BOX. (B) 102-mm SQUARE BOX WITH CAPTIVE NAILS *FOR STUD MOUNTING.* (C) 102-mm SQUARE SINGLE-GANG RAISED ADAPTER RING.

Fig. 5-10 Typical electrical symbols, items they represent, and boxes that could be used. (Photos courtesy of Progress Lighting (1, 3), Cooper Industries (2), and Leviton Manufacturing (4))

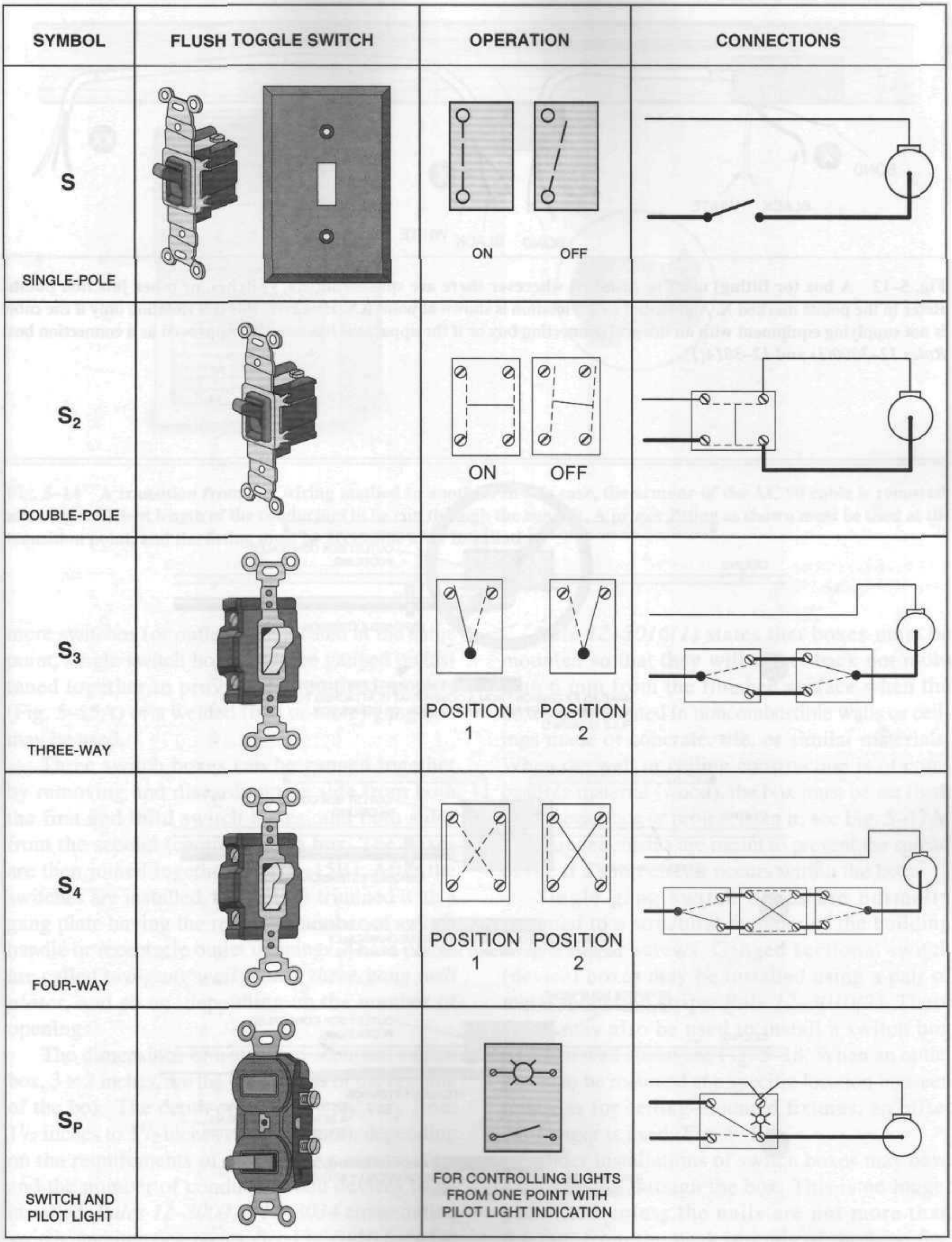


Fig. 5–11 Standard switches and symbols.

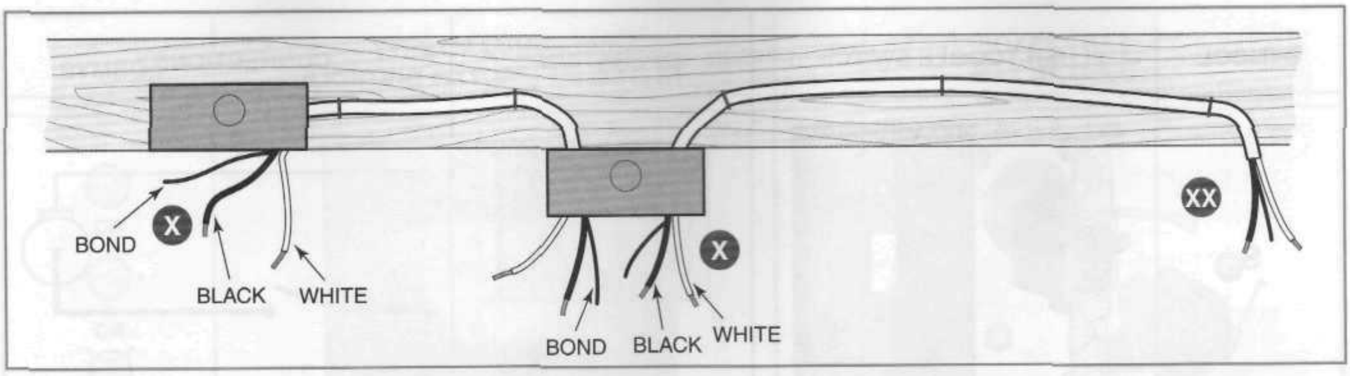


Fig. 5–12 A box (or fitting) must be installed wherever there are splices, outlets, switches, or other junction points. Refer to the points marked X. A potential *CEC* violation is shown at point XX. However, this is a violation only if the cable is not supplying equipment with an integral connection box or if the apparatus has not been approved as a connection box. *Rules 12–3000(1)* and *12–3014(1)*.

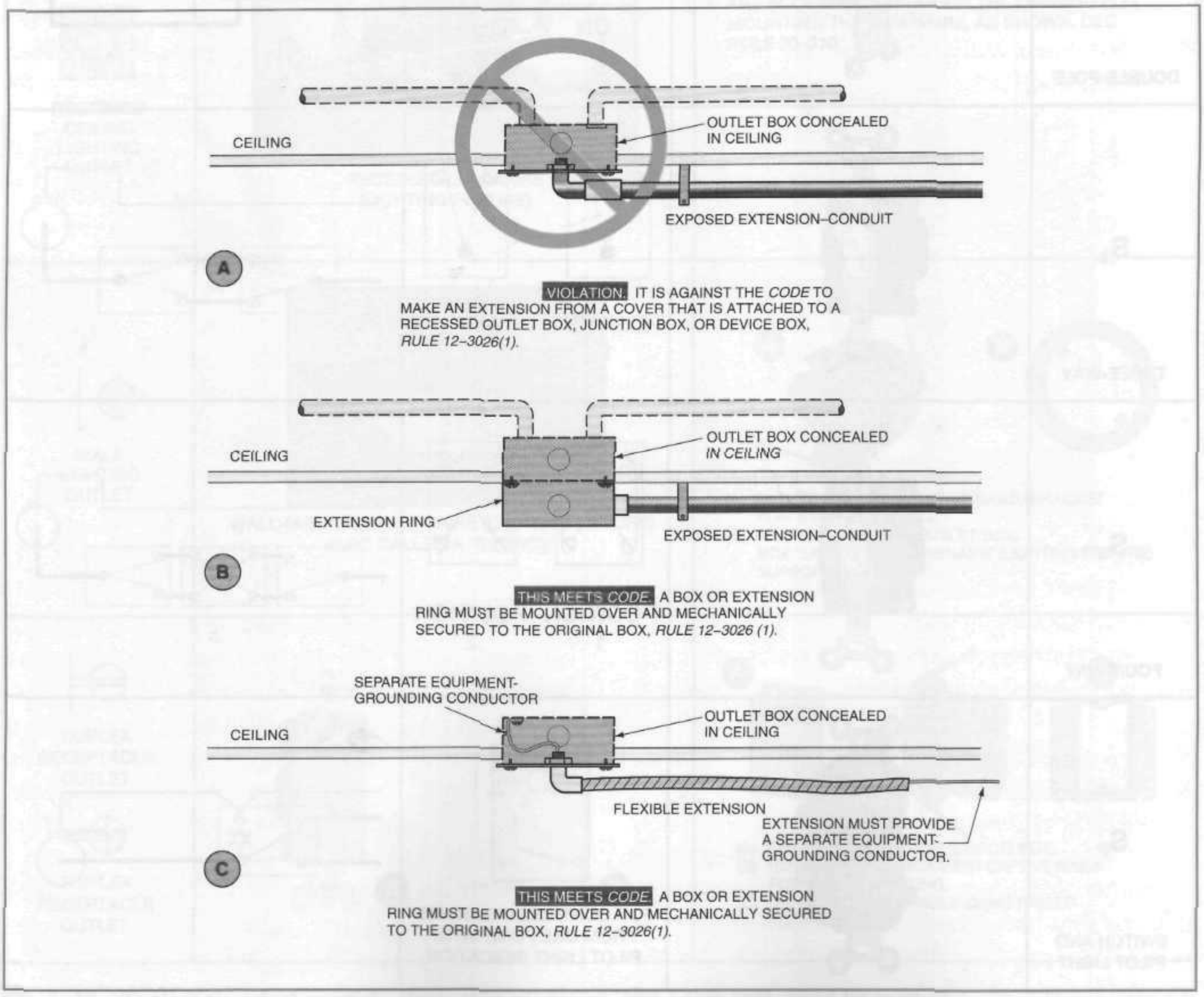


Fig. 5–13 How to make an extension from a flush-mounted box.

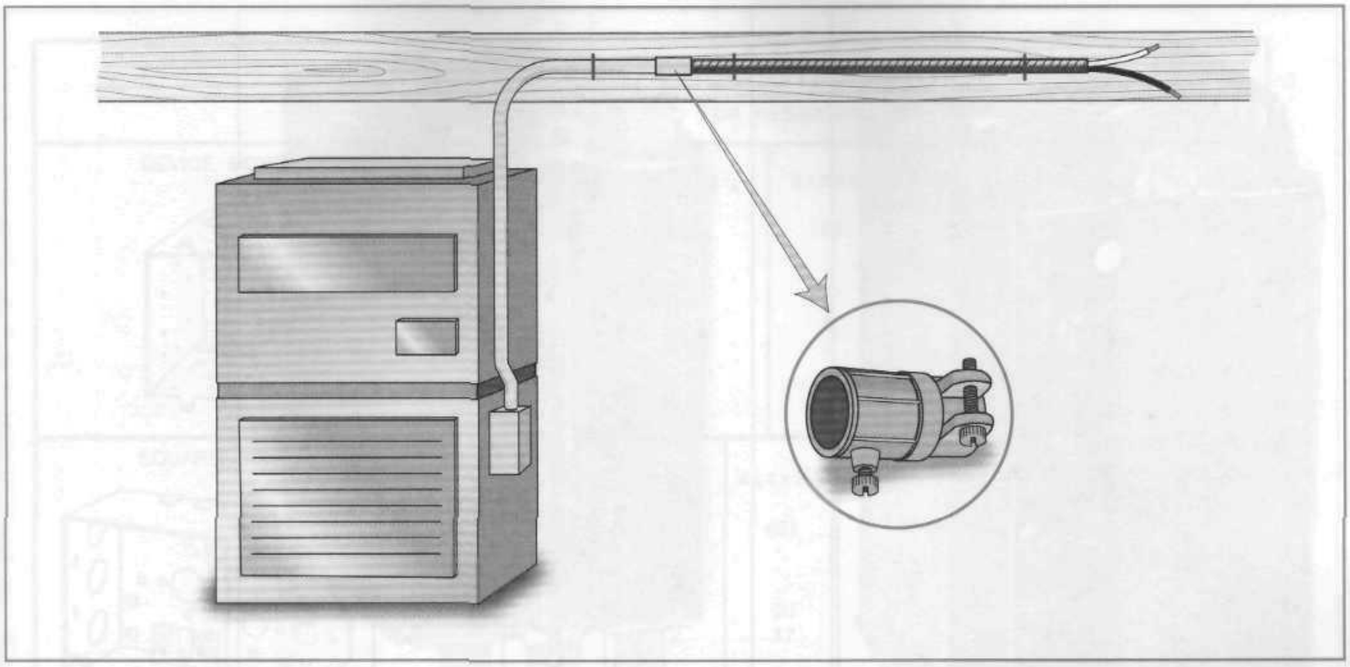


Fig. 5–14 A transition from one wiring method to another. In this case, the armour of the AC 90 cable is removed, allowing sufficient length of the conductors to be run through the conduit. A proper fitting as shown must be used at the transition point, and the fitting must be accessible after installation.

more switches (or outlets) are located at the same point, single switch boxes may be ganged or fastened together to provide the required mounts (Fig. 5–15A) or a welded (two or more) gang box may be used.

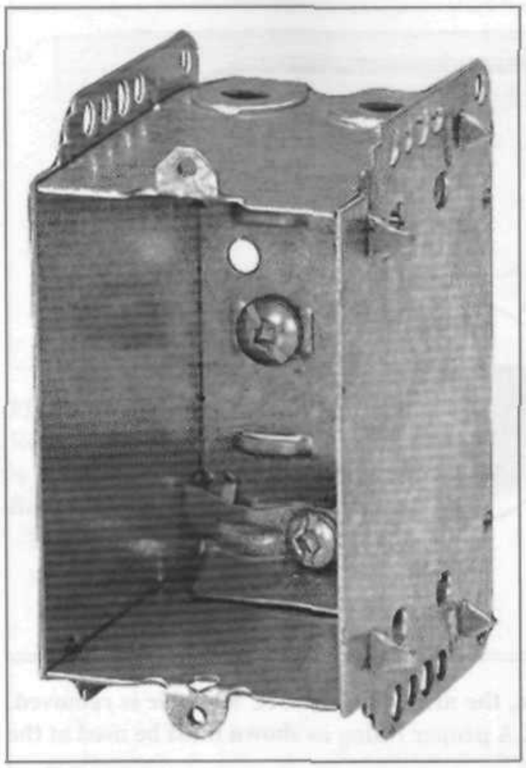
Three switch boxes can be ganged together by removing and discarding one side from both the first and third switch boxes, and both sides from the second (centre) switch box. The boxes are then joined together (Fig. 5–15B). After the switches are installed, the gang is trimmed with a gang plate having the required number of switch handle or receptacle outlet openings. These plates are called *two-gang wall plates*, *three-gang wall plates*, and so on, depending on the number of openings.

The dimensions of a standard sectional switch box, 3 × 2 inches, are the dimensions of the opening of the box. The depth of the box may vary from $1^1/_2$ inches to $3^1/_2$ inches (38 to 89 mm), depending on the requirements of the building construction and the number of conductors and devices to be installed. *Rules 12–3000* to *12–3034* cover outlet, switch, and junction boxes. See Fig. 5–16 for a list of common box dimensions.

Rule 12–3016(1) states that boxes must be mounted so that they will be set back not more than 6 mm from the finished surface when the boxes are mounted in noncombustible walls or ceilings made of concrete, tile, or similar materials. When the wall or ceiling construction is of combustible material (wood), the box must be set flush with the surface or project from it; see Fig. 5–17A. These requirements are meant to prevent the spread of fire if a short circuit occurs within the box.

Single gang switch boxes are normally mounted to a structural member of the building with nails or screws. Ganged sectional switch (device) boxes may be installed using a pair of metal mounting strips, *Rule 12–3010(2)*. These strips may also be used to install a switch box between wall studs; see Fig. 5–18. When an outlet box is to be mounted at a specific location between joists, as for ceiling-mounted fixtures, an offset bar hanger is used (Fig. 5–10).

Older installations of switch boxes may have nails passing through the box. This is no longer permitted unless the nails are not more than 6.4 mm from the back or ends of the box. See *Rule 12–3010(5)*.



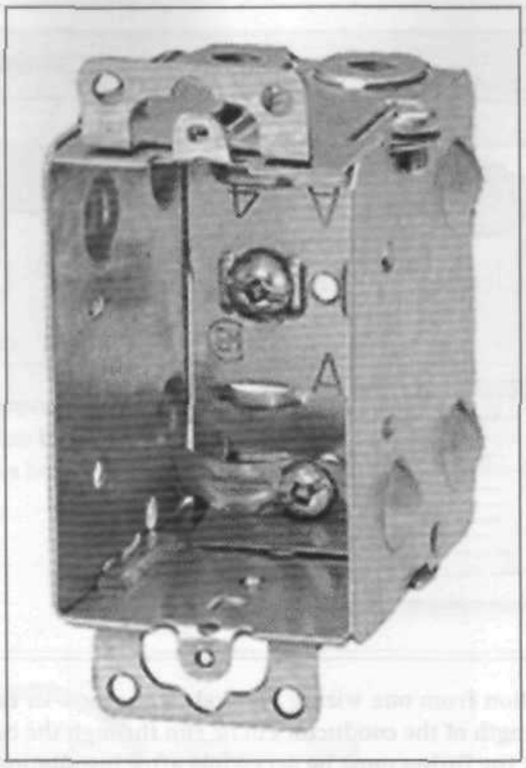


Fig. 5–15A Device boxes. Box on left has welded sides. Box on right has removable sides, which permit several boxes to be ganged together. (Courtesy of Sandy F. Gerolimon)

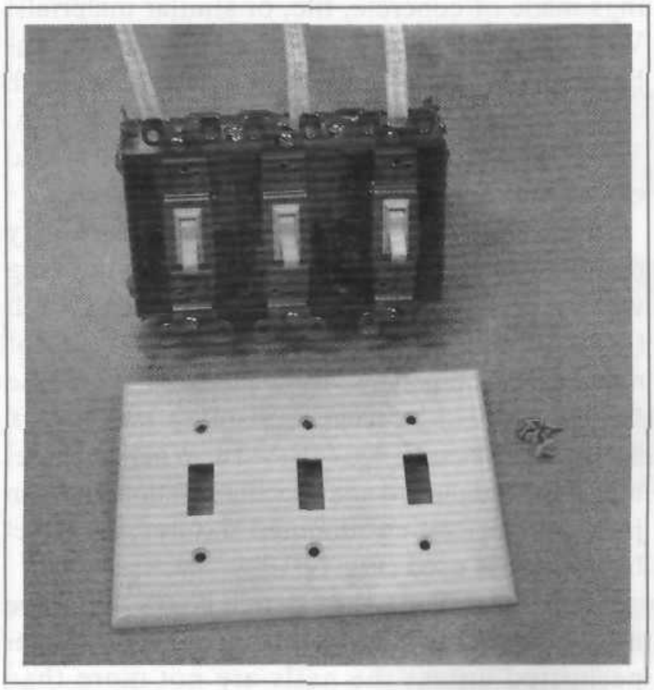


Fig. 5–15B Standard flush switches installed in ganged sectional device boxes. (Courtesy of Sandy F. Gerolimon)

BOXES FOR CONDUIT WIRING

For some types of construction, conduit rather than cable wiring is used.

When conduit is installed in a residence, it is quite common to use 102-mm square boxes trimmed with suitable plaster covers (Fig. 5–16). There are sufficient knockouts in the top, bottom, sides, and back of the box to permit a number of conduits to run into it. Plenty of room is available for the conductors and wiring devices. Note how easily these 102-mm square outlet boxes can be mounted back to back by installing a small fitting between them; see Fig. 5–19B and 5–19C.

You can trim 4-in. (102-mm) square outlet boxes with one-gang or two-gang plaster rings where wiring devices will be installed. Where lighting fixtures will be installed, use a plaster ring having a round opening.

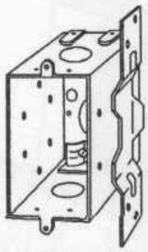
Any unused openings in outlet and device boxes must be closed, as per *Rule 12–3024*, using knockout fillers, Fig. 5–20.

The number of conductors allowed in outlet and device boxes is covered elsewhere in this text.

QUICK-CHECK BOX SELECTION GUIDE

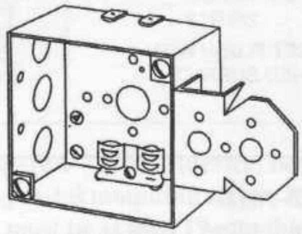
FOR BOXES GENERALLY USED FOR RESIDENTIAL WIRING

DEVICE BOXES



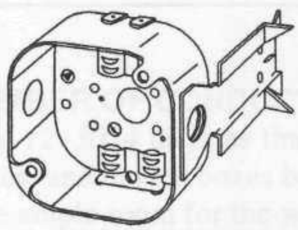
BOX SIZE		3 x 2 x 1½	3 x 2 x 2	3 x 2 x 2¼	3 x 2 x 2½	3 x 2 x 3
VOLUME	Millilitres	131	163	163	204	245
WIRE SIZE	14	5	6	6	8	10
	12	4	5	5	7	8

SQUARE BOXES



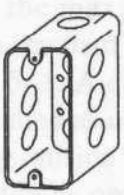
BOX SIZE		4 x 4 x 1½	4 x 4 x 2⅛	4¹¹⁄₁₆ x 4¹¹⁄₁₆ x 1½	4¹¹⁄₁₆ x 4¹¹⁄₁₆ x 2⅛
VOLUME	Millilitres	344	491	491	688
WIRE SIZE	14	14	20	20	28
	12	12	17	17	24

OCTAGON BOXES



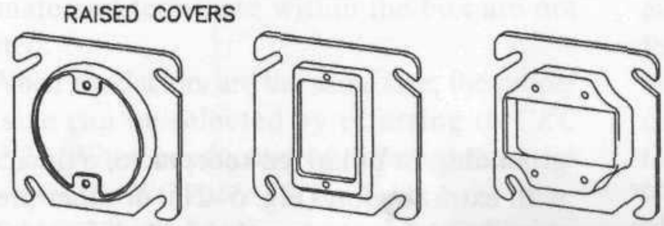
BOX SIZE		4 x 1½	4 x 2⅛
VOLUME	Millilitres	245	344
WIRE SIZE	14	10	14
	12	8	12

UTILITY BOXES



BOX SIZE		4 x 2 x 1½	4 x 2⅛ x 1⅞	4 x 2⅜ x 1⅞
VOLUME	Millilitres	147	229	262
WIRE SIZE	14	6	9	10
	12	5	8	9

RAISED COVERS



WHERE RAISED COVERS ARE MARKED WITH THEIR VOLUME IN CUBIC INCHES, THAT VOLUME MAY BE ADDED TO THE BOX VOLUME TO DETERMINE MAXIMUM NUMBER OF CONDUCTORS IN THE COMBINED BOX AND RAISED COVER.

NOTE: BE SURE TO MAKE DEDUCTIONS FROM THE ABOVE MAXIMUM NUMBER OF CONDUCTORS PERMITTED FOR WIRE CONNECTORS, WIRING DEVICES, CABLE CLAMPS, FIXTURE STUDS, AND GROUNDING CONDUCTORS. THE VOLUME IS TAKEN DIRECTLY FROM *TABLE 23* OF THE ***CEC***.

Fig. 5–16 Quick-check box selection guide. (Courtesy of CSA Group)

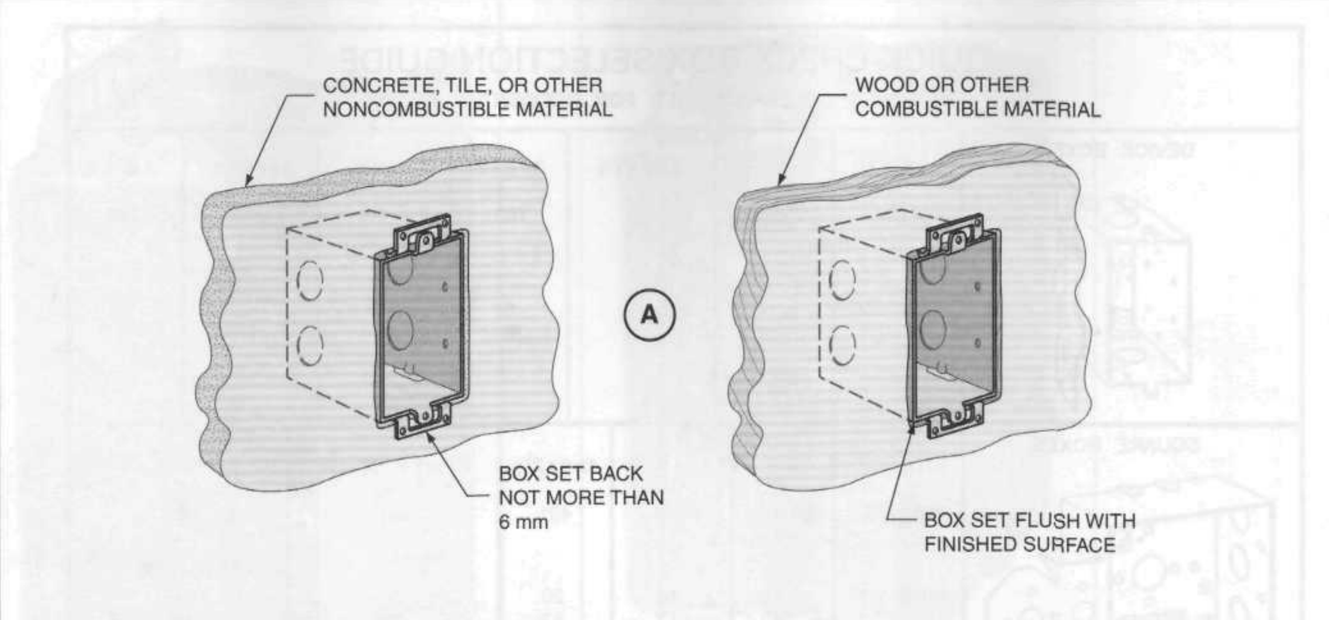


Fig. 5–17A Box position in walls and ceilings constructed of various materials, *Rule 12-3016*.

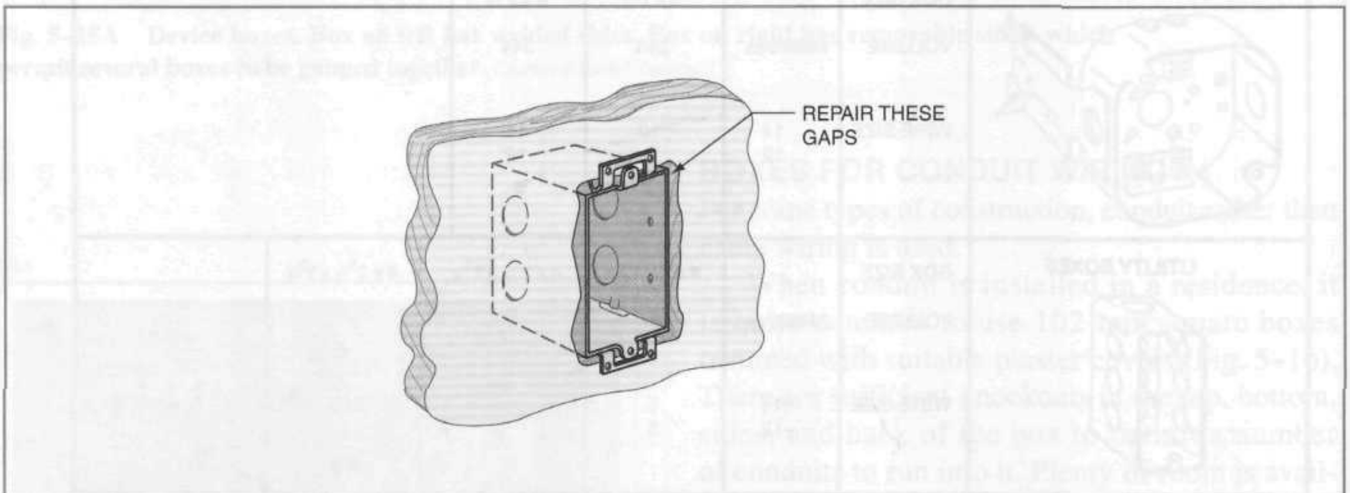


Fig. 5–17B Repair these gaps, *Rule 26–710*.

SPECIAL-PURPOSE OUTLETS

Special-purpose outlets are normally shown on floor plans. They are described by a notation and are also detailed in the specifications. The plans included with this textbook indicate special-purpose outlets by a triangle inside a circle with subscript letters. In some cases, a subscript number is added to the letter.

When a special-purpose outlet is indicated on the plans or in the specifications, the electrician must check for special requirements, such as a separate circuit, a special 240-volt circuit, a special grounding or polarized receptacle, a device box with extra support (Fig. 5–21), or other preparation. Special-purpose outlets include

- central vacuum receptacle
- weatherproof receptacle
- dedicated receptacle, perhaps for a home computer
- air-conditioning receptacle
- clock receptacle

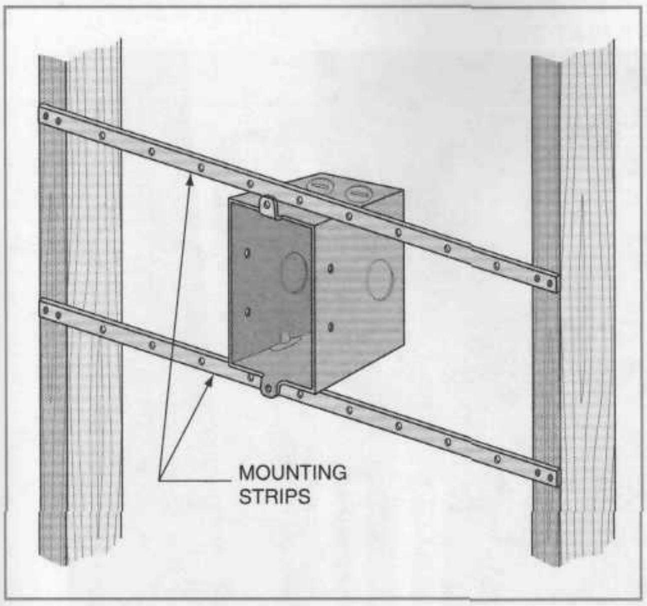


Fig. 5–18A Switch (device) boxes installed between studs using metal mounting strips. If wooden boards are used, they must be at least 19 mm thick and securely fastened to the stud, *Rule 12–3010(2)*.

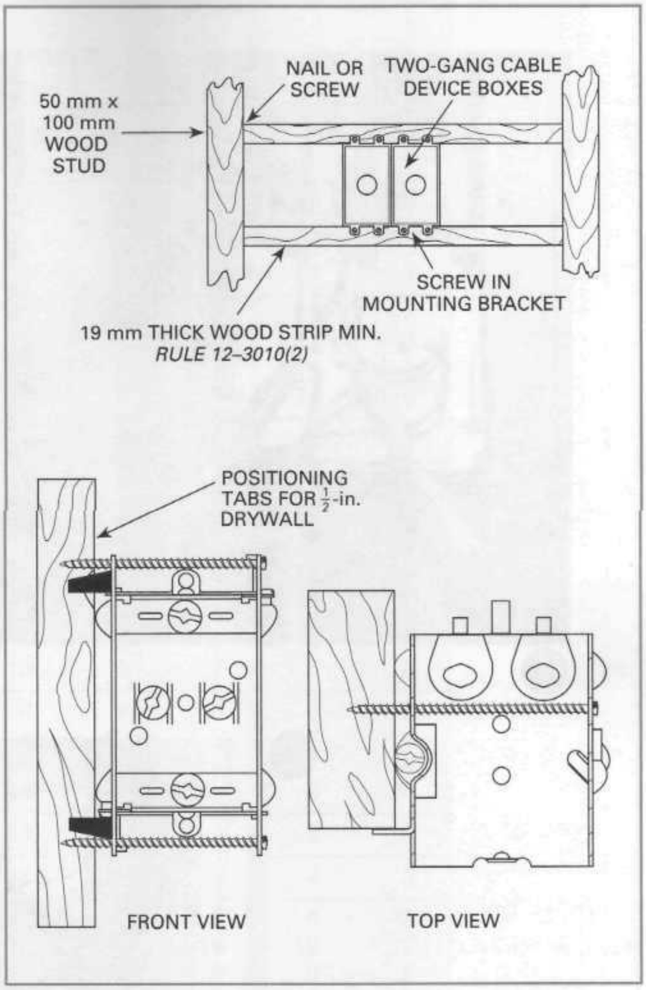


Fig. 5–18B A method of mounting sectional boxes to wood studs.

NUMBER OF CONDUCTORS IN A BOX

Rule 12–3034 dictates that outlet boxes, switch boxes, and device boxes be large enough to provide ample room for the wires without having to jam or crowd the wires into them. *CEC Table 23* specifies the maximum number of conductors allowed in standard outlet boxes and switch boxes; see Table 5–1. A conductor running through the box is counted as one conductor. Each conductor originating outside the box and terminating inside it is counted as one conductor. Conductors that originate and terminate within the box are not counted.

When conductors are the same size, the proper box size can be selected by referring to *CEC Table 23*. When conductors of different sizes are used, refer to *CEC Table 22*; see Table 5–2.

Tables 22 and *23* do not consider fittings or devices such as fixture studs, wire connectors, hickeys, switches, or receptacles that may be in the box. For assistance in this case, see Table 5–3 (page 91). When the box contains one or more fittings (such as fixture studs or hickeys; see Fig. 5–22 on page 89), the number of conductors must be one less than shown in the table for each type of device.

Deduct two conductors for each device mounted on a single strap (switches, receptacles). The deduction of two conductors has become necessary because of severe crowding of conductors in the box when the switch or receptacle is mounted or when dimmer switches are installed. In most cases, dimmer switches are larger than conventional switches.

Deduct one conductor for every two-wire connector. For example, for two- or three-wire connectors deduct one wire; for four or five connectors deduct two wires. There is no deduction for the first wire connector because it will probably be used for the second ground connection. Be sure to include all conductor sizes (Nos. 14, 12, 10, 8, and 6 AWG) when determining the size of the box to be installed. See Figs. 5–23 and Fig. 5–24 for examples of this *CEC* requirement, *Rule 12–3034(1)*.

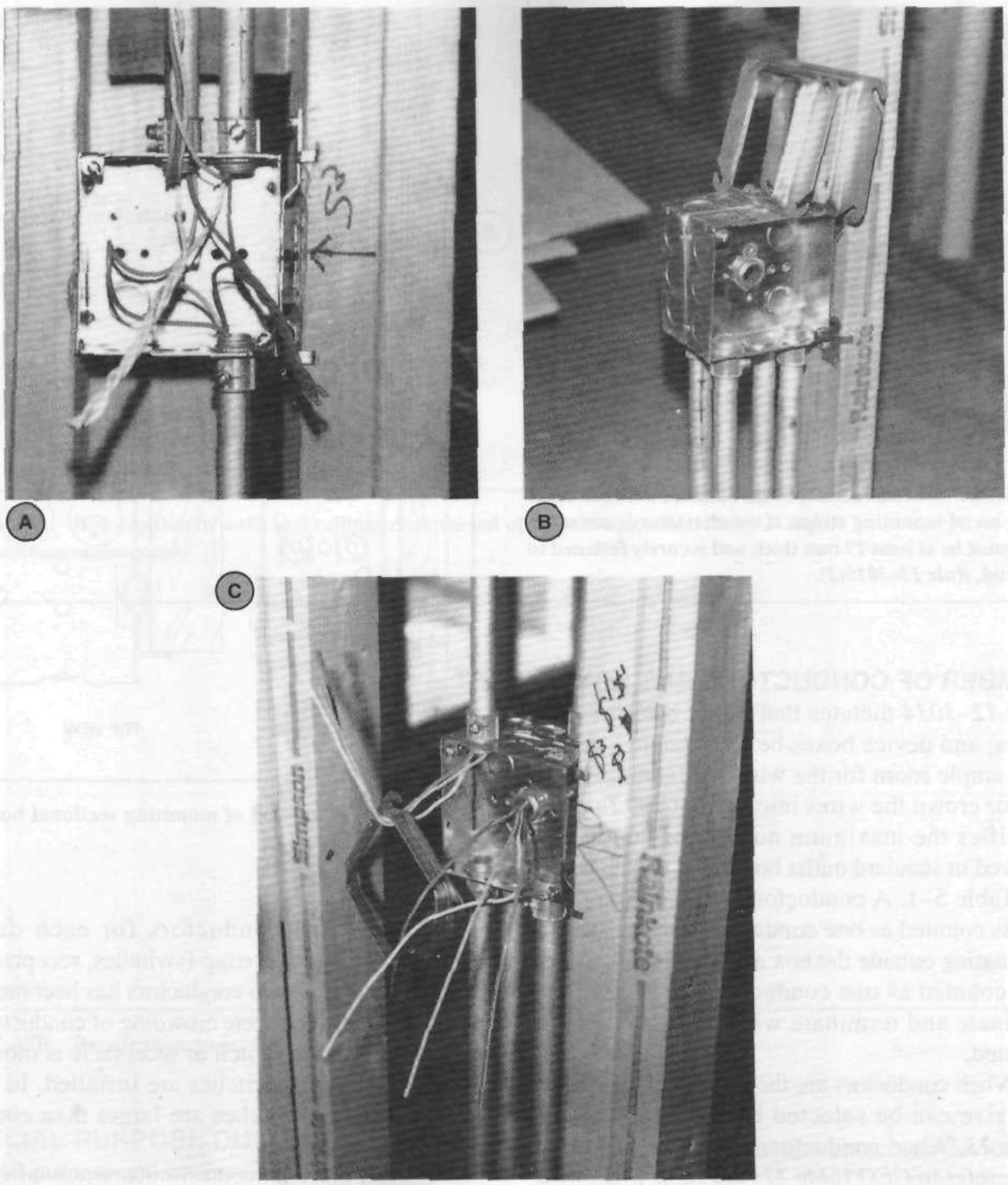


Fig. 5–19 Boxes for conduit wiring. (Delmar/Cengage)

SELECTING A BOX WHEN ALL CONDUCTORS ARE THE SAME SIZE

EXAMPLE: A box contains one fixture stud and two cable clamps. The number of conductors permitted in the box shall be one less than shown in the table. (Deduct one conductor for the fixture stud.)

A further deduction of two conductors is made for each wiring device in the box, but if two more devices are mounted on the same strap, they count

CEC TABLE 23
NUMBER OF CONDUCTORS IN BOXES
(See *Rule 12–3034.*)

Box Dimensions	Trade Size	Capacity, mL (in.³)	Maximum Number of Conductors (per AWG size) 14	12	10	8	6
Octagonal	4 x 1-1/2	245 (15)	10	8	6	5	3
	4 x 2-1/8	344 (21)	14	12	9	7	4
Square	4 x 1-1/2	344 (21)	14	12	9	7	4
	4 x 2-1/8	491 (30)	20	17	13	10	6
	4-11/16 x 1-1/2	491 (30)	20	17	13	10	6
	4-11/16 x 2-1/8	688 (42)	28	24	18	15	9
Round	4 x 1/2	81 (5)	3	2	2	1	1
Device	3 x 2 x 1-1/2	131 (8)	5	4	3	2	1
	3 x 2 x 2	163 (10)	6	5	4	3	2
	3 x 2 x 2-1/4	163 (10)	6	5	4	3	2
	3 x 2 x 2-1/2	204 (12.5)	8	7	5	4	2
	3 x 2 x 3	245 (15)	10	8	6	5	3
	4 x 2 x 1-1/2	147 (9)	6	5	4	3	2
	4 x 2-1/8 x 1-7/8	229 (14)	9	8	6	5	3
	4 x 2-3/8 x 1-7/8	*262 (16)*	*10*	*9*	*7*	*5*	*3*
Masonry	3-3/4 x 2 x 2-1/2	229 (14)/gang	9	8	6	5	3
	3-3/4 x 2 x 3-1/2	344 (21)/gang	14	12	9	7	4
	4 x 2-1/4 x 2-3/8	331 (20.25)/gang	13	11	9	7	4
	4 x 2-1/4 x 3-3/8	364 (22.25)/gang	14	12	9	8	4
Through Box	3-3/4 x 2	3.8/mm (6/in.) depth	4	3	2	2	1
Concrete Ring	4	7.7/mm (12/in.) depth	8	6	5	4	2
FS	1 Gang	229 (14)	9	8	6	5	3
	1 Gang tandem	557 (34)	22	19	15	12	7
	2 Gang	426 (26)	17	14	11	9	5
	3 Gang	671 (41)	27	23	18	14	9
	4 Gang	917 (56)	37	32	24	20	12
FD	1 Gang	368 (22.5)	15	12	10	8	5
	2 Gang	671 (41)	27	23	18	14	9
	3 Gang	983 (60)	40	34	26	21	13
	4 Gang	1392 (85)	56	48	37	30	18

Table 5–1 ***CEC Table 23.*** (Courtesy of CSA Group)

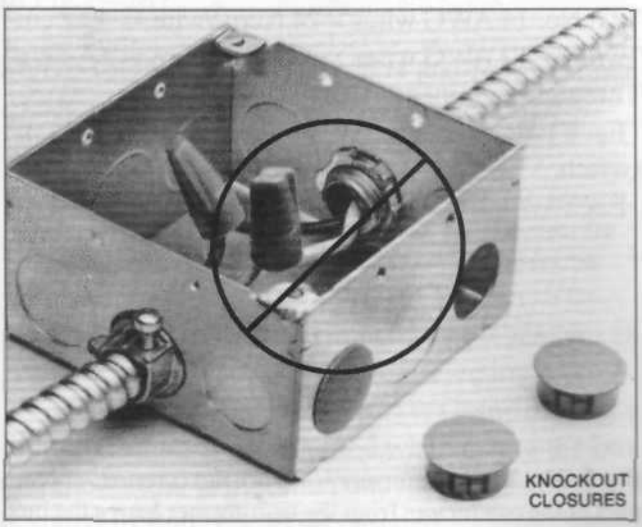


Fig. 5–20 Unused openings in boxes must be closed according to the *CEC Rule 12–3024.* This is done to contain electrical short-circuit problems inside the box or panel and to keep rodents out. (Delmar/Cengage)

WIRES MUST BE 150 mm MINIMUM. *CEC Rule 12–3000(6).* See Fig. 5–2.

CEC TABLE 22 SPACE FOR CONDUCTORS IN BOXES (See *Rule 12–3034.*)	
Size of conductor, AWG	Usable space required for each insulated conductor, mL
14	24.6
12	28.7
10	36.9
8	45.1
6	73.7

Table 5–2 ***CEC Table 22.*** (Courtesy of CSA Group)

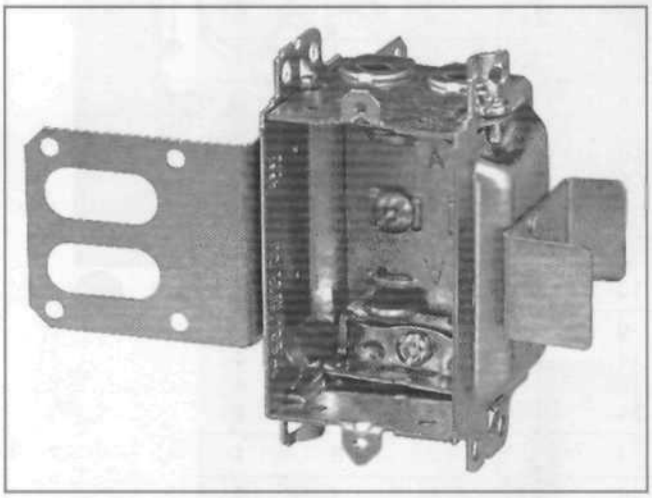


Fig. 5–21 Flush-mounted device box for steel studs with required additional support. (Courtesy of Thomas & Betts Incorporated)

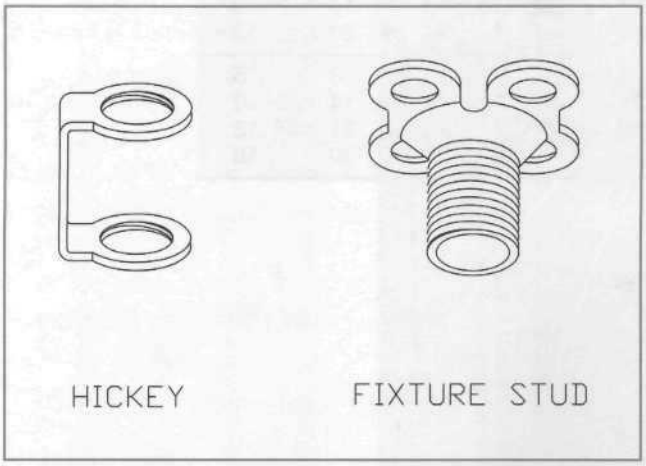


Fig. 5–22 Hickey and fixture stud.

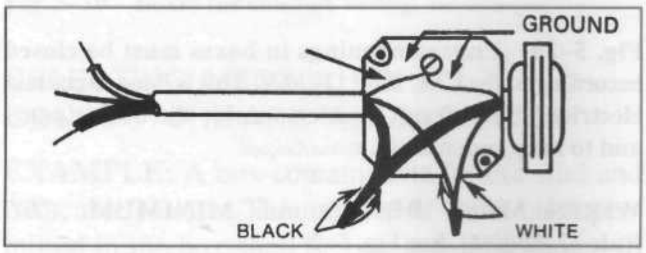


Fig. 5–23 The transformer leads are not counted, since no part of the conductors from the transformer leaves the box.

as a single device. For example, if a switch and a receptacle are mounted on a single strap, only two conductors are deducted.

SELECTING A BOX WHEN CONDUCTORS ARE DIFFERENT SIZES *(RULE 12–3034[4])*

When the box contains different size wires, do the following:*

- Determine the size of conductors to be used and the number of each (e.g., two No. 10 and two No. 12).
- Determine if the box is to contain any wiring devices (switch or receptacle), wire connectors, or fixture studs. This volume adjustment must be based on the volume of the largest conductor in the box.
- Deduct one conductor for each pair of wire connectors. For example, two or three equals one wire, four or five equals two wires. *Note:* If only one wire connector is used, it is not counted.
- Deduct two conductors for each switch or receptacle that is less than 25 mm between the mounting strap and the back of the device.
- Make the necessary adjustments for devices, wire connectors, and fixture studs.
- Size the box based on the total volume required for conductors according to *Table 22.*

* (Courtesy of CSA Group)

EXAMPLE: What is the minimum volume required for a box that will contain one switch, two No. 14 wires, two No. 12 wires, and three No. 33 wire connectors? The cable is armoured cable.

Two No. 14 AWG wires × 24.6 cm^3/wire = 49.2 cm^3
Two No. 12 AWG wires × 28.7 cm^3/wire = 57.4 cm^3
Three wire connectors
Each pair counts as one wire = 28.7 cm^3
switch
Each switch counts as two wires = 57.4 cm^3
Total volume = 192.7 cm^3

Therefore, select a box having a minimum volume of 192.7 mL of space. A $3 \times 2 \times 2^{1}/_{2}$-in. device box has a volume of 204 mL from *Table 23*, and this would be sufficient. The cubic-inch volume may be marked on the box; otherwise refer to the column of *Table 23* entitled "Capacity."

When sectional boxes are ganged together, the volume to be filled is the total volume of the assembled boxes. Fittings, such as plaster rings, raised covers, and extension rings, may be used with the sectional boxes. If these fittings are marked with their volume, or have dimensions comparable to the boxes in *Table 23*, their volume may be considered when determining the total volume [*Rule 12–3034(6)*]. In some cases, the volume listed in *Table 23* is not equivalent to the length × width × depth of the box. When doing calculations using boxes listed in *Table 23*, use the volume found in the table. Otherwise multiply L × W × D to find the actual volume of the box. For example, a 12 × 12 × 6-in. box is not found in *Table 23*. Therefore the box volume is $12 \times 12 \times 6 = 864$ in.^{3} (14.1 L). Figs. 5–25 and 5–26 show how a 19-mm raised cover (plaster ring) increases the wiring space of the box to which it is attached.

Electrical inspectors are very aware that GFCI receptacles, dimmers, and certain types of timers take more space than regular receptacles. Therefore, it is a good practice to install device boxes that will provide lots of room for wires, instead of pushing and crowding the wires into the box.

EXAMPLE: How many No. 12 conductors are permitted in the box and raised plaster ring shown in Fig. 5–26?

SOLUTION: See *Rule 12–3034* and *Tables 22* and *23* for volume required per conductor.

This box and cover will take

$$\frac{418 \text{ mL}}{28.7 \text{ mL per No. 12 conductor}} = \text{14 No. 12 conductors maximum, less the deductions for devices and connectors, per } \textit{Rule 12–3034(2)}.$$

Fig. 5–23 shows how transformer leads No. 18 AWG or larger are treated when selecting a box.

Wire No. 16 or No. 18 AWG supplying a lighting fixture is not counted when sizing the box that the fixture is mounted on; see Fig. 5–24. This is stated in *Rule 12–3034(1)(d)*.

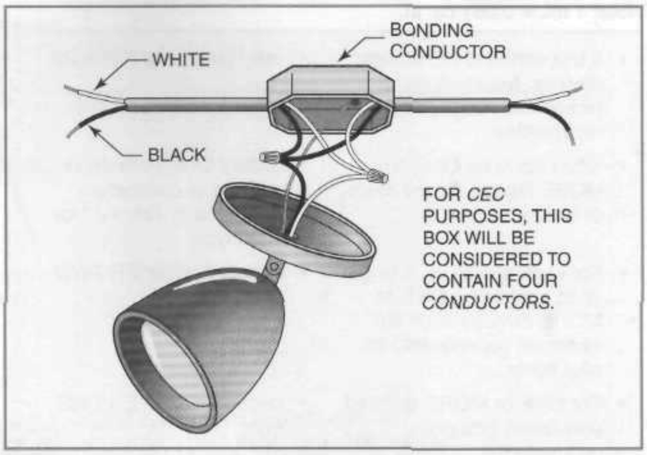


Fig. 5–24 Fixture wires are not counted in determining correct box size. *CEC Rule 12–3034(1)(d)* specifies that No. 18 and No. 16 AWG fixture wires supplying a lighting fixture, mounted on the box containing the fixture wires, shall not be counted.

Fig. 5–16, the quick-check box selection guide, shows some of the most popular types of boxes used in residential wiring. You can refer to it as you work your way through this text.

When wiring with cable, "feeding through" a box is impossible. But, when installing the wiring using conduit, it is possible to feed straight through a box. Only one wire is deducted for a wire running straight through a box.

BOX FILL

The following method can make box fill easier to calculate when determining the proper size of junction box or wall box to install:

1. Count the number of circuit wires.
2. Add one wire for a fixture stud (if any).
3. Add one wire for each pair of wire connectors.
4. Add one wire for one or more isolated (insulated) grounding conductors (if any).
5. Add two wires for each wiring device.

Look up the total count in *Table 23* to find a box appropriate for the intended use that will hold the number of conductors required.

EXAMPLE: Six circuit conductors	6
One wiring device (switch)	+2
Three wire connectors	+1
Total	9

Note: 1 mL = 0.061 cu. in.

• If box contains NO fittings, devices, fixture studs, hickeys, switches, or receptacles	• refer directly to *Table 23*.
• If box contains ONE or MORE fittings, fixture studs, or hickeys...	• deduct ONE from maximum number of conductors permitted in *Table 23* for each type.
• For each device on a single strap containing ONE or MORE devices such as switches, receptacles, or pilot lights...	• deduct ANOTHER TWO from *Table 23*.
• For ONE or MORE isolated (insulated) grounding conductors...	• deduct ANOTHER ONE from *Table 23*.
• For each PAIR of insulated wire connectors...	• deduct another conductor from the number permitted by *Table 23*.
• For conductors running through the box...	• count ONE conductor for each conductor running through the box.
• For conductors that originate outside the box and terminate inside the box...	• count ONE conductor for each conductor originating outside and terminating in the box.
• If no part of the conductor leaves the box—for example, a "jumper" wire used to connect a receptacle...	• don't count the conductors.

Table 5–3 Quick checklist for determining the proper size of boxes.

Therefore, select a box capable of containing nine or more conductors. See *Table 23*.

It is possible to select a smaller box when using EMT than when using the cable wiring method because it is possible to "loop" conductors through the box. These count as only one conductor for the purpose of box fill count; see Fig. 5–27.

LOCATING OUTLETS

Electricians commonly consult the plans and specifications to determine the proper heights and clearances for installing electrical devices. The electrician then has these dimensions verified by the architect, electrical engineer, designer, or homeowner to avoid unnecessary and costly changes in the locations of outlets and switches as the building progresses.

There are no *Code* rules for locating the height of outlets. A number of conditions determine the proper height for a switch box. For example, the height of the kitchen counter backsplash determines where the switches and receptacle outlets are located between the kitchen countertop and the cabinets.

The location of receptacles is covered in *Rule 26–712* of the *CEC* and Unit 6 of this text.

When locating receptacles near electric baseboard heaters, refer to the section "Location of Electric Baseboard Heaters in Relation to Receptacle Outlets" in Unit 17.

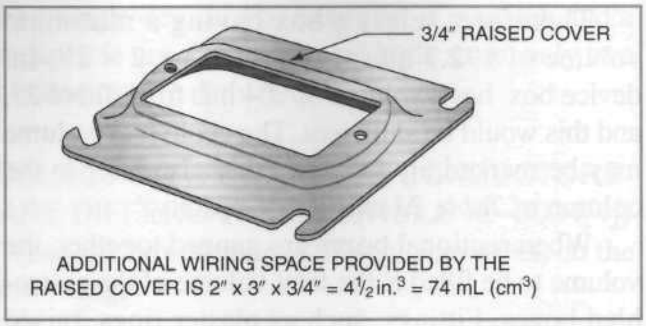


Fig. 5–25 Raised cover. Raised covers are sometimes called *plaster rings*.

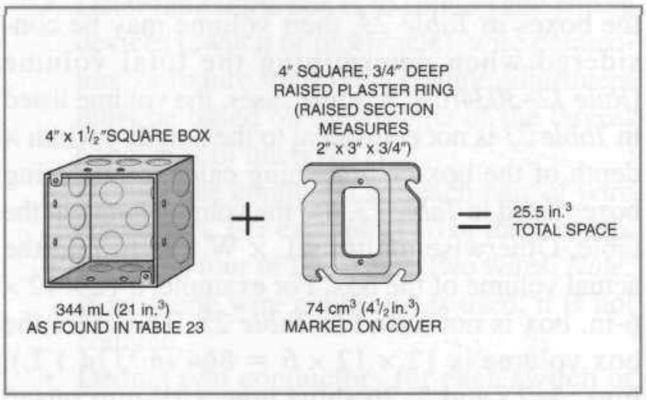


Fig. 5–26 Area of box and plaster ring.

POSITIONING RECEPTACLES

Although no actual *CEC* rules exist on positioning receptacles, there is a concern in the electrical industry that a *metal* wall plate could come loose and fall downward onto the blades of an attachment plug cap that is loosely plugged into the receptacle, thereby creating a potential shock and fire hazard.

Therefore, when metal wall plates are used, position the grounding hole to the top. A loose

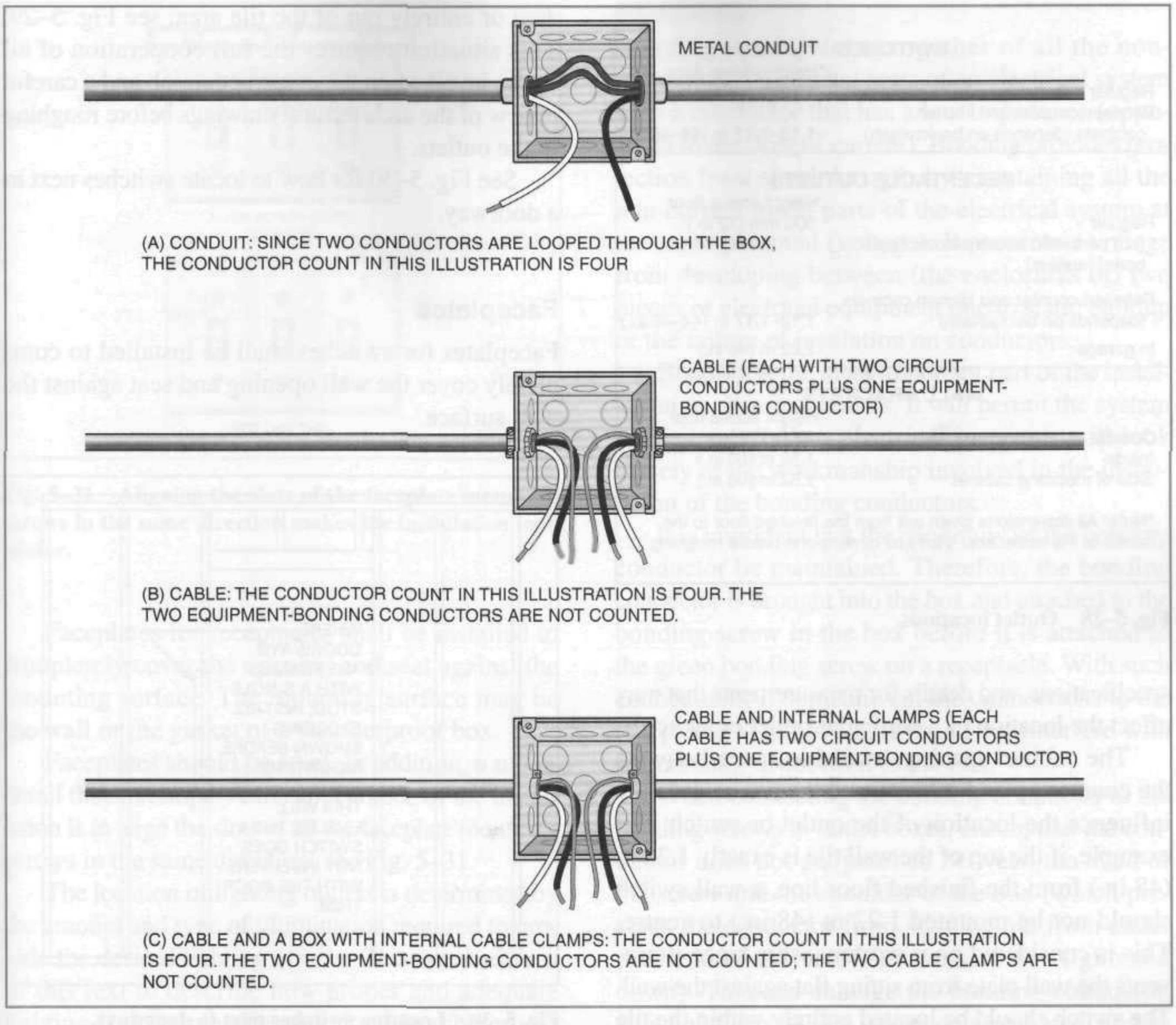
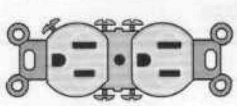


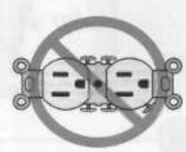
Fig. 5–27 Conductor count for both metal conduit and cable installations.

metal plate could fall onto the grounding blade of the attachment plug cap, but no hazard would result.

Or when metal cover plates are used, position grounded neutral blades on top. A loose metal plate could fall onto these grounded neutral blades with no hazardous effect.



When metal cover plates are used, do not position the "hot" terminal on top. A loose metal plate could fall onto these live blades. If this was a split-circuit receptacle fed by a three-wire, 120/240-volt circuit, the short would be across the 240-volt line.



To ensure uniform installation and safety, and in accordance with long-established custom, standard electrical outlets are located as shown in Fig. 5–28. These dimensions usually are satisfactory. *However, the electrician must check the blueprints,*

SWITCHES	
	*Height above floor
Regular	1.17 m (46 in.)
Between counter and kitchen cabinets (depends on backsplash)	1.12–1.17 m (44–46 in.)
RECEPTACLE OUTLETS	
	*Height above floor
Regular (not permitted above electric baseboard heaters)	300 mm (12 in.)
Between counter and kitchen cabinets (depends on backsplash)	1.12–1.17 m (44–46 in.)
In garage	1.22 m (48 in.)
WALL BRACKETS	
	*Height above floor
Outside	1.8 m (72 in.)
Inside	1.52 m (60 in.)
Side of medicine cabinet	1.52 m (60 in.)

*Note: All dimensions given are from the finished floor to the centre of the outlet box. Verify all dimensions before roughing in.

Fig. 5–28 Outlet locations.

specifications, and details for measurements that may affect the location of a particular outlet or switch.

The cabinet spacing, available space between the countertop and cabinet, and the tile height may influence the location of the outlet or switch. For example, if the top of the wall tile is exactly 1.22 m (48 in.) from the finished floor line, a wall switch should not be mounted 1.22 m (48 in.) to centre. This is considered poor workmanship since it prevents the wall plate from sitting flat against the wall. The switch should be located entirely within the tile area or entirely out of the tile area; see Fig. 5–29. This situation requires the full cooperation of all trades involved on the construction job and a careful review of the architectural drawings before roughing in the outlets.

See Fig. 5–30 for how to locate switches next to a doorway.

Faceplates

Faceplates for switches shall be installed to completely cover the wall opening and seat against the wall surface.

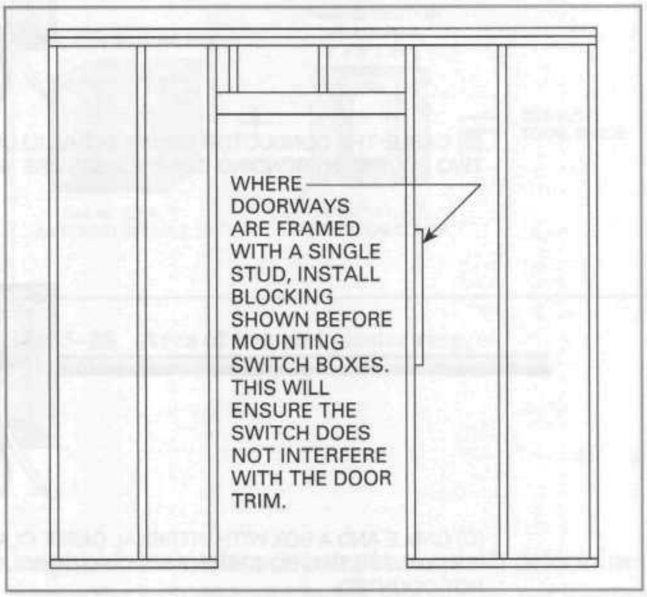


Fig. 5–30 Locating switches next to doorways.

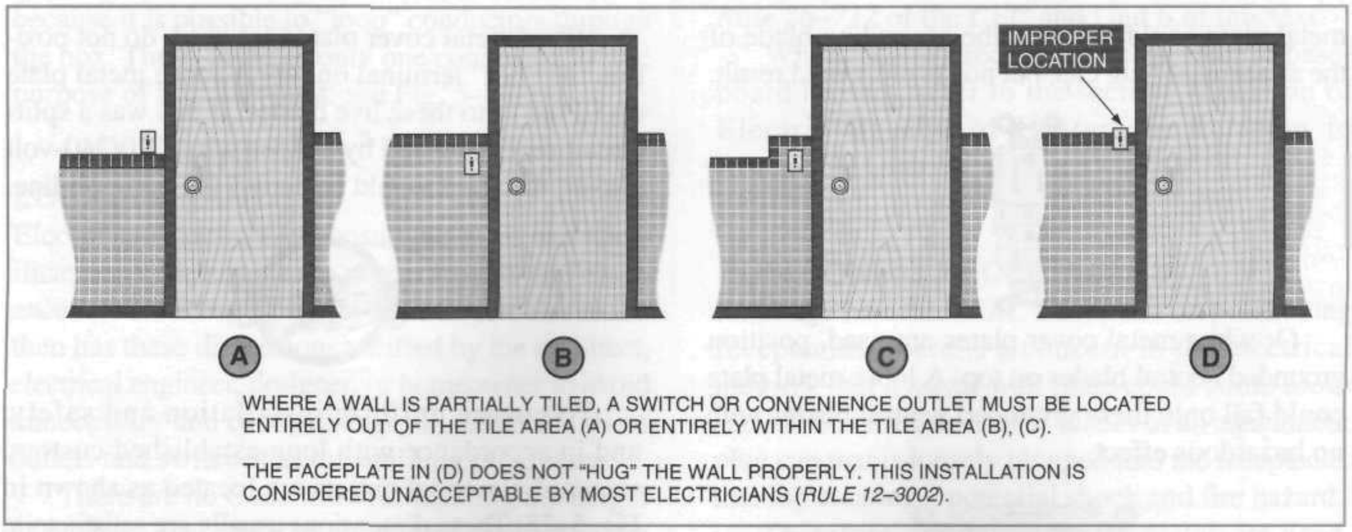


Fig. 5–29 Locating an outlet on a tiled wall.

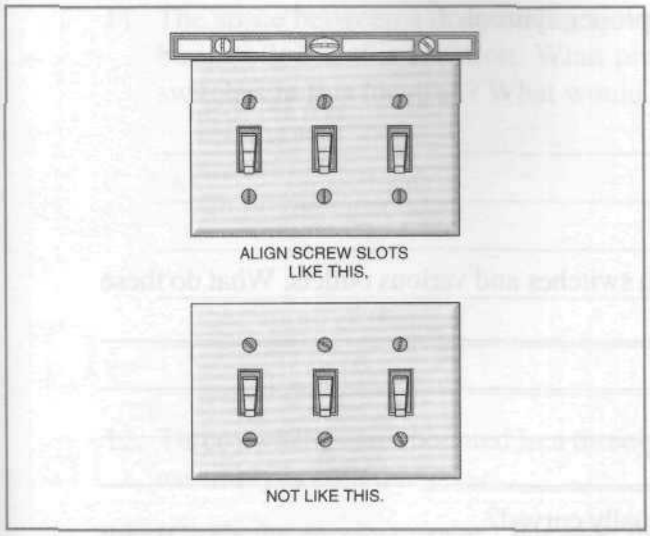


Fig. 5–31 Aligning the slots of the faceplate mounting screws in the same direction makes the installation look neater.

Faceplates for receptacles shall be installed to completely cover the opening and seat against the mounting surface. The mounting surface may be the wall or the gasket of a weatherproof box.

Faceplates should be level. In addition, a minor detail that can improve the appearance of the installation is to align the slots in all the faceplate mounting screws in the same direction; see Fig. 5–31.

The location of lighting outlets is determined by the amount and type of illumination required to provide the desired lighting effects. (It is not the intent of this text to describe how proper and adequate lighting is determined; rather, it covers the proper methods of installing the circuits for such lighting.)

BONDING

Bonding is the joining together of all the non-current-carrying metal parts of an electrical system with a conductor that has a low impedance (opposition to the flow of current). Bonding provides protection from shock hazards by maintaining all the non-current metal parts of the electrical system at the same potential (voltage). It prevents a voltage from developing between (the enclosures of) two pieces of electrical equipment due to static buildup or the failure of insulation on conductors.

Bonding is the most important part of the installation of electrical outlets. It will permit the system to "fail safe." Your electrical inspector will look closely at the workmanship involved in the installation of the bonding conductors.

It is important that the continuity of the bonding conductor be maintained. Therefore, the bonding conductor is brought into the box and attached to the bonding screw in the box before it is attached to the green bonding screw on a receptacle. With such connections, if someone cut the connections to the receptacle to remove it, it would not interfere with the bonding connection to the box.

When connecting the bonding conductor to the bonding screws in outlet boxes, ensure that the conductor does not get pinched between the head of the screw and the shoulder of the box (which prevents the conductor from slipping out from under the head of the screw as the screw is tightened down). This can damage the bonding conductor, which reduces its size (cross-sectional area) and its effectiveness.

REVIEW

Note: Refer to the *CEC* or the blueprints provided with this textbook when necessary.

1. What does a plan show about electrical outlets? ______________________
____
____

2. What is an outlet? ______________________
____
____
____

3. Match the following switch types with the proper symbol.

a. single-pole	S_P
b. three-way	S_4
c. four-way	S
d. single-pole with pilot light	S_3

4. The plans show curved lines running between switches and various outlets. What do these curved lines indicate? ______

5. Why are the lines mentioned in Question 4 usually curved? ______

6. a. What are junction boxes used for? ______

   b. Are junction boxes normally used in wiring the first floor? ______

   c. Are junction boxes normally used to wire exposed portions of the basement? ______

7. How are standard sectional switch (device) boxes mounted? ______

8. a. What is an offset bar hanger? ______

   b. What types of boxes may be used with offset bar hangers? ______

9. What methods may be used to mount lighting fixtures to an outlet box fastened to an offset bar hanger? ______

10. What is the size of the opening of a switch (device) box for a single device? ______

11. The space between a door casing and a window casing is 89 mm. Two switches are to be installed at this location. What problems could you encounter when placing the switches in this location? What would you recommend as a possible solution?

____

____

____

____

____

12. Three switches are mounted in a three-gang switch (device) box. The wall plate for this assembly is called a ______________________ plate.

13. [Circle the correct answer.] For each fixture stud inside a box, (increase) (decrease) the number of conductors allowed by one.

14. a. How high above the finished floor are the switches located in the garage of this dwelling? ______________

b. In the living room of this dwelling? ______________

15. How high above the finished floor are the receptacle outlets in the garage located? ______________ In the living room? ______________

16. Outdoor receptacle outlets in this dwelling are located ______________ mm above grade.

17. In the spaces provided, draw the correct symbol for each of these items:

a. ____ Lighting panel

b. ____ Clock outlet

c. ____ Duplex outlet

d. ____ Outside line telephone

e. ____ Single-pole switch

f. ____ Four-way switch

g. ____ Duplex outlet, split-circuit

h. ____ Lampholder with pull switch

i. ____ Weatherproof outlet

j. ____ Special-purpose outlet

k. ____ Fan outlet

l. ____ Range outlet

m. ____ Power panel

n. ____ Three-way switch

o. ____ Pushbutton

p. ____ Thermostat

q. ____ Electric door opener

r. ____ Multioutlet assembly

18. The front edge of a box installed in a combustible wall must be ______________ with the finished surface. Rule number? ______________

19. List the maximum number of No. 12 AWG conductors permitted in a

a. $4 \times 1\frac{1}{2}$-in. (102×38-mm) octagon box. ______________

b. $4\frac{11}{16} \times 1\frac{1}{2}$-in. ($119 \times 38$-mm) square box. ______________

c. $3 \times 2 \times 2\frac{1}{2}$-in. ($76 \times 51 \times 64$-mm) device box. ______________

20. Hanging a ceiling fixture directly from a plastic outlet box is permitted only if ______
______
______
______
______

21. It is necessary to count fixture wires when counting the permitted number of conductors in a box according to *Rule 12–3034(1)(d).*

    (True) (False) [Underline or circle the correct answer.]

22. *CEC Table 23* allows a maximum of ten wires in a certain box. However, the box will have two wire connectors and one fixture stud in it. What is the maximum number of wires allowed in this box? ______
______

23. When laying out a job, the electrician will usually make a layout of the circuit, taking into consideration the best way to run the cables and/or conduits and how to make up the electrical connections. Doing this ahead of time, the electrician determines exactly how many conductors will be fed into each box. With experience, the electrician will probably select two or three sizes and types of boxes that will provide adequate space to meet *Code* requirements. *CEC Table 23* shows the maximum number of conductors permitted in a given size box. However, the number of conductors shown in the table must be reduced

    by ______ conductor(s) for two wire connectors
    by ______ conductor(s) for the fixture stud
    by ______ conductor(s) for each wiring device mounted on a single strap
    by ______ conductor(s) for one or more bare copper bonding conductors.

24. Define the term *bonding*. Why is the installation of bonding conductors important?
______
______
______
______
______
______

UNIT 6

Determining the Number and Location of Lighting and Receptacle Branch Circuits

OBJECTIVES

After studying this unit, the student will be able to

- determine the number and location of lighting outlets in a dwelling unit
- determine the minimum number of and location of receptacles required in a dwelling unit
- identify *CEC* requirements for lighting and receptacle branch circuits

In the design and planning of dwelling units, it is standard practice to permit the electrician to plan the circuits. Thus, the residence plans do not include layouts for the various branch circuits. The electrician may follow the general guidelines established by the architect; however, all wiring systems must conform to the standards of the *Canadian Electrical Code (CEC)* and the *National Building Code of Canada (NBC),* as well as local and provincial requirements.

This unit focuses on lighting branch circuits and small appliance circuits. The circuits supplying the electric range, oven, clothes dryer, and other specific circuitry not considered to be a lighting branch circuit or a small appliance circuit are covered later in this text.

LIGHTING

In this unit, we look at where lighting fixtures and receptacles must be located to meet the minimum requirements of the *CEC*. Lighting fixtures (luminaires), lamps, and ballasts will be covered in Unit 10.

The provisions for supplying a light fixture in a room or area and whether it is to be controlled by a wall switch are found in *Part 9* of the *National Building Code of Canada*. The *CEC* has adopted these requirements, which are found in *Rules 30–500* to *30–510*. Table 6–1 outlines these requirements for lighting in dwelling units. Fig. 6–1 (page 100) shows them graphically.

RECEPTACLES

Receptacles are required in dwelling units for the connection of large and small appliances. Receptacles installed for small appliances are 15 ampere, 125 volt (two pole, three wire) or 20 ampere, T slot, 125 volt (two pole, three wire).

Some residences are lighted by table and floor lamps plugged into switch-controlled wall receptacle outlets. In bedrooms and living rooms, switch-controlled wall receptacles are permitted in lieu of ceiling and/or wall lighting outlets. Only half of the receptacle may be switched if the receptacle is

ROOM OR AREA	PROVIDE	REFERENCE RULE
Entrance	A luminaire controlled by a wall switch inside the building	*30–500*
Living room, bedroom	At least one luminaire controlled by a wall switch or a receptacle controlled by a wall switch	*30–502*
Kitchen, dining room, hall, bathroom, vestibule, utility room	At least one luminaire controlled by a wall switch	*30–502*
Stairway	All stairways must be lighted A luminaire controlled by a switch at the top and bottom of the stairway when the stairway has four or more risers If the stairway leads to an unfinished basement that does not have an outside exit, a single switch at the top of the stairs may be used	*30–504*
Basement	One luminaire for each 30 m² or portion thereof of unfinished basement The luminiare closest to the stairs must be controlled by switch at the top of the stairs	*30–506*
Storage room	At least one luminaire in the storage room	*30–508*
Garage and carport	At least one luminaire controlled by a wall switch near the doorway When a wall-mounted or ceiling luminaire that is not located above a space that would be occupied by a car is used, a built-in switch is permitted on the luminaire A carport that is lighted by a luminaire at the entrance to the building does not require additional lighting	*30–510*

Table 6–1 ***CEC* requirements for lighting in dwelling units.** (Courtesy of CSA Group)

needed to satisfy the minimum number of receptacles required by *Rule 26–712(a).* This is achieved by removing the tab on the "hot" side of the receptacle (Figs. 6–3, 6–4, and 6–5 on pages 102–104).

This unit will identify the locations where the *CEC* requires 15-ampere, 125-volt (5-15R) and 20-ampere, 125-volt (5-20RA) receptacles. For information on special applications of receptacles or their branch circuits, see Units 11 to 20.

Table 6–2 and Figs. 6–6, 6–7, and 6–8 outline the minimum number of receptacles required in a dwelling unit and their locations.

BASICS OF WIRE SIZING AND LOADING

The *CEC* defines a *branch circuit* as "that portion of the wiring installation between the final overcurrent device protecting the circuit and the outlet(s)"; see Fig. 6–9 on page 107.

The *CEC* defines a *feeder* as the circuit conductors between the service equipment and the final branch circuit overcurrent device. In the residence used as an example in this text, the wiring between Panel A and Panel B is a feeder.

The ampacity (current-carrying capacity) of a conductor must not be less than the rating of the overcurrent device protecting that conductor, *Rule 14–104*. An exception is a motor branch circuit, where it is common to have overcurrent devices (fuses or breakers) sized larger than the ampacity of the conductor. The *CEC* covers motors and motor circuits specifically in *Section 28.* The rating of the branch circuit is determined by the lesser of the rating of either the overcurrent device or the ampacity of the wire. For example, if a 20-ampere conductor is protected by a 15-ampere fuse, then the circuit is a 15-ampere branch circuit, *Rule 8–104(1).*

The ampacity of branch-circuit conductors must not be less than the maximum load to be served. Where the circuit supplies receptacle outlets, as is typical in houses, the conductor's ampacity must be rated to carry the load, *Rule 8–104(2)*. The load current must not exceed 80% of the rating of the overcurrent device for that circuit, *Rules 8–304* and *8–104(5)(a).*

Where the ampacity of the conductor does not match up with a standard rating of a fuse or breaker,

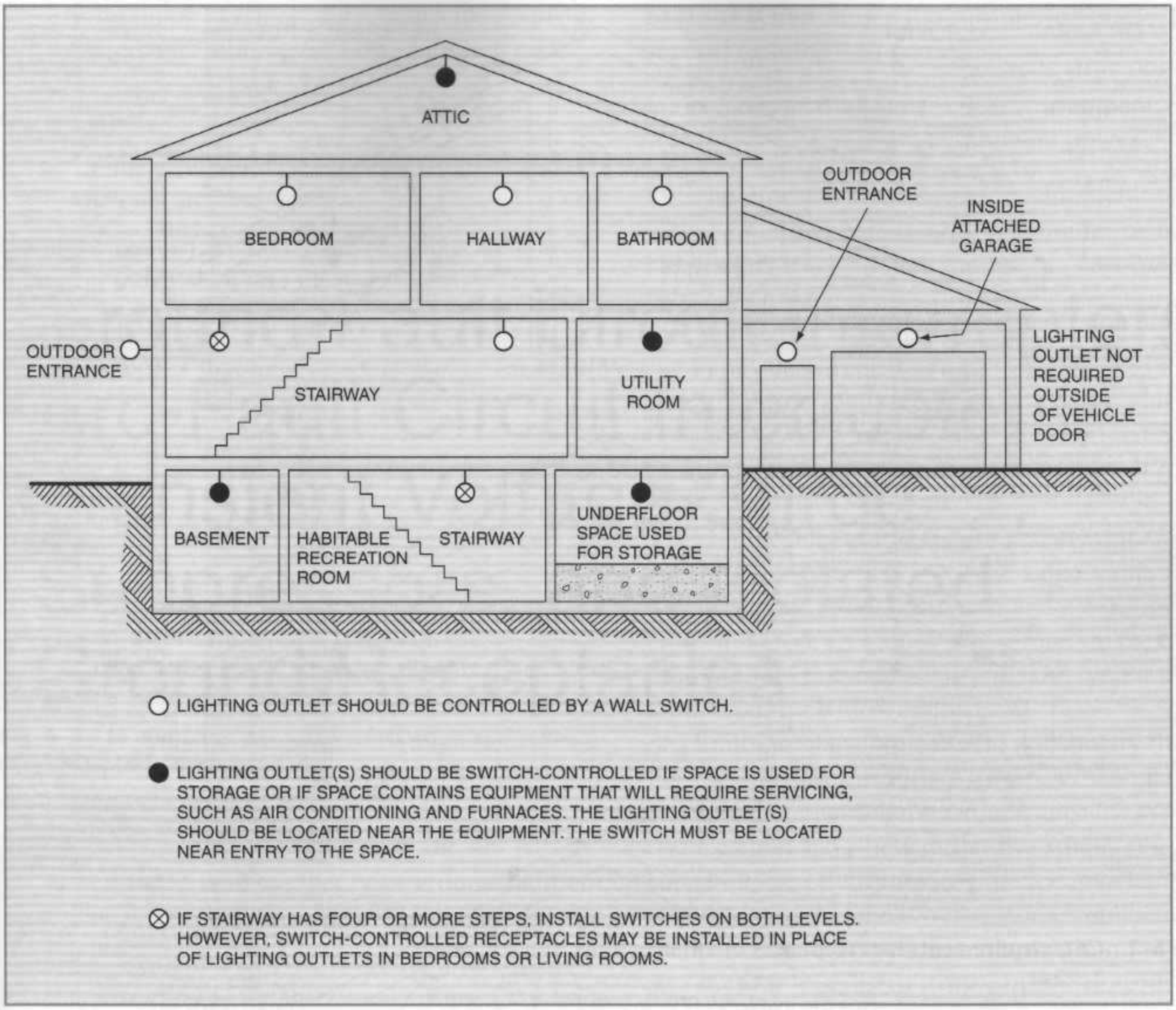


Fig. 6–1 Lighting outlets required in a typical dwelling unit.

the next higher standard size overcurrent device may be used, provided the overcurrent device does not exceed 600 amperes, *Rule 14–104(a)*. This exception is not applicable to residential branch circuits because the standard overcurrent device sizes listed in *CEC Table 13* (Table 6–3, page 103) correspond directly with the ampacities listed in *Table 2* for No. 14 and No. 12 gauge wire. *Table 13* shows that the maximum overcurrent protection is 15 amperes when No. 14 AWG copper wire is used.

Residential branch circuits are fed from panelboards having overcurrent devices that are rated to be run continuously at a maximum of 80% of their ampere rating. The conductors attached to these overcurrent devices may not be loaded to more than 80% of the ampere rating listed in *Table 2*. For example, a 15-ampere circuit breaker has a maximum load of 12 amperes (15 amperes × 0.8). Therefore, the wire must be rated for 15 amperes in *Table 2;* a No. 14 R90 XLPE is suitable.

The ampacities of conductors commonly used in residential occupancies are listed in *Table 2*. These are subject to *correction factors,* which must be applied where there are high ambient temperatures, for example, in attics. See *Note (1)* to *Table 5A*.

Conductor ampacities are also *derated* when four or more conductors are installed in a single raceway or cable. See *Table 5C* (Table 6–4).

A continuous load should not exceed 80% of the ampere rating of the branch circuit. The *CEC* defines a *continuous load* as one that persists under normal operation for "more than one hour in any

ROOM OR AREA	PROVIDE	REFERENCE RULE
Living room, dining room, family room, bedroom	No point along the floor line of a wall may be more than 1.8 m horizontally from a receptacle, including isolated wall spaces 900 mm or longer. See rule for exclusions.	*26–712(a)(c)*
Hallway	No point in a hallway may be more than 4.5 m from a receptacle. Receptacles in rooms off the hallway may be used if the opening to the room from the hallway is not fitted with a door.	*26–712(f)*
Laundry room	One receptacle for the washing machine. At least one additional receptacle.	*26–710(e)*
Bathroom	At least one receptacle, within 1 m of the washbasin and GFCI-protected.	*26–710(f)*
Kitchen	*One receptacle for a refrigerator.* One receptacle for a gas range if gas piping has been provided. Counter receptacles such that no point measured along the back of the counter is more than 900 mm horizontally from a receptacle. Counter receptacles may be 15 A, three-conductor split circuit or 20 A T slot. See Unit 14 for more detail. Isolated work surfaces 300 mm or more require a receptacle. *At least one receptacle for a permanently installed island.* At least one receptacle for counter peninsula. At least one receptacle in a dining area forming part of a kitchen. One receptacle for a microwave oven.	*26–712(d)*
Utility room	At least one receptacle.	*26–712(a)*
Unfinished basement areas	At least one receptacle.	*26–710(e)*
Balcony, porch, veranda	At least one receptacle.	*26–712(e)*
Outdoors	At least one receptacle for the use of outdoor appliances.	*26–714(a)*
Garage, carport	One receptacle for each space.	*26–714(b)*
Miscellaneous	*One receptacle for a cord-connected central vacuum if* ducting system is installed.	*26–710(m)*

Table 6–2 ***CEC* requirements for receptacles in dwelling units.** (Courtesy of CSA Group)

two-hour period if the load does not exceed 225 amperes," *Rule 8–104 (3)(a)*. The *CEC* permits 100% loading on an overcurrent device *only* if that overcurrent device is *listed* for 100% loading. The CSA has *no* listing of circuit breakers of the moulded-case type used in residential installations that are suitable for 100% loading.

This calls for the judgment of the electrician and/or the electrical inspector. Will a branch circuit supplying a heating cable in a driveway likely be on for one hour or more? The answer is "probably." Good design practice and experience tell us to never load a circuit conductor or overcurrent protective device to more than 80% of its rating.

The branch-circuit rating shall *not* be less than any noncontinuous load plus 125% of the continuous load, *Rule 8–104*. For residential applications, all loads are considered to be continuous except for the load on the service or feeder conductors, *Rule 8–200(3)*.

The *CEC* considers most receptacle outlets in a residence part of the basic load, and additional load calculations are *not* necessary. Appliance outlets with loads greater than 12 amperes are not considered part of the basic load; these larger loads are calculated individually. The power requirements for these receptacle outlets will be discussed in detail later in this text.

To determine the number of lighting circuits required, divide the total watts by the voltage rating of the circuit(s) to be used.

In this residence, all lighting circuits are rated at 15 amperes. The maximum loading of these circuits is 12 amperes (15 amperes × 0.8).

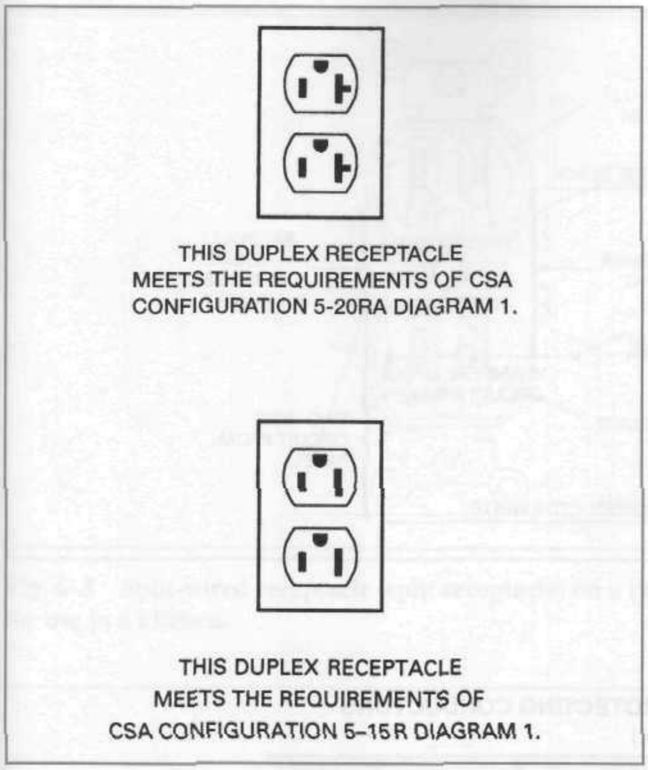


Fig. 6–2 15 and 20 ampere, 125 volt (two pole, three wire) receptacle configurations.

Therefore, the minimum number of circuits for general lighting and power is

$$\frac{\text{Watts}}{\text{120 volts}} = \text{Amperes}$$

$$\frac{\text{Amperes}}{12} = \text{Minimum number of circuits required}$$

Note that the *CEC* provides the minimum number of branch circuits required. For various purposes, you may install more.

Load calculations for electric water heaters, ranges, motors, electric heat, and other specific loads are in addition to the general lighting load, and are discussed throughout this text as they appear.

VOLTAGE

All calculations throughout this text use voltages of 120 volts and 240 volts. *CEC Rule 8–100,* entitled "Current Calculations," states that the voltage divisors to use shall be 120, 208, and 240, as applicable.

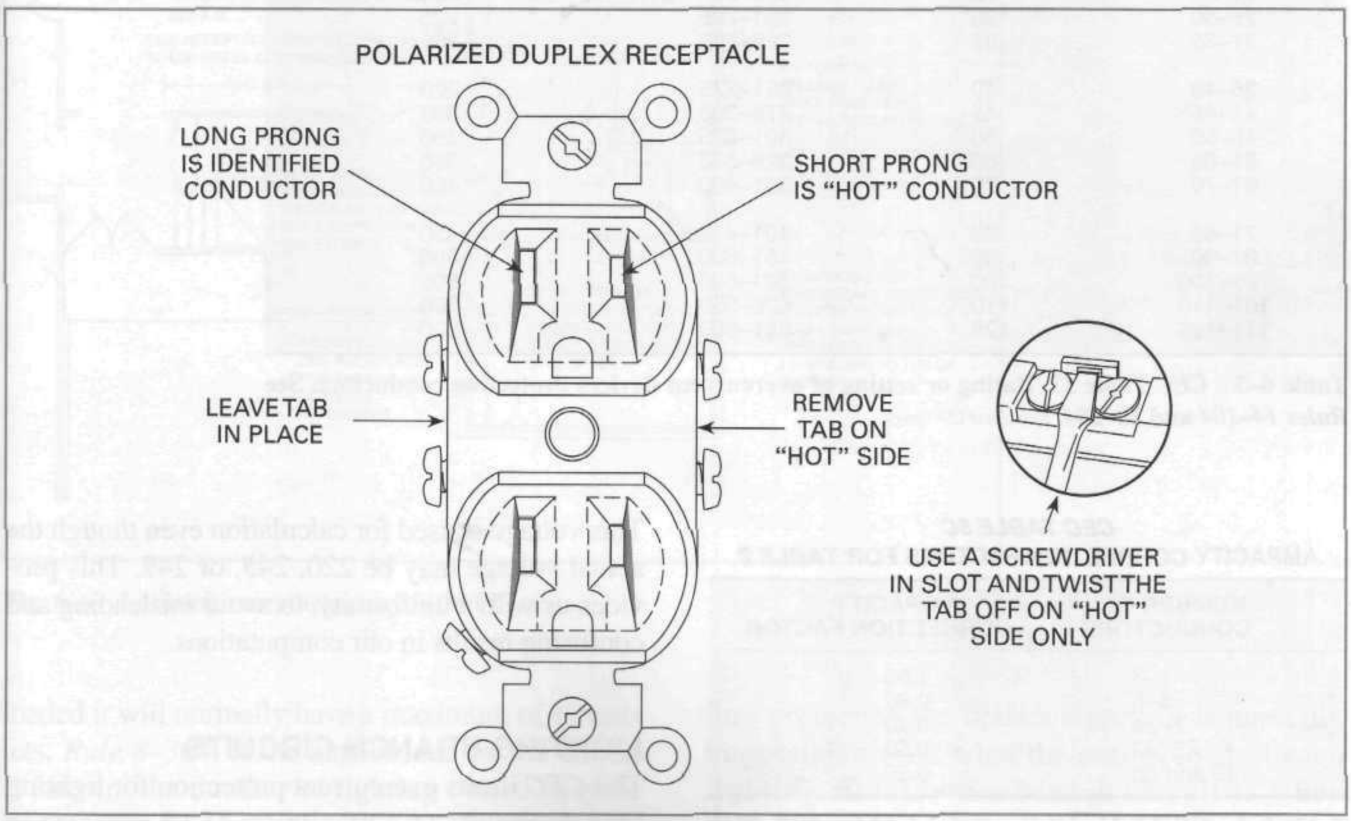


Fig. 6–3 Duplex receptacle showing method for removing tab on hot side.

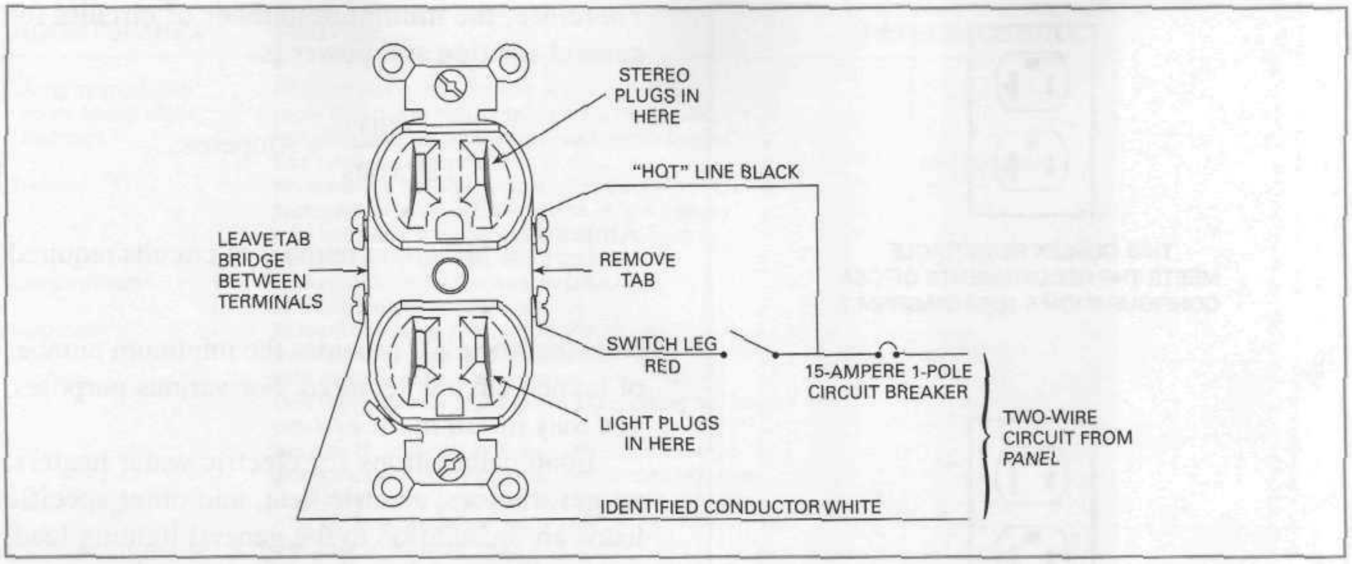


Fig. 6–4 Split-switched receptacle wiring diagram.

CEC TABLE 13
RATING OR SETTING OF OVERCURRENT DEVICES PROTECTING CONDUCTORS
(See *Rules 14–104* and *28–204.*)

AMPACITY OF CONDUCTOR	RATING OR SETTING PERMITTED AMPERES	AMPACITY OF CONDUCTOR	RATING OR SETTING PERMITTED AMPERES
0–15	15	126–150	150
16–20	20	151–175	175
21–25	25	176–200	200
26–30	30	201–225	225
31–35	35	226–250	250
36–40	40	251–275	300
41–45	45	276–300	300
46–50	50	301–325	350
51–60	60	326–350	350
61–70	70	351–400	400
71–80	80	401–450	450
81–90	90	451–500	500
91–100	100	501–525	600
101–110	110	526–550	600
111–125	125	551–600	600

Table 6–3 ***CEC Table 13.*** **Rating or setting of overcurrent devices protecting conductors. See *Rules 14–104* and *28–204.*** (Courtesy of CSA Group)

CEC TABLE 5C
AMPACITY CORRECTION FACTORS FOR *TABLE 2*

NUMBER OF CONDUCTORS	AMPACITY CORRECTION FACTOR
1–3	1.00
4–6	0.80
7–24	0.70
25–42	0.60
43 and up	0.50

Table 6–4 ***CEC Table 5C.*** **See *Rules 4–004* and *12–2210* and *Tables 2* and *4.*** (Courtesy of CSA Group)

This voltage is used for calculation even though the actual voltage may be 220, 245, or 247. This provides us with a uniformity, to avoid misleading and confusing results in our computations.

LIGHTING BRANCH CIRCUITS

The *CEC* limits overcurrent protection for lighting branch circuits to a maximum of 15 amperes in dwelling units, *Rule 30–104*. When a branch is

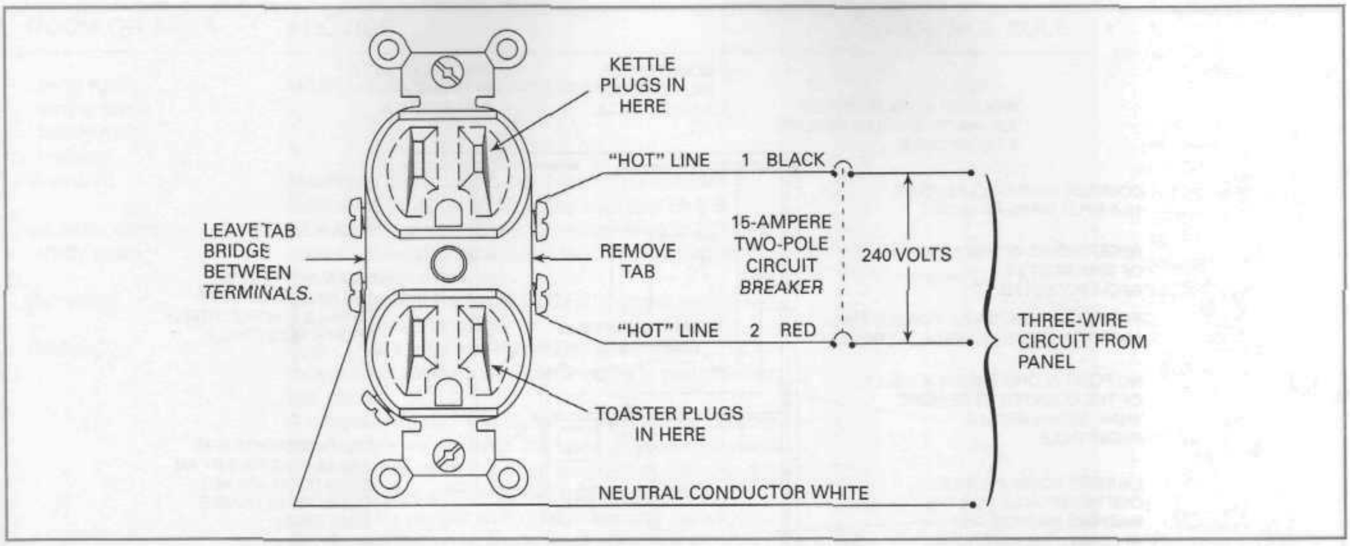


Fig. 6–5 Split-wired receptacle (split receptacle) on a two-pole 15-ampere breaker connected to a three-wire circuit for use in a kitchen.

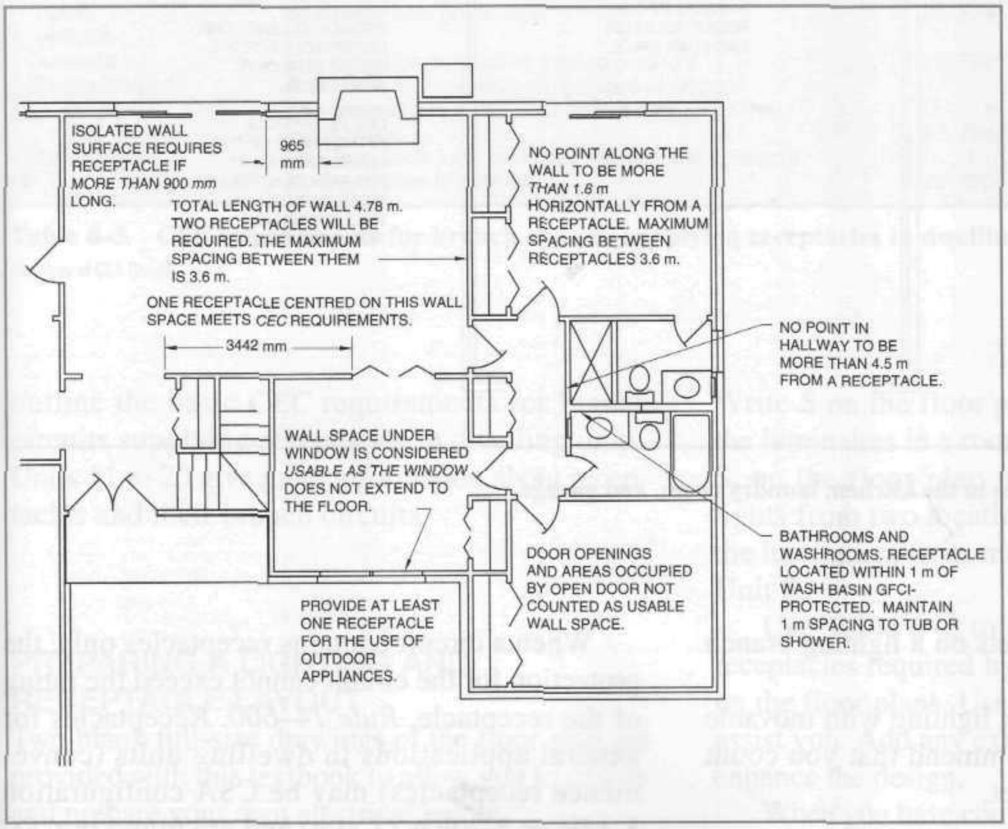


Fig. 6–6 Locating receptacles on the first floor.

loaded it will normally have a maximum of 12 outlets, *Rule 8–304*. If the **actual** load on the circuit is known, the number of lighting outlets may be increased as long as the load on the circuit does not exceed 80% of the rating of the circuit breaker or fuse protecting the branch circuit. It is normally impossible to tell what the **actual** load of each lighting fixture on a branch circuit is when doing the rough-in, unless a large number of recessed luminaires are installed; therefore, the