Total Mods for **Electrical** in **Pending Review: 21**

Total Mods for report: 21

Proposed Code Modifications

This document created by the Florida Department of Business and Professional Regulation - 850-487-1824

TAC: Electrical

Total Mods for **Electrical** in **Pending Review: 21**

Total Mods for report: 21

Sub Code: Building

E7174

1

Date Submitted	11/2/2018	**Section**	454.1.7.8	**Proponent**	Michael Weinbaum
Chapter	4	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Pending Review
Commission Action Pending Review

Comments

General Comments Yes **Alternate Language** Yes

Related Modifications

454.1.4.2, 454.1.9.8.4

Summary of Modification

Reduce lighting requirement in very shallow water, require low voltage underwater lights regardless of pool type

Rationale

There is no reason to require more light at an outdoor wading pool than at any other outdoor pool. Pools with very shallow water or no standing water are less dangerous and less light is acceptable.
The same low voltage requirements should apply to all bodies of water used by people.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

The local entity would have to learn the new rule and apply it if necessary.

Impact to building and property owners relative to cost of compliance with code

Pools with underwater lights in excess of 30 Volts will no longer be compliant

Impact to industry relative to the cost of compliance with code

This is standard practice at new pools. The required devices (transformers, DC power supplies, 12VAC LED lights) are already widely available.

Impact to small business relative to the cost of compliance with code

Pools with underwater lights in excess of 30 Volts will no longer be compliant. These lights are regularly replaced anyhow. A new transformer, sufficient for a smaller pool, costs less than $100. More wading pools and IWFs would be open at night without conflicting with the overall site ambiance.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The existing code is to prevent people from accidentally falling in the pool and potentially drowning if the fall makes them lose consciousness. The 15 V requirement for lights in IWFs is to prevent injury from electric shock.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

15V is stricter than NEC. Revision matches NEC. Applies NEC requirements evenly to all pools.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This eliminates a discrimination between 12V and 24V lights.

Does not degrade the effectiveness of the code

Lighting is still required for night time use, and more lighting is still required where the risk of drowning is higher. The low voltage requirement becomes the same for all features.

Alternate Language

1st Comment Period History

7174-A1

Proponent robert vincent **Submitted** 2/18/2019 **Attachments** Yes

Rationale

Both MOD paragraphs 454.1.7.8 and 454.1.9.8.4 propose that in pool water depth of less than 2" the author requests lighting allowance of 1 footcandle (10 lux). This should be changed to no less than 3 footcandles (30 lux). Reducing lighting levels from 6 foot-candles to 1 foot- candle is an extreme change on Wading pools and Interactive Water Features. The author only focuses on water depth, but fails to consider that IWF can have climbable features and adequate overall lighting is needed for both the patrons to use the feature safely and for adults to adequately supervise their children at IWFs and Wade pools. An applicant always has the right to ask for a specific variance for a particular project in which reduced lighting is desired.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

No enforcement impact on local authority..

Impact to building and property owners relative to cost of compliance with code

Slight increase in electricity from 1 foot-candle to 3 foot-candles; however will be a cost reduction from the current code mandate of 6 foot-candles

Impact to industry relative to the cost of compliance with code

Slight increase in cost from 1 foot-candle to 3 foot-candles; however will be a cost reduction from the current code mandate of 6 foot-candles

Impact to Small Business relative to the cost of compliance with code

Pools with underwater lights in excess of 30 Volts will no longer be compliant. These lights are regularly replaced anyhow. A new transformer, sufficient for a smaller pool, costs less than $100. More wading pools and IWFs would be open at night without conflicting with the overall site ambiance.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Pool patron safety is better served with night lighting luminosity that is adequate for all patrons, all water features, and all egress/ingress points.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Will strengthen code if the 3 foot-candle lower limit is implemented versus the proposed 1 foot-candle. Does not degrade the code.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

No discrimination is expected

Does not degrade the effectiveness of the code

Does not degrade the code if 3 foot-candles is the lower code limit; and would degrade the code (for safety) if the 1 foot-candle is allowed.

Is the proposed code modification part of a prior code version? No

1st Comment Period History

E7174-G1

Proponent Kari Hebrank **Submitted** 2/17/2019 **Attachments** No

Comment:

The Florida Swimming Pool Association SUPPORTS this code proposal.

1st Comment Period History

E7174-G2

Proponent robert vincent **Submitted** 2/18/2019 **Attachments** No

Comment:

454.1.4.2.5 lighting mod should be technical input by FBC Electrical TAC.

454.1.4.2.5

Underwater lighting, or lighting that may be exposed nozzle-directed pool water, shall not exceed 30 volts DC or 15 volts AC. Such lights shall be installed in accordance with manufacturer's specifications, and be approved for such use by UL or NSF.

...

454.1.7.8 Lighting.

Wading pools are exempt from underwater lighting requirements but shall have lighting installed for night use of 10 foot candles (100 lux) if indoors or ~~6~~ 3 footcandles (~~60~~ 30 lux) for outdoor night use. Such illumination shall be provided over the pool water surface and the pool deck surface. If the maximum depth of the wading pool is two inches (51 mm) or less, the outdoor, night use lighting requirement is reduced to 1 footcandle (10 lux).

...

454.1.9.8.4

If night operation is proposed, ~~6~~ 1 footcandles (~~60~~ 10 lux) of light shall be provided on the pool deck and the water feature area. ~~Lighting that may be exposed to the feature pool water shall not exceed 15 volts, shall be installed in accordance with manufacturer's specifications and be approved for such use by UL or NSF.~~

Mod 7174-A1

The following are edits of the submitted SW7174, and no other language is revised. bob v

454.1.7.8 Lighting.

Wading pools are exempt from underwater lighting requirements but shall have lighting installed for night use of 10 foot candles (100 lux) if indoors or ~~6~~ 3 footcandles (~~60~~ 30 lux) for outdoor night use. Such illumination shall be provided over the pool water surface and the pool deck surface. ~~If the maximum depth of the wading pool is two inches (51 mm) or less, the outdoor, night use lighting requirement is reduced to 1 footcandle (10 lux).~~

...

454.1.9.8.4

If night operation is proposed, ~~6 1 footcandles (60 10 lux)~~ 3 footcandles (30 lux) of light shall be provided on the pool deck and the water feature area. ~~Lighting that may be exposed to the feature pool water shall not exceed 15 volts, shall be installed in accordance with manufacturer's specifications and be approved for such use by UL or NSF.~~

E7209

2

Date Submitted	11/7/2018	**Section**	449.3.15	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **Yes** | **Alternate Language** **Yes**

Related Modifications

7210, 7211, and 7212

Summary of Modification

This proposed modification revises the requirements for lightning and surge protection for added clarity and effective enforcement.

Rationale

This proposed modification simply revises the language to clarify the rules. The change to .1 corrects the proper name for the NFPA 780 Standard. The changes to .2, .4, and .5 are minor editorial revisions for clarity. The change to .6 corrects the product name from "suppressors" to "protectors" as indicated by the UL 497 and UL 497A Standards.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification does not add any new criteria so impacts to the local entity are minimal.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building or property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance to industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance to small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed change clarifies the rules for lightning and surge protection which directly impacts the health, safety, and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves the code by adding clarity and correcting used terms.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

Alternate Language

1st Comment Period History

7209-A2

Proponent Bryan Holland **Submitted** 1/8/2019 **Attachments** Yes

Rationale

The only alternative language being proposed is under Section 449.3.15.6 where "low voltage system main or branch circuits" is being replaced with "communication systems". No other changes being recommended for this proposed modification. This will match the language in SP7255, SP7218, and a SP7211 comment.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This comment does not add any new criteria, just clarification, so impacts to the local entity are minimal.

Impact to building and property owners relative to cost of compliance with code

This comment will not change the cost of compliance to building and property owners.

Impact to industry relative to the cost of compliance with code

This comment will not change the cost of compliance to industry.

Impact to Small Business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance to small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This comment adds clarification which directly impacts health, safety, and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This comment improves the code by correcting the terminology of the revised section.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This comment does not discriminate against materials, products, or systems of construction.

Does not degrade the effectiveness of the code

This comment enhances the effectiveness of the code.

1st Comment Period History

E7209-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

449.3.15 Lightning protection.

449.3.15.1

A lightning protection system shall be provided for all new buildings and additions in accordance with NFPA 780, Standard for the Installation of Lightning Protection Systems.

449.3.15.2

Where additions are constructed to existing buildings, the existing building's lightning protection system, if present, shall be interconnected to the new lightning protection system.~~connected to the new lightning protection system, shall be inspected and brought into compliance with current standards.~~

449.3.15.3

A lightning protection system shall be installed on all buildings in which outpatient surgical procedures, cardiac catherization procedures, or pain management procedures that utilize I.V. drip sedation are provided.

449.3.15.4

~~There shall be surge protection~~ Surge protective devices (SPDs) shall be installed in accordance with NFPA 70, National Electrical Code, as required by NFPA 780, Standard for the Installation of Lightning Protection Systems for all normal and emergency electrical services.

449.3.15.5

Additional surge protection shall be provided for all low voltage and power connections to all electronic equipment in critical care areas and life safety systems and equipment such as fire alarm, nurse call and other critical systems. Protection shall be in accordance with NFPA 70, National Electrical Code and the appropriate IEEE Standards for the type of equipment protected.

449.3.15.6

All low-voltage system main or branch circuits entering or exiting the structure shall have surge ~~suppressors~~protectors installed for each pair of conductors and shall have visual indication for protector failure to the maximum extent feasible.

449.3.15 Lightning protection.

449.3.15.1

A lightning protection system shall be provided for all new buildings and additions in accordance with NFPA 780, Standard for the Installation of Lightning Protection Systems.

449.3.15.2

Where additions are constructed to existing buildings, the existing building's lightning protection system, if present, shall be interconnected to the new lightning protection system.connected to the new lightning protection system, shall be inspected and brought into compliance with current standards.

449.3.15.3

A lightning protection system shall be installed on all buildings in which outpatient surgical procedures, cardiac catherization procedures, or pain management procedures that utilize I.V. drip sedation are provided.

449.3.15.4

There shall be surge protection Surge protective devices (SPDs) shall be installed in accordance with NFPA 70, National Electrical Code, as required by NFPA 780, Standard for the Installation of Lightning Protection Systems for all normal and emergency electrical services.

449.3.15.5

Additional surge protection shall be provided for all low voltage and power connections to all electronic equipment in critical care areas and life safety systems and equipment such as fire alarm, nurse call and other critical systems. Protection shall be in accordance with NFPA 70, National Electrical Code and the appropriate IEEE Standards for the type of equipment protected.

449.3.15.6

All low-voltage system main or branch circuits communication systems entering or exiting the structure shall have surge suppressorsprotectors installed for each pair of conductors and shall have visual indication for protector failure to the maximum extent feasible.

E7211

Date Submitted	11/7/2018	**Section**	464.4.7	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	Yes

TAC Recommendation Pending Review
Commission Action Pending Review

Comments

General Comments **Yes** **Alternate Language** **Yes**

Related Modifications

7209, 7210, and 7212

Summary of Modification

This proposed modification adds requirements for lightning and surge protection in ALFs identical to the current and proposed requirements for nursing homes.

Rationale

This proposed modification adds requirements for lightning and surge protection in ALFs identical to the current and proposed requirements for nursing homes in Section 450.3.19. These two occupancy types have very similar uses, occupant loads, construction types, and exposure to the hazards of lightning and transient surges. Currently, ALFs are not afforded the same level of protection as nursing homes are against these hazards. There have been several reported fires as a result of lightning strikes to ALFs all across the state of Florida. These incidents have resulted in significant loss of property and extensive cost to the owners and residents of these properties.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will require the local entity to enforce additional criteria on ALFs similar to nursing homes. This includes additional permitting, plan review, inspection, commissioning, and record-keeping.

Impact to building and property owners relative to cost of compliance with code

This proposal will increase the cost of construction to building and property owners of ALFs. See the attached cost study.

Impact to industry relative to the cost of compliance with code

This proposed modification will increase the cost of compliance to industry. See the attached cost study.

Impact to small business relative to the cost of compliance with code

This proposed modification will likely not impact small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public and those working, living, and visiting ALFs in the state of Florida.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification strengthens the code by expanding lightning and surge protection into ALFs identical to what is currently required for nursing homes.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code by harmonized the hazard mitigation of lightning and transient surges at both nursing homes and ALFs.

1st Comment Period History

7211-A1

Proponent Bryan Holland **Submitted** 1/8/2019 **Attachments** Yes

Rationale

The only alternative language being proposed is under Section 464.4.7.5 where "low voltage system main or branch circuits" is being replaced with "communication systems". No other changes being recommended for this proposed modification. This will match the language in SP7255, SP7218, and a SP7209 comment.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This comment has no impact on the local enforcement entity as it only provides clarity and no new requirements

Impact to building and property owners relative to cost of compliance with code

This comment has no impact on building or property owners.

Impact to industry relative to the cost of compliance with code

This comment has no impact on industry.

Impact to Small Business relative to the cost of compliance with code

This proposed modification will likely not impact small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This comment provides clarification of the rule which directly relates to health, safety, and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This comment improves the use and clarity of the code.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This comment does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This comment enhances the effectiveness of the code.

1st Comment Period History

E7211-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

1st Comment Period History

E7211-G2

Proponent James gregory **Submitted** 2/16/2019 **Attachments** No

Comment:

I do not support adding this requirement to Assisted Living Facilities for the following reasons:
1. ALFs are not health care facilities. They are residential facilities reviewed as either R4 or I-1 of the FBC and Board and Care in the Life Safety Code.
2. Only limited nursing services are provided. All residents must be ambulatory.
3. ALFs do not have any life support or Type I EES unlike nursing homes and hospitals.
4. The large majority of ALFs constructed in the state are small homes from 5 to 7 residents. This is will be a heavy economic impact of those small homes.
5. All new ALFs must be fully sprinklered so there is already ample fire protection.

1st Comment Period History

E7211-G3

Proponent Deborah Franklin **Submitted** 2/18/2019 **Attachments** No

Comment:

FHCA does not support adding this requirement to Assisted Living Facilities for the following reasons:
1. ALFs are not health care facilities. They are residential facilities reviewed as either R4 or I-1 of the FBC and Board and Care in the Life Safety Code.
2. Only limited nursing services are provided. All residents must be ambulatory.
3. ALFs do not have any life support or Type I EES unlike nursing homes and hospitals.
4. The large majority of ALFs constructed in the state are small homes from 5 to 7 residents. This is will be a heavy economic impact of those small homes.
5. All new ALFs must be fully sprinklered so there is already ample fire protection.

1st Comment Period History

E7211-G4

Proponent Susan Anderson **Submitted** 2/18/2019 **Attachments** No

Comment:

The Florida Senior Living Association (FSLA) disagrees that placing institutional, nursing homes style regulations on assisted living facilities to protect the building from fire damage is necessary. Further, a review of NFPA records of fire incidents in assisted living facilities in the state of Florida indicates a lack of physical harm to residents over at least, the past two decades, that also informs against the proposed code modification. The intent of the Legislature in Part I of Chapter 429, Florida Statutes, specifically states that assisted living facilities "should be operated and regulated as residential environments with supportive services and not as medical or nursing facilities." S. 429.01(2), Fla. Stat. Section 429.41(1) goes further to state that regulations should "ensure a safe and sanitary environment that is residential and noninstitutional in design or nature." Danger to residents from fire in assisted living facilities in Florida has been successfully addressed by current regulations and the proposed modification is unnecessary and burdensome. In addition, FSLA adopts and incorporates the comments submitted by James Gregory and Debbie Franklin.

464.4.7 Lightning protection.

464.4.7.1

A lightning protection system shall be provided for all new buildings and additions in accordance with NFPA 780, Standard for the Installation of Lightning Protection Systems.

464.4.7.2

Where additions are constructed to existing buildings, the existing building's lightning protection system, if present, shall be interconnected to the new lightning protection system.

464.4.7.3

Surge protective devices (SPDs) shall be installed in accordance with NFPA 70, National Electrical Code, as required by NFPA 780, Standard for the Installation of Lightning Protection Systems for all normal and emergency electrical services.

464.4.7.4

Additional surge protection shall be provided for all low voltage and power connections to all electronic equipment in critical care areas and life safety systems and equipment such as fire alarm, emergency call and other critical systems. Protection shall be in accordance with NFPA 70, National Electrical Code and the appropriate IEEE Standards for the type of equipment protected.

464.4.7.5

All low-voltage system main or branch circuits entering or exiting the structure shall have surge protectors installed for each pair of conductors and shall have visual indication for protector failure to the maximum extent feasible.

464.4.7 Lightning protection.

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A lightning protection system shall be provided for all new buildings and additions in accordance with NFPA 780, Standard for the Installation of Lightning Protection Systems.

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Additional surge protection shall be provided for all low voltage and power connections to all electronic equipment in critical care areas and life safety systems and equipment such as fire alarm, emergency call and other critical systems. Protection shall be in accordance with NFPA 70, National Electrical Code and the appropriate IEEE Standards for the type of equipment protected.

464.4.7.5

All communication systems entering or exiting the structure shall have surge protectors installed for each pair of conductors and shall have visual indication for protector failure to the maximum extent feasible.

Lightning Protection Installation Cost Study

Prepared by Michael Chusid, RA FCSI for East Coast Lightning Equipment, Inc.
2015-July

Background

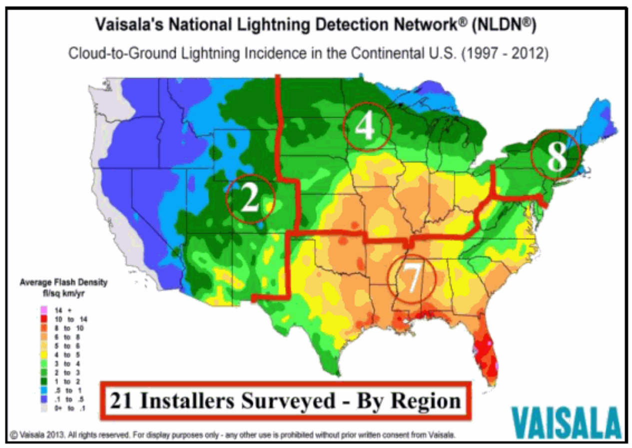
Lightning accounts for about $1 billion a year in homeowner's insurance claims for property damage. Lightning fires in non-residential properties cause an average of over $100 million in direct property damage annually, not including damage due to electrical or equipment malfunctions, non-fire-related structural damage, or consequential damages. Additional risks include injury and death due to lightning strikes.[1]

Fortunately, reliable lightning protection of buildings and structures is available. Data on the cost of installing lightning protection, however, has not been readily available. The purposes of this study, therefore, are 1) to understand the cost of installing lightning protection, and 2) to provide building owners and their architects, engineers, and risk management consultants with cost estimating guidelines for use during the planning and design phases of construction projects.

To prepare this study, East Coast Lightning Equipment, Inc. (www.ecle.biz) collected construction cost data from lightning protection installers throughout the US. The cost data, summarized below, confirms that lightning protection is economical and can be justified on a cost-to-benefit basis in at-risk buildings.

Methodology

During the second quarter of 2015, lightning protection installers were asked to submit "bids" for installation of lightning protection on three hypothetical projects. Prices were to include installer's overhead and profit but not a general contractor's mark-up. The projects include a single-family residence, a low-rise building typical of educational, commercial, and industrial occupancies, and a five story building typical of many office buildings, healthcare, and similar occupancies. See Appendix for survey instrument.



Responses were received from 21 installers that are certified for lightning protection work by the Lightning Protection Institute. The distribution of respondent trade territories is shown on map according to US Census Regions. The distribution of respondents is similar to the frequency of lightning strikes; higher in Eastern and Southern states, least in the West.

The results were tabulated by Michael Chusid, RA, FCSI, an independent construction consultant, www.chusid.com, and are summarized below.

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[1] www.iii.org/fact-statistic/lightning, accessed 2015-06-03.

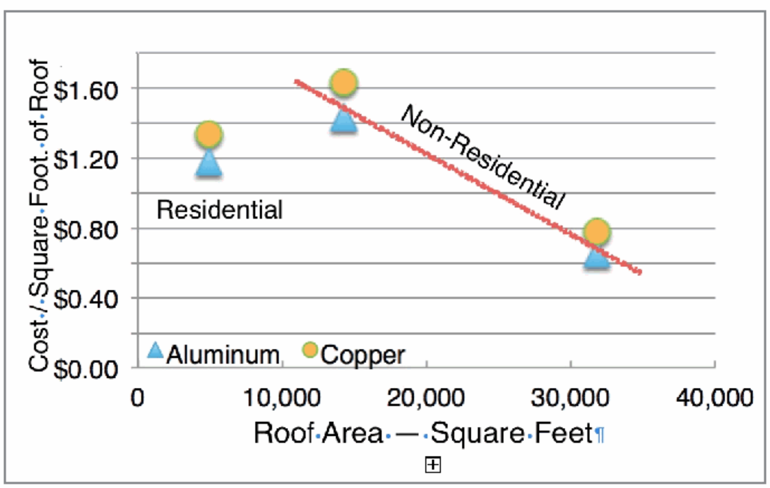
Lightning Protection Installation Cost Study

Key Findings

Lightning Protection Installation Cost Estimates						
	Residential Building		Low-Rise Building		5-story Building	
	Aluminum	Copper	Aluminum	Copper	Aluminum	Copper
Northeast						
$/Sq.Ft. of Roof	$1.56	$1.58	$0.74	$0.89	$1.75	$1.89
$/Sq.Ft. of Floor	$0.94	$0.95	$0.54	$0.65	$0.35	$0.38
South						
$/Sq.Ft. of Roof	$0.98	$1.10	$0.42	$0.50	$1.16	$1.33
$/Sq.Ft. of Floor	$0.59	$0.66	$0.31	$0.37	$0.23	$0.27
Midwest						
$/Sq.Ft. of Roof	$0.88	$1.06	$0.78	$1.02	$1.45	$1.82
$/Sq.Ft. of Floor	$0.53	$0.64	$0.58	$0.75	$0.29	$0.37
West						
$/Sq.Ft. of Roof	$1.60	$1.77	$0.88	$1.04	$1.46	$1.61
$/Sq.Ft. of Floor	$0.96	$1.06	$0.65	$0.76	$0.29	$0.32
National						
$/Sq.Ft. of Roof	$1.18	$1.34	$0.65	$0.78	$1.44	$1.64
$/Sq.Ft. of Floor	$0.71	$0.80	$0.48	$0.58	$0.29	$0.33

Cost of protecting sitework, such as trees, is not included.

Estimated Cost of Lightning Protection per Square Foot of Roof Area, National Averages



Lightning Protection Installation Cost Study

Analysis

General: Variations between regions are due to regional trade practices, wages and benefits, soil conditions governing the type of ground terminals used, and other factors. Variations within regions can also be significant, especially between urban and rural locations.

Copper lightning protection equipment is generally more expensive than aluminum due to commodity prices. There are also regional biases that favor one material over the other.

Nonresidential Buildings: In nonresidential buildings, roof area is the most significant factor in determining the work required to install lightning protection. Hence, multistory buildings will generally cost less per square foot of interior floor area.

Costs will generally be more in buildings with extensive roof top equipment and demanding architectural considerations; less in building with a modicum of rooftop equipment and a simple configuration.

Buildings over 75 feet in height (Class II) will incur additional expenses. These estimates do not apply to buildings that house explosives and other special occupancies.

Residential Buildings: In most homes with pitched roofs, air terminals need only be installed at the roof ridge, not the perimeter of the roof. This explains why lightning protection costs for the home in our study is below the trend line shown for non-residential construction.

Note, however features such as dormers, chimneys, balconies, skylights, rooftop equipment, and large flat areas can add to the cost.

How to Use

These cost estimates can be used in the early stages of planning or designing a project. Once the overall configuration of a building is determined, consultation with a qualified lightning protection designer or installer will yield a more accurate estimate and identify ways to improve protection while reducing costs.

These cost estimates are subject to change with time and can be adjusted using the *Engineering News Record* Construction Cost Indexes or other databases of historical construction costs. Lightning protection costs are also subject to fluctuations in raw material costs.

For Additional Information

Lightning Safety Alliance, www.LightningSafetyAlliance.org

Lightning Protection Institute, www.lightning.org

East Coast Lightning Equipment, Inc., www.ecle.biz, info@ecle.biz, +1 860-379-2046

Lightning Protection Installation Cost Study

APPENDIX

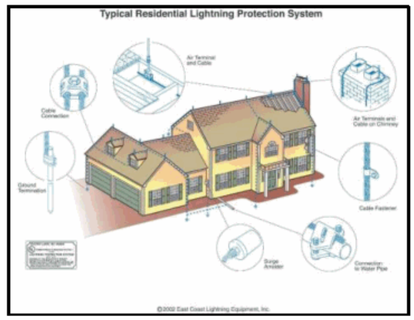
The following survey instrument was sent via e-mail to qualified lightning protection professionals.

ECLE requests your assistance in creating cost estimating guidelines that can be used by architects and engineers. Many designers ask us about the cost of installing lightning protection so they can include lightning protection in their project estimates. Your information will help them make better cost-to-benefit calculations that will, we believe, make it more likely for them to specify lightning protection. Please take a few minutes to look at the three buildings below then send us your price estimate to perform each of the installations.

Your data will be **confidential**. Michael Chusid, RA FCSI, a construction industry consultant, will compile regional and national averages and use the information to write articles for leading construction industry publications. We will send you a copy of his report as our thank you.

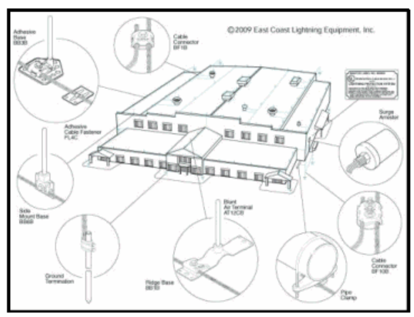
Residential Project

Assume the following:
Normal grounding conditions
Concealed installation - new construction
LPI or UL Certification Required
Please price in copper and aluminum
Price as you would to a GC or EC



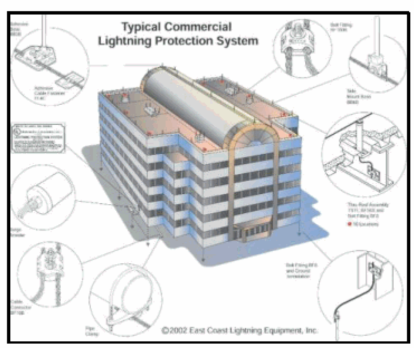
High School Project

Assume the following:
Normal grounding conditions
Exposed installation - existing construction
EPDM Roof
LPI or UL Certification Required
Please price in copper and aluminum
Price as you would to a GC or EC



Government Office Building Project

Assume the following:
Normal grounding conditions
Structural Steel to Ground installation
New construction
Built-Up Roof
LPI or UL Certification Required
Please price in copper and aluminum
Price as you would to a GC or EC
Click to download office dimensions



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Apparent lightning strike caused ALF fire

By Austin L. Miller
Posted Jun 16, 2017 at 4:27 PM
Updated Jun 16, 2017 at 6:48 PM

The fire that forced the evacuation of residents and staff at an assistant living facility in Belleview was apparently caused by Mother Nature.

According to a spokesperson from the State Fire Marshal's Office, it appears the fire was caused by a lightning strike. Damage to the attic area is approximately $30,000. The exact cause of the fire won't be determined until the investigation is complete.

Marion County Fire Rescue officials said Friday there were reports of heavy weather with lightning in the area prior to the fire. Fire officials said the blaze started in the attic above the electric panels and moved along the trusses.

Firefighters, sheriff's deputies and others placed 56 residents from Hampton Manor Assisted Living, 10590 SE 62nd Avenue Road, onto buses that transported them to another Hampton Manor facility.

Fire officials said they received the call about 5:05 p.m. and arrived on scene at 5:11 p.m. The fire was under control at 5:29 p.m.

Beatrice Kelty, community director at Hampton Manor, told the Star-Banner that Donna Clifford was in the kitchen when she heard a pop sound in the breaker and then saw fire in the ceiling. Clifford, the dietary supervisor, immediately pulled the alarm. There were seven staff members on duty at the time of the fire.

Kelty said she quickly went to the kitchen and doused the blaze with a fire extinguisher. Kelty said she and the other team members, including Dawn Crossley, a resident care manager, went to get the residents and evacuate them.

None of the residents were in the kitchen at the time of the fire. When the fire started, Kelty said, they were in the middle of dinner.

“My team was excellent and the residents cooperated,” Kelty said.

According to a fire report, as the fire made its way through the attic, a single fire sprinkler was activated and it contained the fire to the general area until firefighters arrived. The report also said that as soon as flames were seen in the attic, a staff member pulled the kitchen pull station that activated the hood. Though no fire was present in the hood, fire officials said it prevented the gas from going into the kitchen.

“The early actions by the staff to activate the fire alarm and notify MCFR along with the operation of the sprinkler system allowed for a quick response and to contain the damage,” according to the report.

Cindy Campbell, director of operations, told the Star-Banner that all the residents remain at the Hampton Manor at 1500 SE 24th Road because the Belleview building sustained significant damage in the kitchen area.

Campbell said its unknown when the repairs will begin or end or when residents will be able to return to the Belleview building. For now, she said, they’re looking for an alternate location, and the residents at the Southeast 24th Road facility are adjusting well.

Contact Austin L. Miller at 867-4118, austin.miller@starbanner.com or @almillerosb.

E7212

Date Submitted	11/7/2018	**Section**	457.1.4.1.5	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Pending Review
Commission Action Pending Review

Comments

General Comments Yes **Alternate Language** No

Related Modifications

7209, 7210, and 7211

Summary of Modification

This proposed modification revises the requirements for surge protection for added clarity and effective enforcement.

Rationale

This proposed modification simply revises the rule to add clarity and to remove an incorrect reference to the NEC.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will have no impact on the local entity relative to code enforcement.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building and property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance to industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance to small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification clarifies the rules related to surge protection which directly relates to the health, safety, and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves the code by adding clarity to the rule.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

1st Comment Period History

E7212-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

457.1.4.1.5 Surge protection.

Surge protection in compliance with ~~the~~NFPA 70, National Electric Code~~, Article 280, as incorporated by reference in Chapter 27 of the Florida Building Code, Building,~~ shall be installed to protect the ~~each~~ service ~~entrance~~ equipment and have integral visual indication of surge protector failure. Additional surge protection shall be provided for all low-voltage and power connections to all electronic equipment and conductors entering or exiting the building and other life safety systems equipment such as fire alarm, telephone, and nurse call. Protection shall be in accordance with appropriate IEEE standards for the type of equipment being protected.

E7218

Date Submitted	11/8/2018	**Section**	453.17.7	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments Yes | **Alternate Language** No

Related Modifications

7209, 7210, 7211, and 7212

Summary of Modification

This proposed modification revises the section to match the language for lightning and surge protection for hospitals (449.3.15), nursing homes (450.3.19), and as proposed for assisted living facilities (464.4.7).

Rationale

The current language of the section is vague and nondescript. The proposed language aligns the section with lightning and surge protection requirements found in 449.3.15 for hospitals, 450.3.19 for nursing homes, and as proposed in 464.4.7 for assisted living facilities. These prescriptive details will assist design professionals, installers, and AHJs when applying and enforcing this rule.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will not impact the local entity.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of construction for building and property owners of SREF structures.

Impact to industry relative to the cost of compliance with code

This proposed modification will have no fiscal impact on industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will have no impact on small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public by harmonizing all lightning and surge protection requirements of the FBC-B.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves the code by adding prescriptive and clear rules for compliance.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

1st Comment Period History

E7218-G1

Proponent	Vincent Della Croce	**Submitted**	1/8/2019	**Attachments**	No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

453.17.7 Lightning protection.

~~All facilities in high lightning risk areas shall be evaluated using the Risk Assessment Guide in NFPA 780 and other standards which address lightning protection, and shall be protected accordingly.~~

453.17.7.1

A lightning protection system shall be provided for all new buildings and additions in accordance with NFPA 780, Standard for the Installation of Lightning Protection Systems.

453.17.7.2

Where additions are constructed to existing buildings, the existing building's lightning protection system, if present, shall be interconnected to the new lightning protection system.

453.17.7.3

Surge protective devices (SPDs) shall be installed in accordance with NFPA 70, National Electrical Code, as required by NFPA 780, Standard for the Installation of Lightning Protection Systems for all normal and emergency electrical services.

453.17.7.4

All communication systems entering or exiting the structure shall have surge protectors installed for each pair of conductors and shall have visual indication for protector failure to the maximum extent feasible.

E7220

Date Submitted	11/8/2018	**Section**	453.17.8	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **Yes** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposed modification slightly revises the wording of the section to correspond with terms used in the NEC related to GFCI protection.

Rationale

This proposed modification revises the language used in the section to correspond to terms used in the NEC related to GFCI protection. The change also recognizes that GFCI protection can be provided by other than GFCI-type receptacles, such as GFCI-type circuit breakers supplying the branch circuits to the locations identified in the rule.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will have no impact on the local entity.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will have no impact on the building or property owner of SREF structures.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance to industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance to small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Rules for GFCI protection are directly connected to the health, safety, and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves the code by aligning the FBC-B language with that used in the NEC related to GFCI protection.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification actually removes a product discrimination by clarifying that all NEC suitable types of the GFCI protection can be utilized to meet the requirements of the section.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

1st Comment Period History

E7220-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

453.17.8 ~~Ground fault interrupter (GFI) receptacles~~. Ground-Fault Circuit-Interrupter Protection for Personnel (GFCI).

GFCI protection of receptacles shall be ~~installed as required by~~ provided in accordance with NFPA 70, National Electrical Code ~~of Chapter 27~~ and in the following locations:

1. All elementary special needs, prekindergarten, and kindergarten classroom receptacles.

2. All building entry vestibule receptacles.

3. All mechanical, boiler and electrical room receptacles.

E7255

Date Submitted	12/20/2018	**Section**	450.3.19	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **Yes** **Alternate Language** **No**

Related Modifications

7209, 7211, and 7212

Summary of Modification

This proposed modification revises the requirements for lightning and surge protection for added clarity and effective enforcement.

Rationale

This proposed modification simply revises the language to clarify the rules. The change to .1 corrects the proper name for the NFPA 780 Standard. The changes to .2, .3, and .4 are minor editorial revisions for clarity. The change to .5 corrects the product name from "suppressors" to "protectors" as indicated by the UL 497 and UL 497A Standards.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification does not add any new criteria so impacts to the local entity are minimal.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building or property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will not impact the industry relative to the cost of compliance with code.

Impact to small business relative to the cost of compliance with code

This proposed modification will not impact businesses relative to the cost of compliance with code.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed change clarifies the rules for lightning and surge protection which directly impacts the health, safety, and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves the code by adding clarity and correcting used terms.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

1st Comment Period History

E7255-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

450.3.19 Lightning protection.

450.3.19.1

A lightning protection system shall be provided for all new buildings and additions in accordance with NFPA 780, Standard for the Installation of Lightning Protection Systems.

450.3.19.2

Where additions are constructed to existing buildings, the existing building's lightning protection system, if present, shall be interconnected to the new lightning protection system.~~connected to the new lightning protection system, shall be inspected and brought into compliance with current standards.~~

450.3.19.3

~~There shall be sure protection~~ Surge protective devices (SPDs) shall be installed in accordance with NFPA 70, National Electrical Code, as required by NFPA 780, Standard for the Installation of Lightning Protection Systems for all normal and emergency electrical services.

450.3.19.4

Additional surge protection shall be required for all low voltage and power connections to all electronic equipment in critical care areas and life safety systems and equipment such as fire alarm, nurse call and other critical systems. Protection shall be in accordance with NFPA 70, National Electrical Code and the appropriate IEEE Standards for the type of equipment protected.

450.3.19.5

All ~~low-voltage~~ communication systems ~~main or branch circuits~~ entering or exiting the structure shall have surge ~~suppressors~~ protectors installed for each pair of conductors and shall have visual indication for protector failure to the maximum extent feasible.

E7362

Date Submitted	11/20/2018	**Section**	422.6	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposed modification adds essential electrical system criteria for ambulatory care facilities.

Rationale

The code currently does not provide any guidance on what essential electrical system requirements are needed in an ambulatory care facility. This new Section in 422.6 and 2702.17 will give users of the code a pointer to the applicable requirements in the NFPA 99 and NFPA 70. This also correlates the FBC-B with the FFPC.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will not impact the local entity relative to code enforcement.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building and property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public by adding clarity to the code and pointers to other applicable sections and applicable industry standards.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves and strengthens the code by providing the user guidance on where to get information for ambulatory care facility essential electrical system.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

422.6 Electrical systems. In ambulatory care facilities, the essential electrical system for electrical components, equipment and systems shall be designed and constructed in accordance with the provisions of Chapter 27 and NFPA 99.

2702.2.17 Ambulatory care facilities. Essential electrical systems for ambulatory care facilities shall comply with Section 422.6.

E7370

9

Date Submitted	11/20/2018	**Section**	412.6.7	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposed modification adds electrical classification criteria to the rules for aircraft paint hangers.

Rationale

This proposed modification provides some needed guidance for classifying the hazardous location within an aircraft paint hanger. these requirements will harmonize the FBC-B with the FFPC and NFPA 70.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will not impact the local entity relative to code enforcement.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building and property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public by providing needed guidance on the classification of hazardous location at and around aircraft paint hangers.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves and strengthens the code.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

[F] 412.6.7 Electrical. Electrical equipment and devices within the aircraft paint hangar shall comply with NFPA 70.

[F] 412.6.7.1 Class I, Division I hazardous locations. The area within 10 feet (3048 mm) horizontally from aircraft surfaces and from the floor to 10 feet (3048 mm) above the aircraft surface shall be classified as a Class I, Division I location.

[F] 412.6.7.2 Class I, Division 2 hazardous locations. The area horizontally from aircraft surfaces between 10 feet (3048 mm) and 30 feet (9144 mm) and from the floor to 30 feet (9144 mm) above the aircraft surface shall be classified as a Class I, Division 2 location.

E7385

Date Submitted 11/21/2018	**Section** 917	**Proponent** Bryan Holland
Chapter 9	**Affects HVHZ** No	**Attachments** No

TAC Recommendation Pending Review
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposed modification adds a new Section on "Mass Notification Systems" to the code.

Rationale

The need for real-time effective emergency communications in the United States came into sharp focus in the 20th century in response to threats to homeland security and our educational occupancies. We have learned from the recent incidents that occurred in our college/university campuses and other buildings, and have created installation guidelines to be followed for Life Safety. When a mass disaster event occurs, the need for real time information communicated in a clear and concise method via various paths is very critical to Life Safety. The Risk Analysis and the Emergency Response Plan have been shown to be the needed steps to take in this complicated life safety concern today and in the future. This action will NOT require a mass notification system to be installed; it requires the Risk Analysis which is outlined in detail within NFPA 72. That analysis prepared by a registered design professional along with stakeholders of the college and AHJ that will outline what is needed for this location and application. This code change proposal provides a requirement that a Risk Analysis be created for every new building of size that requires a fire alarm system in college's campuses. NFPA 72 has a chapter dedicated to Emergency Communication Systems-Mass Notification. The requirements for Risk Analysis and qualifications for those performing these services are within NFPA 72; they are matured and are in the 3rd cycle of revisions. Mass Notification can cover One Way, Two Way, Wide Area (outside) In-Building Mass Notification and Distributed Recipient (Cell phone, laptop) forms of communication. All of this is covered in detail in NFPA 72. Mass Notification is a subset of ECS for all hazards concerns. Another is EVACS which is the Em Voice Alarm Communication System which is defined for FIRE incidents, and now can be utilized for mass notification.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will not impact the local entity relative to code enforcement other than verifying the risk analysis has been completed and acted upon accordingly.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building and property owners unless the mass notification system is recommended by risk analysis and the cost of the system is absorbed by the building and property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will increase the cost of compliance with the code as a risk analysis will be required for qualifying occupancy types and the outcome may result in a required mass notification system to be installed.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public by addressing a growing need for mass notification in certain occupancies to warn the public of a hazard or danger.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves and strengthens the code by giving the user of the code a pointer to the applicable industry standard (NFPA 72) to perform a risk analysis.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

SECTION 917

MASS NOTIFICATION SYSTEMS

[F] 917.1 College and university campuses. Prior to construction of a new building requiring a fire alarm system on a multiple-building college or university campus having a cumulative building occupant load of 1,000 or more, a mass notification risk analysis shall be conducted in accordance with NFPA 72. Where the risk analysis determines a need for mass notification, an approved mass notification system shall be provided in accordance with the findings of the risk analysis.

E7208

Date Submitted 11/7/2018
Chapter 27
Section 2703
Affects HVHZ No
Proponent Bryan Holland
Attachments Yes
TAC Recommendation Pending Review
Commission Action Pending Review

Comments

General Comments Yes

Alternate Language No

Related Modifications

7207

Summary of Modification

This proposed modification will add mandatory surge protection requirements to buildings under the scope of the FBC-B.

Rationale

This revision is intended to address the recognized need for surge protection to protect the sensitive electronics and systems found in most modern appliances, safety devices (such as AFCI, GFCI and smoke alarms) and equipment used in buildings. Additionally, the expanding use of distributed energy resources (DER) within electrical systems often results in more opportunity or greater exposure for the introduction of surges into the system.

Electronic life-saving equipment such as fire alarm systems, IDCI's, GFCI's, AFCI's and smoke alarms, may be damaged when a surge occurs due to lighting, internal local switching as well as external utility switching. Other equipment is also damaged when subjected to surge. In many cases, electronic devices and equipment can be damaged and rendered inoperable by a surge and yet this damage is undetected by the owner. It is practical to require a SPD to provide a general level of protection. In almost all new service installations, as well as service upgrades, no consideration is given to providing a general level of protection to the "whole structure" which would include those devices that cannot be afforded a cord connected Type 3 SPD protection. 2703.4 is included to require that when a service is upgraded, an SPD is to be installed.

Studies by recognized authorities including NEMA, IEEE, and UL, all substantiate the fact that surges can and do cause significant damage. Nationwide Insurance organizations recognize the need for effective surge protection as well and have published recommendations that include point-of-use surge protectors and installation of surge protection at service equipment.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will require additional enforcement requirements related to electrical services. The impact will be minor.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will increase the cost of compliance to building and property owners where the cost of providing a mandatory SPD is passed-on to the consumer.

Impact to industry relative to the cost of compliance with code

SPDs are available with a large variety of ratings, configurations, and options. The cost can be as low as $25 per device to several hundred-dollars where higher levels of protection or other performance features are selected.

Impact to small business relative to the cost of compliance with code

This proposed modification will increase the cost to small business owners where the cost of providing a mandatory SPD is passed-on to the consumer.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification will enhance the health, safety, and welfare of the general public by reducing the negative impacts of transient surges to a building's premises wiring system and equipment.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification strengthens and improves the code by closing an essential life and property saving protection gap in the current code.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against any material, product, method, or system of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code by adding life and property saving surge protection.

1st Comment Period History

E7208-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

Section 2703

Surge Protection

2703.1 Surge Protective Device.
All services supplying buildings under the scope of this code shall be provided with a surge protective device (SPD).

2703.2 Location.
The surge protective device shall be an integral part of the service equipment or shall be located immediately adjacent thereto.

Exception: The surge protective device shall not be required to be located in the service equipment if located at each next level distribution equipment downstream toward the load.

2703.3 Type.
The surge protective device shall be a Type 1 or Type 2 SPD.

2703.4 Replacement.
Where service equipment is replaced, all of the requirements of this section shall apply.

National Electrical Manufacturers Association

A NEMA Low Voltage Surge Protective Devices Section White Paper
VSP 1-2017

Susceptibility of Electrical and Electronic Components to Surge Damage

Published by

National Electrical Manufacturers Association (NEMA)
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Foreword

This is a new NEMA white paper based on member-supported testing. To ensure that a meaningful publication was developed, draft copies were distributed to groups within NEMA that have an interest in this topic. Their comments and suggestions provided vital input prior to final NEMA approval and resulted in a number of substantive changes in this publication. To remain up to date with advancing technology, this publication will be periodically reviewed by the Low Voltage Surge Protective Devices Group of the NEMA Commercial Products Division.

Proposed or recommended revisions should be submitted to:

Senior Technical Director, Operations
National Electrical Manufacturers Association
1300 North 17th Street, Suite 900
Rosslyn, Virginia 22209

This white paper was developed by the Low Voltage Surge Protective Devices Group of the NEMA Commercial Products Division. Approval of this white paper does not necessarily imply that all members of the Product Group voted for its approval or participated in its development.

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Mersen USA	Newburyport, MA
MVC-Maxivolt	Amarillo, TX
Pentair Engineered Electrical & Fastening Solutions	Solon, OH
Phoenix Contact	Middletown, PA
Raycap, Inc.	Post Falls, ID
Schneider Electric USA	Salt Lake City, UT
Siemens Industry, Inc.	Norcross, GA
Southwire Company	Clearwater, FL
Space Age Electronics	Sterling, MA
Surge Suppression, LLC	Brooksville, FL
Thomas & Betts, a member of the ABB Group	Richmond, VA

The National Electrical Manufacturers Association (NEMA) provides information to assist with answering various questions related to the application and use of surge protective devices.

Executive Summary

The NEMA Low Voltage Surge Protection Devices, 05VS, has been asked to provide an overview of electrical and electronic equipment surge susceptibility. This overview will help the electrical community, engineers, consumers, and technicians understand the various transient conditions to which electrical and electronic equipment may be subjected. The intent is not to evaluate individual companies' equipment as to safety or product performance, but to create awareness and offer guidance based on real-world testing on protection. This will be helpful in preventing problems with products. While there are many documents, papers, standards, web sites, and other media that talk about the harmful effects of transient impulses practical and empirical data is not readily available. Some of the explanations for this lack of data are the variable conditions electrical equipment is subjected to events such as electrical equipment failure, electronic equipment process interruption, insulation breakdown in electric conductors and electronic circuits, electronic component breakdown, premature aging of electrical and electronic components, etc. The standards community has many test procedures and evaluation practices for a prescribed environment. The challenge is that these environments are normally under standard test conditions, for example, 25°C. There are two are issues that are not covered under these standard test conditions.

a. What is the upset capability of the equipment?
b. What level of voltage or current would cause damage to equipment?

Quantitative data on how big or how many transient impulses are required to significantly reduce the life of or cause failure of an electrical or electronic device is almost nonexistent. Reasons for this lack of available information are the variable conditions under which an electrical device is subjected, i.e., at one location normal operating voltage might have a range of 110 to 135 Vac. Other locations may have more consistent supply voltage, but how many times does it fluctuate? When it does change, how long was the unstable condition? How large was the transient condition? When a system is influenced by another device or system, how large is the impact on the rest of the equipment?

The 05VS section understands that every possible combination of events and test equipment cannot be tested. The burden placed upon manufactures and consumers would be impractical. For instance, what happens when a transient impulse occurs to an electrical device when it is at its maximum operating temperatures, upper and lower boundaries? As every electrical device has its own unique set of environmental conditions, a frequent request is, "How many surges does it take to damage my equipment" or "How much longer will my equipment last with and without surge protection?"

Another missing piece of information is data on the cumulative effect of transient impulses. The average person, unless taught otherwise, often believes that surge damage is a one-time event. When lightning strikes and a piece of equipment is damaged, the damage may be attributed to a transient impulse. But when a piece of equipment fails due to the accumulation of numerous smaller magnitude surges, the failure is attributed to the age of equipment, poor quality of the equipment, or a hundred other unexplained conditions.

For this paper, the term "surge" and "transient" are used interchangeably.

Scope

The purpose of this paper is to present the test results of actual devices in a real-world surge environment. This white paper will generate some information on the surge susceptibility for various electrical components. This white paper is not meant to be an exhaustive study, nor a complete test spectrum. It is merely a means to provide useful information to the electrical community, both for those who design electronic and electrical equipment and for those who install and use electronic and electrical equipment. The tests were performed in certified testing laboratories. The tests were completed using standardized test sequences and parameters. The test specimens used were off-the-shelf devices; they were not modified or altered in any way. The electrical products used were selected to represent a broad spectrum of common electrical components familiar to all users of electrical appliances.

The results obtained by this testing can be used as a guide to the reaction of electrical devices under various conditions. Some devices might show malfunctions, and some may experience upset events caused by surge events in actual installations. Upset conditions will be a concern if any other electronics are controlling a critical safety component. For example, a control transformer with an upset output could cause process failure for equipment being run by the transformer.

Test Methodology

A variety of waveforms were selected to represent surge conditions. These waveforms are based on the standard waveforms found in the current edition of IEEE C62.41.2 with the addition of some intermediate waveforms from an earlier version of this standard. They are a representation of impulse events created by interruptions in the electrical system. Most equipment is designed to handle minor variations in nominal operating voltages. However, surges can range in impact and adversity and may affect nearly all equipment under certain conditions. Here are some of the standard waveforms for equipment surge susceptibility. While most equipment has a nominal level of intrinsic resistibility, based on environment, application, and installation, additional or redundant levels of surge protection may be recommended.

The following standard waveforms were used in the testing protocol:

a) Category C Low / Category B Combination Wave (6,000 V / 3,000 A)
b) Category C Low / Category B Combination Wave (4,000 V / 2,000 A)
c) Category B Combination Wave (2,000 V / 1,000 A)
d) Category B Ring Wave (6,000 V / 500 A)
e) Category B Ring Wave (4,000 V / 333 A)
f) Category B Ring Wave (2,000 V / 167 A)
g) Category A Ring Wave (6,000 V / 200 A)
h) Category A Ring Wave (4,000 V / 133 A)
i) Category A Ring Wave (2,000 V / 67 A)

Note: See IEEE Std. C62.41.2 TM-2002 especially Clause 6.2; Tables 2, 3 and 4; and the notes associated with those tables for further explanation of the surge test levels selected.

The 6,000 V combination wave was developed to represent a variety of surge events. These events may be externally or internally generated electrical surges, such as when a utility capacitor bank is switched into or out of an electrical system. Internal events can come from inductive load switching. This surge is not meant to be a replication of lightning impulses, but rather a representation of the energy produced from an impulse during normal electrical operating conditions. For additional information on lightning impulses, please see NFPA 780 *Standard for the Installation of Lightning Protection Systems.*

These tests were designed to determine the number and magnitude of surges some common electrical devices used in residential, commercial and industrial applications could withstand before failure. Each sample was tested starting with the highest magnitude IEEE C62.41.2 waveform from the list above, the 6,000 V / 3,000 A Category C Low Combination Wave. If the sample could withstand 300 surges, the test was stopped.

If the sample failed before 300 surges in this category were applied, then the surge generator was re-calibrated to output the next lower surge waveform. This continued until the sample withstood 300 surges.

The following common electrical and electronic devices were tested:

a) Incandescent Bulb
   - Common 120 V, 60 W screw-base bulb
b) Compact Fluorescent Bulb
   - Common 120 V, 60 W (equivalent) screw-base bulb
c) Electronic Ballast & Fluorescent Bulb
   - Common 120 V electronic ballast with two 25 W, 36 inch fluorescent tubes
d) LED Bulb
   - Common 120 V, 60 W (equivalent) screw-base bulb
e) Control Transformer
   - Industrial 50 VA, 120 V to 24 V transformer
f) Variable Frequency Drive (VFD)
   - Industrial 120 V single-phase, 0.33 HP VFD
g) Uninterruptable Power Supply (UPS)
   - Common 120 V, 500 VA, off-line UPS

The test procedure was designed to subject the test samples to a range of surges of different types and magnitudes representing real-world applications. The testing started with IEEE Category C and then proceeded to Categories B and A (decreasing in severity). If the sample failed during the first series of test surges, a new sample was tested with surges of the next lower level until the test sample passed 300 surges without issue.

> Note: that the test samples were not directly connected to the surge generator. The samples were connected through a 10 meters (30 feet) length of cable. This is a better representation of a practical and actual electrical installation.

The following steps were taken to conduct the test on each device:

a) The open circuit voltage waveform and short circuit current waveform were measured to verify the test waveform.
b) The sample to be tested was attached to the output of the generator using a 10 meters cable (12-2 non-metallic sheathed cable).
c) Apply the highest combination surges from Table 1 to the first test sample. Perform up to 300 strikes unless the sample fails. The impulses are injected at 60 second intervals and are applied at the peak of the AC sine wave (90 degrees of the power frequency).
d) If the sample fails, apply the surge waveform in the next column to the right in Table 1 in 60 second intervals at 90 degrees of the power frequency for up to 300 strikes or until the device fails and record results.
e) Continue testing with the test waveform in the next column to the right in Table 1 until one sample passes the test of 300 surges.

Test Results

Table 1 contains the compiled results of the surge susceptibility testing. The first column describes the device being tested. The devices tested were all commercially available products manufactured by a variety of companies. The second column lists the number of the sample being tested. This is followed by the nine different surge waveforms used in the testing, starting with the highest voltage and current waveforms on the left and working to the lowest magnitude waveforms on the right.

The number in the columns under the different test waveforms are the number of surges of that surge type when the sample failed. None of the samples survived more than one of Category C Low Combination Wave (6,000 V / 3,000 A) waveform. When a number “1” appears in a column, then the test sample failed on the first surge in that category. When there is a “300” in a column under one of the test waveforms, then the test sample survived 300 of those waveforms without damage. At that point, the testing was stopped, as the sample would have passed all the surge waveforms to the next lowest value (to the right in Table 1).

Table 1: Test Results

Sample	Sample Number	Category C Low / Category B Combination Wave			Category B Ring Wave			Category A Ring Wave		
		6 kV 3,000 A	4 kV 2,000 A	2 kV 1,000 A	6 kV 500 A	4 kV 333 A	2 kV 167 A	6 kV 200 A	4 kV 133 A	2 kV 67 A
Incandescent Bulb	1	1								
	2		1							
	3			1						
	4				1					
	5					1				
	6						1			
	7							44		
	8								300	
Compact Fluorescent Bulb	1	1								
	2		1							
	3			1						
	4				300					
Electronic Ballast & Fluorescent Bulb	1	1								
	2		1							
	3			1						
	4				300					
LED Bulb	1	1								
	2		1							
	3			1						
	4				300					
50 VA Control Transformer	1				53					
VFD 0.33 HP	1	1								
	2				300					
	3*				20, L-G					
500 VA UPS	1				300					

Note: All VFD surges were performed Line to Neutral in positive polarity except for VFD sample number 3 which was tested Line to Ground.

Conclusions

Table 1 in this document shows the surge test results for some common products. They cover a range of products from an incandescent light bulb to an uninterruptible power supply. These are common devices that are connected to an electrical supply and are exposed to everyday electrical surges that can be damaged by these events. The surges applied in this testing are at the same levels to be expected in common electrical installations.

As documented in the test results, the surge environment can produce a variety of effects. Surge damage can be experienced in a single event or as the result of an accumulation of surges. For example, in the case of an incandescent light bulb, the damage can be immediate or from repeated surges as shown by the quantity of the 44 surges in the Category A environment (i.e., test sample 7 in the table above). The application of a quality surge protective device can prevent damage to common electrical or electronic products. Surge protection is just as effective when used in commercial and industrial environments.

Electrical equipment is subject to surge damage, and these results show conclusively that everyday electrical devices are damaged by surges of the level expected in a normal electrical distribution system. The application of a surge protective device within a home or facility can alleviate the effects and save the cost or replacement for many electrical or electronic devices. For additional information on surge protection and its applications, visit www.NEMASurge.org.

§

Data Assessment for Electrical Surge Protection Devices

Phase 1
Final Report

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FOREWORD

Every year there are widespread anecdotal reports of homeowners' property damage to electrical and electronic equipment resulting from electrical surges. The revision cycle of the 2011 edition of NFPA 70, *National Electrical Code®* (NEC®) included several proposals (e.g. NEC 4-53 and NEC 4-127) to add new requirements for a Surge Protective Device for all dwelling units. These proposals were rejected by the respective Code Making Panel (i.e., CMP-4) due to a lack of reliable data to support such requirements.

The goal of this project is to develop a data collection plan to assess loss related to electrical surge in homes, and address the potential impact electrical surge protection devices would have in mitigating these losses. The deliverables from this project represent a Phase I study in support of a potential second phase (not included in the scope of this effort).

The Research Foundation expresses gratitude to the report authors Eddie Davis, Nick Kooiman, and Kylash Viswanathan, all with Hughes Associates, Inc. Likewise, appreciation is expressed to the Project Technical Panelists and all others who contributed to this research effort for their on-going guidance. Special thanks are expressed to the project sponsors Eaton Corporation and the National Electrical Manufacturers Association for providing the funding for this phase 1 project.

The content, opinions and conclusions contained in this report are solely those of the authors.

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Data Assessment for Electrical Surge Protective Devices

Prepared for:

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Quincy, MA 02169-7471

Project Number: 1ELD62001.001
October 2014

EXECUTIVE SUMMARY

Purpose

The Fire Protection Research Foundation sponsored this project to address electrical surge protection for residential dwelling units. The goal of the project is to develop a data collection plan to assess loss related to electrical surges in homes, and address the potential impact electrical surge protection devices (SPDs) would have in mitigating these losses. The deliverables from this project represent a Phase I study (this report) in support of a potential second phase (not included in the scope of this effort).

Report Content

This report provides information regarding:

- Surge phenomena and their sources.
- Surge protection methods.
- Surge protection strategies recommended by various sources.
- Industry standards and their recommendations.
- Available data associated with electrical surges and their impact.
- Recommended data collection in support of code-making efforts.

Surge Protection

Sources of Surges

A surge is a transient wave of voltage or current. The duration is not tightly specified but is usually less than a few milliseconds. The following are typical sources of surges:

- Lightning.
- Utility switching, including capacitor switching.
- Equipment switching and switching inductive loads within a facility.

Protection against surges is referred to as *surge protection*, and includes protection against both surge voltages and currents. The devices used to protect against surges are referred to as *surge* *protective devices*, or SPDs. A surge of duration longer than a few milliseconds is referred to as a swell or temporary overvoltage (TOV) and requires a different type of protection design; SPDs can fail if exposed to long duration TOVs.

Surge Effects

Surges can cause equipment damage. Large surges damage equipment and other components in the electrical distribution system. Smaller surges can cumulatively damage equipment and can cause nuisance equipment tripping. Both surge voltage and current can be damaging. In the case of lightning strokes, the surge can be carried into a facility via all of the connected conductive paths.

There is a limit on how high of a voltage can be transmitted into a facility or residence. Above a certain level, a high voltage will result in flashover in the insulation system of electrical equipment and conductors. A flashover can cause insulation damage, electric shock, and fire.

NEMA surveys of facility managers confirmed catastrophic failure or damage of electrical or electronic equipment due to a lightning event or voltage surge and premature failure of electrical or electronic equipment, including failure of life safety equipment.

The Insurance Information Institute report for 2013 identified 114,740 insurer-paid lightning claims for residential locations. The average lightning paid-claim amount was $5,869.

Residential Surge Protection

Residential surge protection has long been viewed as an important safety consideration and guidance has been issued by IEEE and NIST to help homeowners protect their house and its contents. This protection has often been described as being similar to an insurance policy, partly because there is not an NFPA code requirement for SPD installation in residences. Today's residences often contain electronic equipment throughout, including appliances, computers, security systems, life safety equipment, automation systems for internet-enabled applications, and home entertainment systems.

Industry Standards

SPDs are routinely used in facilities that are potentially exposed to voltage or current surges from nearby lightning, utility switching, or other sources; and there are many manufacturers of SPDs and these manufacturers often offer guidance regarding SPD installation ratings and recommended applications. However, industry codes and standards provide limited guidance regarding selection, rating, and application.

One limitation with surge protection design is that there is no industry standard that describes what is an acceptable level of surge protection for standard facilities or residential locations. Although industry codes and standards are available that establish standardized surge criteria and assist with the application of specific surge protector types, these standards do not provide adequate design guidance that ensures a facility is properly protected against surges. There is no existing industry guidance for surge protection of residential facilities.

Refer to Section 3 for an overview of the available industry standards.

Data Acquisition Plan

Surge Data and Its Effects

Lightning strokes, either direct, nearby, or some distance away can cause voltage and current surges into a facility. Information is available regarding lightning strokes and their intensity. But, less information is available regarding the extent to which these surges are transmitted into commercial facilities, industrial facilities, or residences. Section 4.2 describes the difficulty associated with obtaining this data.

Available Data

Vaisala owns and operates the National Lightning Detection Network (NLDN) that provides accurate lightning data information across the USA. And, Vaisala can provide lightning location reports that provide individual cloud-to-ground lightning strikes and the intensity of strike at a specific location on the date of loss. This capability represents the largest and most complete source of lightning surge location and intensity.

Data for lightning surges that extend to the inside of facilities is not readily available. Published papers and IEEE C62.41.1 provide information regarding the expected surge levels within a facility or residence, but extensive data is not available.

Switching-related surge data, either internally or externally generated, is sparse. The added difficulty with this data is that these surges often do not cause immediate failure of electrical and electronic equipment; the damage occurs as a cumulative effect.

The largest documented source of surge effects is contained within the insurance claim documents for damage caused by surges. The Insurance Information Institute in collaboration with State Farm® produces annual reports of insurance claims associated with lightning-induced damage.

Data Acquisition Plan

There are challenges in obtaining usable data applicable to residential applications, such as:

- Confirming that equipment failures were a direct result of a surge event.
- Establishing any median and upper bounds to actual surge levels since this is not recorded inside facilities.
- Defining the protection improvement realized by applying SPDs.

Given the scarcity of real data relating to surges and the effects of surges, the approach described below is recommended.

The purpose of the recommended data acquisition approach is to produce real data regarding damage and injuries caused by surges. This information is intended to assist the NFPA 70 code-making committees with additional technical data to support a decision to require or not require SPDs for the variety of electrical applications proposed in past NFPA 70 update cycles (refer to Section 1.2).

The starting point for this project is to acquire the nationwide lightning stroke data for the continental USA for 2013 (or 2014 if the project starts in 2015). This information can tie back to insurance claim data and possibly provide surge current values for the locations of interest.

The Insurance Information Institute is proposed to manage the insurance industry claim data. Their involvement assures that the insurance industry claim reports can remain confidential while allowing access to additional data that might be contained in the claim reports.

The Insurance Information Institute already publishes annual summaries of the number of lightning-related insurance claims and the claim amount. Additional information of interest that might be available in the claim data includes:

- Date and location of surge event (to establish geographical correlations).
- Electronic equipment and appliances damaged.
- Life safety equipment damaged – smoke detectors, CO or CO_2 detectors, or other equipment.
- Fires caused by surge effects.
- Personal injuries associated with the surge event.
- Presence of or lack of installed SPDs.

Life safety equipment damage, fires caused by surge events, and personal injuries are of particular interest for code-making efforts.

Although the annual Insurance Information Institute survey has historically focused on residential claims, the survey for this project should include commercial and industrial claims also. NEMA assistance and direction with this effort will be helpful.

NEMA Low Voltage Surge Protective Devices Section (5-VS) participation is recommended for the following:

- Assisting with project scope, including commercial and industrial users.
- Reviewing the project checklist for the type of information to be obtained from the insurance industry.
- Reviewing failure data report summaries.
- Considering recommended SPD design principles, including the specification of surge protection in low-lightning flash density areas versus high-lightning flash density areas. Should NFPA elect to require SPDs in dwelling units or other applications, then minimum surge protection current limits should also be addressed, similar to the method provided in NFPA 780. As SPD surge current rating increases (and the degree of protection), the SPD cost also increases.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

INTRODUCTION

1.1 Project Overview

The Fire Protection Research Foundation sponsored this project to address electrical surge protection for residential dwelling units. The goal of the project is to develop a data collection plan to assess loss related to electrical surges in homes, and address the potential impact electrical surge protection devices (SPDs) would have in mitigating these losses. The deliverables from this project represent a Phase I study (this report) in support of a potential second phase (not included in the scope of this effort).

The project includes the following activities that are documented in this report:

- Literature review – review of literature to include fundamental factors contributing to electrical surges, existing data associated with losses, case studies of SPD effectiveness, and overview of SPD designs.

- Preliminary data collection plan – develop a preliminary data collection plan that will address the identified data gaps. When implemented, the data collection plan should provide a comprehensive review of electrical surge related losses in homes in the United States and address the potential impact of electrical surge protection devices in mitigating these losses.

- Final report – to be issued after review of the draft report.

1.2 NFPA 70 Committee Report on Proposals – 2013

Each update cycle for NFPA 70, *National Electrical Code*®, includes numerous proposals for changes throughout the document. In particular, the installation of SPDs has been proposed for virtually all low-voltage (600 volts or less) electrical distribution equipment. Because of the breadth of these recommendations, the proposals and their reasons for rejection are summarized here. Although this Fire Protection Research Foundation report is focused on SPDs for residential dwelling units, the proposals for SPDs cover a much broader set of electrical distribution equipment.

The *National Electrical Code® Committee Report on Proposals – 2013 Annual Revision Cycle*[1] provides a summary of all proposals and their disposition in support of the 2014 edition of NFPA 70. With respect to the application of SPDs, the following proposals were submitted:

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[1] The *National Electrical Code® Committee Report on Proposals – 2013 Annual Revision Cycle*. The 2010 version provided similar recommendations.

- Proposal 4-65 Log #3318 NEC-P04 – New Article 225.41 Surge Protection. A Type 1 or Type 2 listed SPD shall be installed on all outside branch circuits and feeders and shall be located at the point where the outside branch circuits and feeders receive their supply.

- Proposal 4-143 Log #3319 NEC-P04 – Article 230.67 Surge Protection. A Type 1 or Type 2 listed SPD shall be installed on all services.

- Proposal 4-143a Log #3504 NEC-P04 – Article 230.67 Dwelling Unit Surge Protection.
(A) Surge Protective Device. All dwelling units shall be provided with a surge protective device (SPD) installed in accordance with Article 285.
(B) Location. The surge protective device shall be an integral part of the service disconnecting means or shall be located immediately adjacent thereto.
(C) Type. The surge protective device shall be a Type 1 or Type 2 SPD.
(D) Replacement. Where service equipment is upgraded, all of the requirements of this section shall apply.

- Proposal 5-244 Log #3320 NEC-P05 – New Article 285.2 Required uses. A listed SPD shall be installed in or on the following equipment that is rated at 1000 volts or less.
(1) Switchboards and panelboards
(2) Motor control centers
(3) Industrial control panels
(4) Control Panels for elevators, dumbwaiters, escalators, moving walks, platform & stairway chairlifts
(5) Power distribution units supplying information technology equipment in information technology rooms
(6) Solar photovoltaic (PV) combiner boxes, recombiner boxes, and inverters
(7) Roof-top air conditioning and refrigerating equipment
(8) Adjustable-speed drive systems
(9) Burglar alarm panels
(10) Fire alarm panels
(11) Critical Operations Power Systems
(12) Small Wind Electric Systems

- Proposal 9-117 Log #3321 NEC-P09 – Article 408.6 Surge Protection. A listed SPD shall be installed in or on all switchboards and panelboards.

- Proposal 11-14 Log #3322 NEC-P11 – Article 409.70 Surge Protection. A listed SPD shall be installed in or on all industrial control panels.

- Proposal 11-42 Log #3323 NEC-P11 – New Article 430.92 Surge Protection. A listed SPD shall be installed in or on all motor control centers.

- Proposal 11-55 Log #3324 NEC-P11 – New Article 430.121 Surge Protection. A listed SPD shall be installed in or on all adjustable-speed drive systems.

- Proposal 11-84 Log #3325 NEC-P11 – New Article 440.9 Surge Protection. A listed SPD shall be installed in or on all roof-top air-conditioning and refrigerating equipment.

- Proposal 12-49 Log #3326 NEC-P12 – New Article 620.56 Surge Protection. A listed SPD shall be installed in or on control panels for elevators, dumbwaiters, escalators, moving walks, platform and stairway chairlifts.

- Proposal 12-140 Log #3327 NEC-P12 – New Article 645.18 Surge Protection. A listed SPD shall be installed in or on all switchboards, panelboards, and power distribution units supplying information technology equipment in information technology rooms.

- Proposal 12-169 Log #3328 NEC-P12 – New Article 670.6 Surge Protection. A listed SPD shall be installed in or on all industrial machinery.

- Proposal 4-254 Log #3329 NEC-P04 – New Article 690.12 Surge Protection. A listed SPD shall be installed in or on all solar photovoltaic (PV) combiner boxes, recombiner boxes, and inverters.

- Proposal 13-98 Log #3330 NEC-P13 – New Article 700.8 Surge Protection. A listed SPD shall be installed in or on all emergency systems switchboards and panelboards.

  Note: Although the *Committee Report on Proposals* lists the Final Action as Reject, the 2014 edition of NFPA 70 does include a new Article 700.8 that states:

  700.8 Surge Protection
  A listed SPD shall be installed in or on all emergency systems switchboards and panelboards.

- Proposal 4-405 Log #3331 NEC-P04 – New Article 705.13 Surge Protection. A Type 1 listed SPD shall be installed at the point of connection of all interconnected electric power production sources.

- Proposal 3-131 Log #3332 NEC-P03 – New Article 725.36 Surge Protection. A listed SPD shall be installed in or on all burglar alarm control panels.

- Proposal 3-179 Log #3333 NEC-P03 – New Article 760.36 Surge Protection. A listed SPD shall be installed in or on all fire alarm control panels.

The NFPA 70 Panel rejected the above proposals on various bases, including:

- *Surge protection is permitted to be installed and should not be required, as surge probabilities vary by locality, and different types of electrical loads have differing surge protection requirements. Surge protection must also be periodically maintained or replaced. The user should make the decision to install this protection.*

- *While the use of SPD's is appropriate in many instances, it is not always needed in every installation. System designers should apply SPD's where needed. Equipment manufacturers frequently provide integrated surge protection when it is deemed appropriate. The substantiation provided does not warrant the imposition of this new requirement.*

- *Surge protective devices have proven to provide benefits for components and systems against the damages of voltage surges, but the substantiation for this proposal does not document that such protection would specifically benefit HVAC equipment installed on a roof. In addition this may not work with high resistance, impedance or ungrounded systems. The NFPA FPRF is working on a project in this area which may provide information in the future.*

- *CMP-13 acknowledges that surges may result in failures. However, the proposal does not state what type or level of protection should be required. Further substantiation through a formal research report that presents evidence of the type of SPD and the level of protection required would present the opportunity for the panel to reconsider the proposal.*

Miscellaneous changes were made to the 2014 edition of NFPA 70 Article 285, *Surge-Protective Devices (SPDs), 1000 Volts or Less*, but these changes do not affect the locations where surge protection has been required.

1.3 Report Content

This report provides information regarding:

- Surge phenomena and their sources.
- Surge protection methods.
- Surge protection strategies recommended by various sources.
- Industry standards and their recommendations.
- Available data associated with electrical surges and their impact.
- Recommended data collection in support of code-making efforts.

2

SURGE PROTECTION FUNDAMENTALS

Section 2 provides an overview of electrical surges and protection against the effects of these destructive surges.

2.1 Sources of Surges

A surge is a transient wave of voltage or current. The duration is not tightly specified but is usually less than a few milliseconds. The following are typical sources of surges:

- Lightning.
- Utility switching, including capacitor switching.
- Equipment switching and switching inductive loads within a facility.

The following summarizes the effects of these various surge sources.

Table 2-1
Sources of Surges

Source of Surge	Peak Voltage Magnitude	Frequency of Occurrence	Comments
Lightning	<1,000 volts to >40,000 volts with average of about 20,000 volts	Weekly to rarely, depending on location	Magnitude depends on proximity of stroke to facility and coupling of stroke to facility electrical system. Voltages within a facility above 6,000 volts are unlikely due to flashover.
Utility Capacitor and System Switching	Up to 1,300 volts on a 480 volt system	Never to several times a day, depending on utility	Capacitors might or might not be installed nearby.
Facility Equipment Switching	Up to 2,000 volts on a 480 volt system	Many times a day	Magnitude is small compared to lightning-induced transients, but switching can occur frequently.

Protection against surges is referred to as *surge protection*, and includes protection against both surge voltages and currents. The devices used to protect against surges are referred to as *surge protective devices*, or SPDs. A surge of duration longer than a few milliseconds is referred to as a swell or temporary overvoltage (TOV) and requires a different type of protection design; SPDs can fail if exposed to long duration TOVs.

2.1.1 *Lightning Surges*

Lightning-induced surges into an electrical system are caused by lightning strokes to the ground, towers, or structures. A lightning stroke can produce peak discharge currents ranging from a few thousand amperes to 200,000 amperes, or higher. This lightning discharge current is developed within a few microseconds and typically discharges most of its energy within a millisecond. The location where a lightning stroke will occur is not completely predictable; cloud-to-ground strokes have been recorded almost 20 miles from the base of the source cloud.

The frequency of lightning strokes varies with geographical location. Figure 2-1 shows the Vaisala lightning flash density map for the United States. Lightning strokes are a rare occurrence in Portland Oregon while they can be a routine event in Orlando Florida.

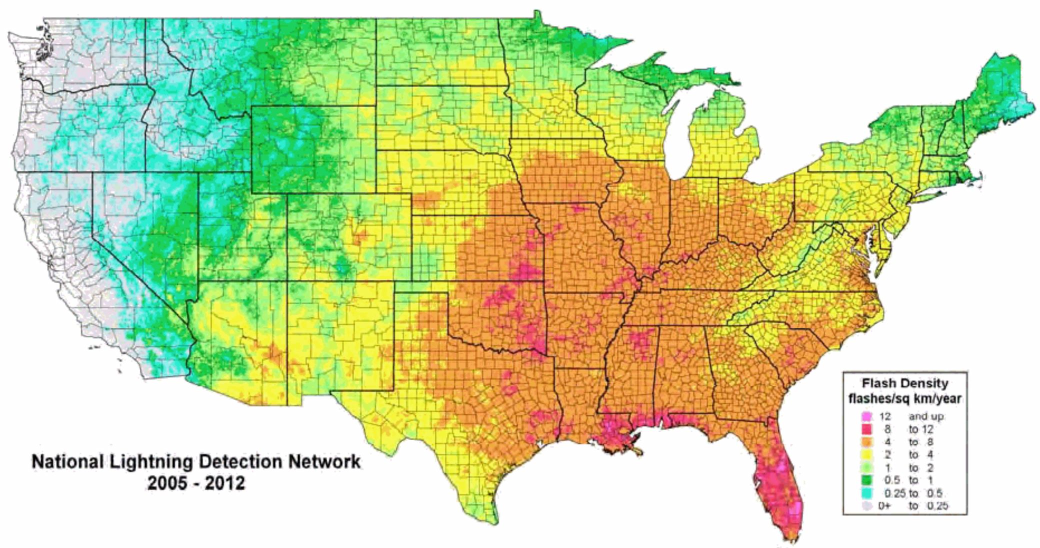

Figure 2-1
Lightning Flash Density Map
Courtesy Vaisala

A single intense storm can produce thousands of lightning strokes. Schneider Electric Data Bulletin DB03A, *Surge Protection: Measured Lightning Stroke Data*, describes a July 2000 storm in Tampa Florida that recorded 33,863 lightning strokes during a 14 hour period. Both positive and negative polarity strokes were detected,[2] with the following recorded surge currents:

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[2] A lightning stroke is a lightning discharge between a thundercloud and the ground and commonly referred to as cloud-to-ground lightning. The most common type of lightning stroke is referred to as a negative lightning stroke and usually originates near the bottom of the cloud with a large concentration of negative charge in the cloud base. The term *negative lightning* means that there is a net transfer of negative charge from the cloud to the ground. Positive lightning strokes represent only about 5% of the lightning strokes and tend to originate in the more positively charged top of the cloud.

Positive Lightning Stroke Surge Currents

- 95% – less than 30 kA
- 98% – less than 60 kA

Negative Lightning Stroke Currents

- 82% – less than 30 kA
- 98% – less than 60 kA

For this Tampa Florida storm, notice that the above results show that 2% of the lightning strokes produced surge currents greater than 60 kA. A few lightning strokes approached 200 kA. But, over 80% of the lightning strokes produced surge currents less than 60 kA.

This data correlates reasonably well with a report from the IEEE Lightning and Insulator Subcommittee of the T&D Committee that showed a 50% probability of less than about 20 kA, a 95% probability of less than about 60 kA, and a 99% probability of less than about 100 kA.[3]

A lightning-induced surge is a high magnitude impulsive transient of very short duration, typically measured in microseconds or milliseconds. But, during this short period, significant system damage can occur. Figure 2-2 shows an example.

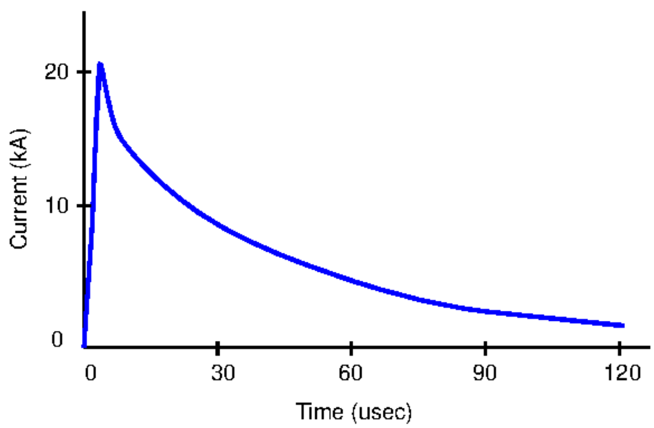

Figure 2-2
Typical Lightning Surge Current

Lightning-induced surges can be introduced into the electrical distribution system by any of the following methods, either alone or in combination:[4]

[3] Refer to Lightning and Insulator Subcommittee of the T&D Committee, *Parameters of Lightning Strokes: A Review*, IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005, for the actual range of values.

- Direct lightning strokes to the service entrance, either at low voltage lines or on the high voltage windings of service entrance transformers.
- Nearby strokes that induce voltages in distribution transformer secondary circuits.
- Strokes near the service entrance that induce surges onto the electrical system.
- Strokes to a building that induce surges in the system ground with respect to power supplies.
- Surges that cause surge protector operation, thereby placing a surge on the ground and neutral wire common to the low voltage system.

The greatest number of lightning-caused surges that will be seen originate on the high voltage side of the distribution transformer. Far less often, the surges will be caused by a local stroke impinging on the facility, service entrance transformer, or nearby equipment. Most surges, regardless of whether they originate on the primary or secondary side of the transformer are not from a direct stroke; usually, the surge is caused by a stroke to the pole, tower, ground wire, or nearby object with the surge electromagnetically coupled into the distribution or service conductors. Once into the electrical system wiring, surges on the high side of the transformer are coupled into the secondary and transmitted throughout a facility.

2.1.2 *Utility Switching*

Utility switching is a broad term that applies to how utility configurations are occasionally changed. Each switching operation can produce a transient that can momentarily exceed equipment voltage ratings. Although the transients are not as large in magnitude as a nearby lightning stroke, switching transients can cause cumulative damage to electrical equipment. And, if switching results in a temporary overvoltage (TOV), it can also cause SPD failure.

Capacitor switching is a special case of utility switching. Capacitors might also be switched periodically by large industrial power customers. Capacitor switching can be a common every-day event, occurring several times each day in some locations, as a utility adjusts system voltage and compensates for inductive loads.

Capacitor switching causes a surge voltage by the following process. The voltage across a capacitor is zero before it is switched into the circuit. As a capacitor is switched, there is a momentary short circuit across the capacitor as the system voltage is applied to the zero voltage of the capacitor. At the capacitor location, the bus voltage momentarily experiences a step change to zero volts. After the initial step change, the voltage recovers and then overshoots as the system eventually return to its steady state value. Thereafter, the system oscillates until damping returns the voltage to its steady-state value. During the initial oscillation period, the peak transient voltage can approach 200 percent of the normal peak system voltage (common peak surge voltages can range from 150 percent to 180 percent of normal). Another factor contributing to the transient is the inrush current as the capacitor energizes; this inrush current

[4] IEEE C62.41.1, *Guide On The Surge Environment In Low-Voltage (1000V And Less) AC Power Circuits*, uses the terms "direct flash", "near flash", and "far flash" to distinguish between lightning strokes and how they induce a surge on a facility.

can have a resonant frequency anywhere from 300 hz to 1,000 hz depending on the installed inductance and capacitance, which adds to the system oscillations. Figure 2-3 shows an example of a capacitor switching transient.

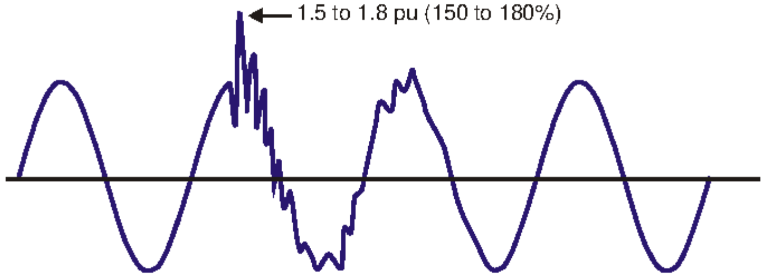

Figure 2-3
Voltage Waveform for Capacitor Switching Transient

Capacitors inside a facility can resonate with the switching-induced oscillations, thereby magnifying the peak voltage and extending the period until the voltage returns to normal. Magnification of the switching transient can occur if the utility switched capacitor bank is much larger than the facility capacitor bank and there is little resistive load (mostly motor load) to provide a damping mechanism.

2.1.3 *Facility Internal Switching*

Switched equipment in a facility electrical system or residence results in the inductive release of energy that creates a momentary voltage surge. Even minor switching, such as deenergizing lighting loads, can cause a significant inductive surge in the system. This type of switching accounts for the overwhelming majority of switching transients. However, the magnitude of this type of surge is much smaller than for lightning-induced surges.

2.2 Surge Effects

Surges can cause equipment damage.[5] Large surges damage equipment and other components in the electrical distribution system. Smaller surges can cumulatively damage equipment and can cause nuisance equipment tripping. Both surge voltage and current can be damaging. In the case of lightning strokes, the surge can be carried into a facility via all of the connected conductive paths. The following figures show examples of damage caused by surges.

[5] Refer to IEEE 1100, *Powering and Grounding Electronic Equipment*, for additional information regarding the effects of surges.

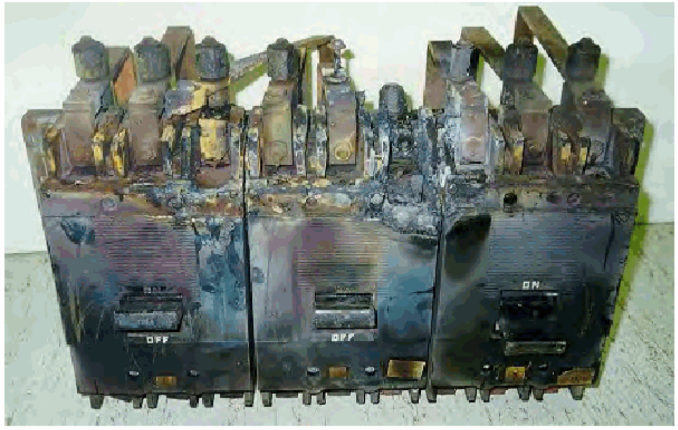

Figure 2-4
Circuit Breaker Failure Caused by Surge Voltage

Figure 2-5
Copper Busbar Melted by Surge Current

Figure 2-6
Circuit Board Damage Caused by Surge Voltage

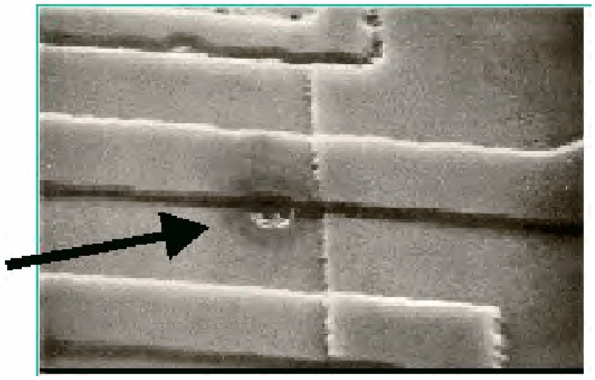

Figure 2-7
Micro Circuit Damage Caused by Surge Voltage

Electronic equipment is susceptible to surge transients. Computers and internet-enabled devices are not only at risk in the power supply but can also be damaged by surges that propagate into the equipment via the communications link.

There is a limit on how high of a voltage can be transmitted into a facility or residence. Above a certain level, a high voltage will result in flashover in the insulation system of electrical equipment and conductors. A flashover can cause insulation damage, electric shock, and fire.

2.2.1 *NEMA Surveys*

The NEMA Low Voltage Surge Protective Devices Section (5-VS) sponsored surveys of surge damage in 2013 and 2014.[6] The surveys were targeted towards facility managers and attempted to accomplish the following:

- Determine if SPDs are installed.
- Obtain failure data for electrical or electronic equipment due to a lightning event or voltage surge.
- Determine the frequency of damage incidents.
- Address the type of equipment damaged.
- Summarize the cost of damage.

The following summarizes the 2014 survey results:

- 100 respondents completed the survey.

[6] NEMA 2013 *U.S. Surge Protection Damage Survey* and NEMA *Surge Damage Survey Results – Wave 2*. Refer to http://www.nemasurge.org for reports.

- A plurality (48%) of respondents noted that their facility had experienced unexplained process interruptions. Catastrophic failure or damage of electrical or electronic equipment due to a lightning event or voltage surge and premature failure of electrical or electronic equipment were both frequently reported (41%) events. More than a third (38%) noted the occurrence of lockup of computer or industrial process systems.

- For most respondents (61%), it cost less than $10,000 to repair the damage resulting from voltage surges, but a sizable number (16%) reported damage costing in excess of $50,000 to fix.

- Nearly 95% of those who reported having experienced a surge event resulting in equipment damage indicated that they subsequently purchased surge protection. Virtually all of those who did so, purchased immediately or within three months of the event.

- Over 65% reported downtimes associated with voltage surges of 6 hours or more.

- Respondents reported damage or loss of function of the following types of life safety equipment because of voltage surges:

  - ♦ Smoke detector (34.7%)
  - ♦ CO2 detector (18.7%).
  - ♦ Fire alarm system (41.3%).
  - ♦ Security system (49.3%).
  - ♦ Ground fault circuit interrupters (22.7%).
  - ♦ Emergency lighting (32.0%)
  - ♦ Emergency generators or backup power (33.3%).
  - ♦ Fire pumps (12.0%).
  - ♦ Elevators or escalators (24.0%).
  - ♦ Safety interlocking systems on machines (26.7%)

  Of the respondents, only 14.7% stated that no life safety equipment was damaged or lost function.

- When asked if anyone had been injured, either directly or indirectly, as a result of a voltage surge, 10.7% replied yes.

The NEMA survey is significant in that it shows the effect of surges on life safety equipment and the potential impact to personnel in a facility.

2.2.2 *Insurance Information Institute Surveys*

The Insurance Information Institute[7] provides periodic reports of homeowner insurance claims associated with lightning-induced damage. Their report for 2013, produced in collaboration with State Farm®, included the following:

- There were 114,740 insurer-paid lightning claims in 2013, down 24% from 2012.
- The average lightning paid-claim amount was also down in 2013, slipping by 8.3% to $5,869 from $6,400 in 2012.
- The decline in lightning damage last year is consistent with data from the National Weather Service, which recorded 137 days in 2013 with lightning causing property damage, while 160 such days were recorded in 2012—a 14 percent decrease.
- Despite the drop in the number of paid claims in 2013, the average cost per claim rose nearly 122% from 2004-2013. The average cost per claim has generally continued to rise, in part because of the huge increase in the number and value of consumer electronics in homes.

2.3 Surge Protective Devices (SPDs)

2.3.1 *Typical Configuration*

Most SPDs in use for the applications covered by this report use metal oxide varistors (MOVs) to accomplish surge suppression in the electrical power system. MOVs exhibit nonlinear resistance characteristics as a function of voltage. Within the MOV voltage rating, the resistance usually exceeds 10,000,000Ω, but the resistance drops to less than 0.1Ω when the MOV is exposed to an overvoltage, such as a transient voltage spike due to a nearby lightning stroke. It is this characteristic that makes MOVs an effective protection element.

The MOV is essentially a matrix of zinc oxide grain boundaries that have a nonlinear resistance characteristic. The series combination of the boundaries defines the MOV voltage rating, the parallel combination defines the total current that can be passed, and the bulk volume determines how much energy that it can absorb. When an MOV is energized with an AC voltage, resistive and reactive current flows through the highly capacitive disc.

Most SPDs are connected in parallel with the circuit and operate when a transient voltage exceeds the voltage protection rating. Parallel surge protectors have little interaction with the circuit under normal conditions.

A different technology is commonly used for communications lines, referred to as a gas discharge tube (GDT), which is a spark gap type of surge suppression device. When subjected to a surge voltage, the gas discharge tube sparks over, thereby causing an arc to ground. The hermetically sealed tubes used today can have a precise and repeatable turn-on voltage. Gas discharge tubes consist of a spark gap in series with a resistance or varistance to limit the discharge current to safe levels.

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[7] Their reports are accessible at http://www.iii.org/.

2.3.2 *SPD Classification*

UL 1449 classifies SPDs by type depending, in part, on their location in the system and their level of internal protection:

- Type 1 – Permanently connected SPDs intended for installation between the secondary of the service transformer and the line side of the service equipment overcurrent device, as well as the load side, including watt-hour meter socket enclosures and intended to be installed without an external overcurrent protective device. They must have overcurrent protective devices either installed internally on the SPD or included with it. While these are primarily intended for installation before the main service disconnect, Type 1 SPDs can be installed in Type 2 and Type 4 locations such as distribution panels, end-use equipment. Residential installations are often Type 1, installed near the incoming meter.

- Type 2 – Permanently connected SPDs intended for installation on the load side of the service equipment overcurrent device; including SPDs located at the branch panel. While some will have internal overcurrent protective components, Type 2 SPDs can rely on the service entrance overcurrent disconnect device for over current protection. These SPDs can be installed in service equipment, distribution panels, and end-use equipment.

- Type 3 – Point of utilization SPDs, installed at a minimum conductor length of 10 meters (30 feet) from the electrical service panel to the point of utilization, for example cord connected, direct plug-in, receptacle type and SPDs installed at the utilization equipment being protected.

- Type 4 – Component SPDs, including discrete components as well as component assemblies.

Permanently installed self-contained SPDs are usually Type 1 or Type 2.

2.3.3 *SPD Ratings*

SPDs are tested and rated in accordance with UL 1449. The following ratings are normally provided for each model and size of SPD:

- Nominal voltage and frequency.

- Maximum continuous overvoltage (MCOV) – defines the voltage at which the SPD will start conducting to ground. Continuous operation above the MCOV will lead to SPD failure.

- Voltage protection rating (VPR) – a UL 1449 rating of the limiting voltage measured during the transient-voltage surge suppression test using the combination wave generator at a setting of 6kV, 3kA. A lower VPR is better.

- Surge current rating – the maximum surge current that an SPD is rated to carry without excessive overheating and consequent premature breakdown or combustion risk. The surge current rating is expressed in thousands of amps (kA) and is an indicator of how many MOVs are installed in parallel inside the device. SPDs are readily available rated for as low as ≤20 kA up to ≥600 kA. SPD price tends to increase as surge current rating increases.

- Protection modes – line-to-line, line-to-ground, line-to-neutral, neutral-to-ground.
- Short circuit current rating (SCCR).
- Surge life – expected number of surges that the SPD can withstand.

Other important attributes include monitoring and design for the environment at the installation location.

2.4 Residential Surge Protection

Residential surge protection has long been viewed as an important safety consideration and guidance has been issued in the past to help homeowners protect their house and its contents[8]. This protection has often been described as being similar to an insurance policy, partly because there is not an NFPA code requirement for SPD installation in residences. Today's residences often contain electronic equipment throughout, including appliances, computers, security systems, life safety equipment, automation systems for internet-enabled applications, and home entertainment systems.

2.4.1 *Design*

SPDs used in residential applications are typically designed for 240/120 volts with the electrical power neutral bonded to ground at the service entrance. A permanently-installed SPD can be installed at the incoming meter (Type 1) or at the service entrance (Type 2). Type 3 SPDs can still be installed at the point of use for electronic equipment also.

The IEEE document, *How to Protect Your House and Its Contents from Lightning, IEEE Guide for Surge Protection of Equipment Connected to AC Power and Communication Circuits*, provides an excellent overview of the design and installation considerations for SPDs. A permanently-installed SPD should be installed by a qualified electrician and should consider quality of the grounding system, lead length for connections, overcurrent protection, and disconnect capability. Installation in accordance with NFPA 70 is a requirement.

2.4.2 *General Cost*

Prices vary widely for SPDs. An SPD intended for residential use (240/120 volts) and rated for 50 kA surge current can cost as little as $125 and as much as $500. Integrated protection to protect the incoming power lines as well as the phone/internet communication lines can cost an additional $100. A reasonable level of protection can typically be realized for about $500.

One consideration is how high of a surge current rating to specify. Cost tends to increase as the surge current rating increases because of the additional MOV modules that are required. The cost can be considerably higher for three-phase circuits, partly because there are more protection

[8] Key documents include *How to Protect Your House and Its Contents from Lightning, IEEE Guide for Surge Protection of Equipment Connected to AC Power and Communication Circuits*, by Richard L. Cohen and others, ISBN 0-7381-4634-X, 2005 and NIST Special Publication 960-6, *Surges Happen! How to Protect the Appliances in Your Home*, 2001. Some insurance companies also provide guidance on their websites.

modes to consider compared to a single-phase application and partly because the surge current rating might be higher. For residential applications, a surge current rating above 30 kA likely is adequate for 80% to 90% of lightning strokes.[9] A surge current rating above 60 kA likely is adequate for virtually all lightning strokes. In lightning-prone areas (refer to Figure 2-1), a higher surge current rating can also provide a longer SPD life if it is exposed to repeated surges.

[9] Lightning strokes produce the largest surges.

3

INDUSTRY STANDARDS

Section 3 provides an overview of industry codes and standards that apply to SPDs.

SPDs are routinely used in facilities that are potentially exposed to voltage or current surges from nearby lightning, utility switching, or other sources; and there are many manufacturers of SPDs and these manufacturers often offer guidance regarding SPD installation ratings and recommended applications. However, industry codes and standards provide limited guidance regarding selection, rating, and application.

One limitation with surge protection design is that there is no industry standard that describes what is an acceptable level of surge protection for standard facilities or residential locations. Although industry codes and standards are available that establish standardized surge criteria and assist with the application of specific surge protector types, these standards do not provide adequate design guidance that ensures a facility is properly protected against surges. There is no existing industry guidance for surge protection of residential facilities.

3.1 NFPA Codes and Standards

3.1.1 *NFPA 70*

NFPA 70 distinguishes between surge arresters for applications over 1,000 volts (Article 280) and SPDs for applications 1,000 volts or less (Article 285). Each Article provides installation requirements.

NFPA 70[10] requires SPDs for the following applications:

- Article 501.35, Surge Protection – required Class I Division 1 and 2 locations.
- Article 694, Wind Electric Systems. Article 694.7(D) requires, "*A surge protective device shall be installed between a small wind electric system and any loads served by the premises electrical system. The surge protective device shall be permitted to be a Type 3 SPD on a dedicated branch circuit serving a small wind electric system or a Type 2 SPD located anywhere on the load side of the service disconnect.*"
- Article 700, Emergency Systems. New Article 700.8, Surge Protection, was added in 2014 and requires, "*A listed SPD shall be installed in or on all emergency systems switchboards and panelboards.*"

[10] The *National Electrical Code® Handbook* provides additional discussion of surge protection requirements.

- Article 708, Critical Operations Power Systems (COPS). Article 708.20(D) requires, "*Surge protection devices shall be provided at all facility distribution voltage levels*".

- If surge protection is provided, Article 646, Modular Data Centers, requires that SPDS are listed, labeled, and installed in accordance with Article 285.

Article 285 provides requirements regarding the installation of SPDs, but it provides limited guidance for when a SPD is required or recommended ratings. The NFPA 70 Handbook also avoids discussion regarding the application of SPDs. In other words, NFPA 70 provides guidance regarding SPD installation, but provides no information regarding SPD selection and rating.

3.1.2 *NFPA 780*

NFPA 780[11], *Standard for the Installation of Lightning Protection Systems*, is more specific regarding the application of SPDs for lightning protection systems. This standard provides detailed requirements for the application of SPDs in support of a lightning protection system, including SPD rating information. Key requirements include:

- SPDs shall be installed at all power service entrances.

- The SPD shall protect against surges produced by a 1.2/50 µs and 8/20 µs combination waveform generator.

- SPDs at the service entrance shall have a nominal discharge current (I_n) rating of at least 20 kA 8/20 µs per phase.

- Signal, data, and communications SPDs shall have a maximum discharge current (I_{max}) rating of at least 10 kA 8/20 µs when installed at the entrance.

- The published voltage protection rating (VPR) for each mode of protection shall be selected to be no greater than those given in Table 4.20.4 for the different power distribution systems to which they can be connected. The maximum allowed VPR per mode of protection varies from 600 to 1,800 volts, depending on the service voltage and connection type.

- The maximum continuous operating voltage (MCOV) of the SPD shall be selected to ensure that it is greater than the upper tolerance of the utility power system to which it is connected.

- SPDs at grounded service entrances shall be wired in a line-to-ground (L–G) or line-to-neutral (L–N) configuration. Additional modes, line-to-line (L–L), or neutral-to-ground (N–G) shall be permitted at the service entrance. For services without a neutral, SPD elements shall be connected line-to-ground (L–G). Additional line-to-line (L–L) connections shall also be permitted.

[11] NFPA 780, *Standard for the Installation of Lightning Protection Systems*, 2014 Edition.

- Installation of surge suppression hardware shall conform to the requirements of NFPA 70, *National Electrical Code*. SPDs shall be located and installed so as to minimize lead length. Interconnecting leads shall be routed so as to avoid sharp bends or kinks.

Although NFPA 780 only applies to lightning protection systems, it provides clear SPD design, rating, and installation guidance for these systems.

3.2 IEEE Standards

IEEE has historically taken the lead with respect to characterizing the surge environment. The following sections discuss key IEEE documents that apply to SPDs.

3.2.1 *IEEE C62.41.1*

IEEE C62.41.1, *Guide On The Surge Environment In Low-Voltage (1000V And Less) AC Power Circuits*, provides comprehensive information about surges and the environment in which they occur. This guide form the basis for IEEE surge testing criteria and is recommended for any review of surge characteristics. IEEE C62.41.1 is also valuable as a source of recorded data of surge events. Temporary over-voltages are also discussed, including their potential impact on SPDs.

3.2.2 *IEEE C62.41.2*

IEEE C62.41.2, *Recommended Practice On Characterization Of Surges In Low-Voltage (1000V And Less) AC Power Circuits*, presents recommendations for selecting surge waveforms, and the amplitudes of surge voltages and currents used to evaluate equipment immunity and performance of SPDs. The following figures show the surges recommended by IEEE C62.41.2 for consideration.

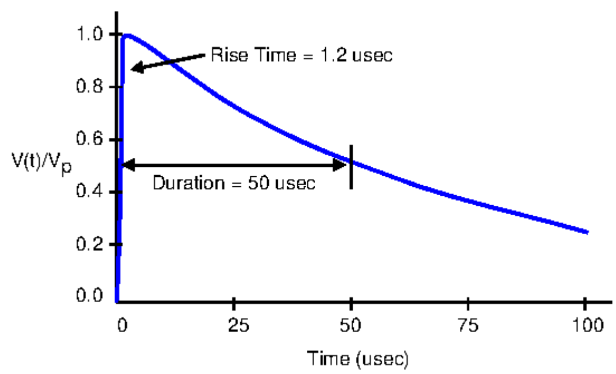

Figure 3-1
Combination Wave—1.2 x 50 µsec, Open Circuit Voltage

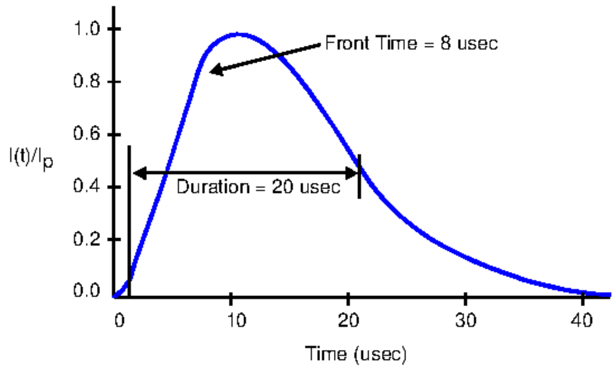

Figure 3-2
Combination Wave—8 x 20 µsec, Short Circuit Current

The second type of IEEE C62.41.2 surge voltage is called a 100 khz ring wave with a waveform below.

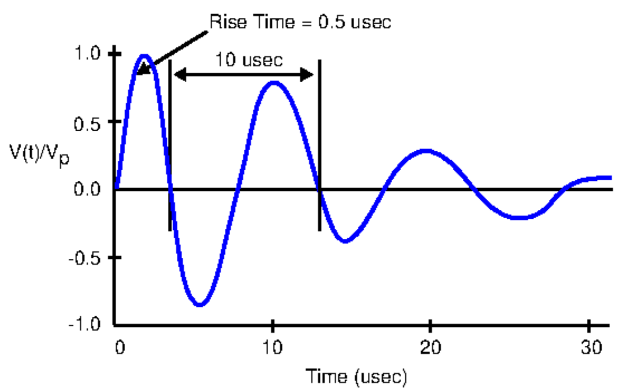

Figure 3-3
100 khz Ring Wave—Open Circuit Voltage

The combination and ring waves are intentionally generic in shape, in that peak magnitudes are not provided. Voltage and current values are assigned according to distance into the distribution system.

3.2.3 *IEEE C62.45*

IEEE C62.45, *Recommended Practice On Surge Testing For Equipment Connected To Low-Voltage (1000V And Less) AC Power Circuits*, describes surge testing procedures using simplified waveform representations (described in IEEE C62.41.2) to obtain reliable measurements and enhance operator safety.

3.2.4 *IEEE 1100*

IEEE 1100, *Powering and Grounding Electronic Equipment*, provides guidance regarding SPDs. Unfortunately, the information provided in IEEE 1100 is dated and does not reflect the current SPD products that arevavailable; much of the information provided is over 15 years old. But, IEEE 1100 provides a good discussion of surge effects and protecting against surges.

3.2.5 *IEEE 1692*

IEEE 1692, *IEEE Guide for the Protection of Communication Installations from Lightning Effects*, provides design guidelines to help prevent lightning damage to communications equipment within structures.

3.3 UL Documents

3.3.1 *UL 1449*

In the USA, SPDs are manufactured and specified in accordance with UL 1449, Third Edition, *Surge Protective Devices*, which was issued on September 29, 2006 with an effective date of September 29, 2009. This revision to UL 1449 changed how surge protective devices (SPDs) are named, tested, and rated. UL 1449 listing is specifically required by NFPA 780 and SPD listing (presumably to UL 1449) is required by NFPA 70. UL 1449 defines the performance requirements for an SPD; however, it does not address the engineering application of SPDs. UL also addresses additional related product performance criteria in UL 1283, *Electromagnetic Interference Filters*, and the UL 497 series, *Protectors for Fire Alarm Signaling Circuits*.

UL 1449, Third Edition, improved the harmonization of methods with IEC 61643 series, *Low Voltage Surge Protective Devices*, but there still remain some differences in approach between the UL and IEC test methods.

UL 1449, Third Edition, changed testing and rating requirements such that an SPD listed to UL 1449, Second Edition, cannot be compared to an SPD listed to UL 1449, Third Edition; the differences are too significant. Some of the key changes include:

- New performance tests use more surge current, resulting in higher let-through voltages. The older tests were performed at 500 amperes and 6,000 volts. The new tests are performed at 3,000 amperes and 6,000 volts.
- Test results for the new performance tests in the Third Edition are higher than the equivalent tests in the Second Edition, which has resulted in manufacturers changing their product literature. With a surge current of 6 times the Second Edition level, the Third Edition results for let-through voltage must be higher (the let-through voltage or clamping voltage was referred to as suppressed voltage rating in the Second Edition and is referred to as voltage protection rating in the Third Edition).
- Terminology has changed.
- UL 1449 is now ANSI-approved.

3.3.2 *UL 497*

The UL 497 series, *Protectors for Fire Alarm Signaling Circuits*, provides performance standards and testing procedures for enclosures, corrosion protection, field wiring connections, and components of SPDs, as well as product labeling and installation instructions.

3.3.3 *UL 1283*

UL 1283, *Electromagnetic Interference Filters*, provides requirements for electromagnetic interference (EMI) filters. It addresses filters installed on, or connected to, 600 V or lower voltage circuits and 50-60 Hz frequency. These filters are used to attenuate unwanted radio frequency (RF) signals, such as noise or interference generated from electromagnetic sources. They consist of capacitors and inductors used alone or in combination with each other and may be provided with resistors.

4

DATA ACQUISITION PLAN

Section 4 provides an overview of the recommended data acquisition plan for SPDs.

4.1 Type of Desired Data

In order to address fully the potential application of SPDs as a code requirement, the following types of data would be especially helpful:

Installations With SPDs Installed

- Characterization of surge events that were successfully diverted without damage to electronic equipment, electrical equipment, or the structure.
- Characterization of surge events that occurred with subsequent damage to electronic equipment, electrical equipment, or the structure.
- Characterization of surge events that resulted in damage or loss of function to life safety equipment.

Installations Without SPDs Installed

- Characterization of surge events that did not cause damage to electronic equipment, electrical equipment, or the structure.
- Characterization of surge events that occurred with subsequent damage to electronic equipment, electrical equipment, or the structure.
- Characterization of surge events that resulted in damage or loss of function to life safety equipment.

Surge Characterization

- Real data recording of lightning-induced surges.
- Real data recording of switching-induced surges, either internally generated (appliances or motors turning on or off) or externally generated (such as capacitor switching).

The problem lies in acquiring the above data, which is the goal of this project. The above information does not really exist, except in a few limited scope studies and in insurance claim documents. Refer to the following sections for more information.

4.2 Data to Characterize the Nature of Surges

Lightning strokes, either direct, nearby, or some distance away can cause voltage and current surges into a facility. Information is available regarding lightning strokes and their intensity. But, less information is available regarding the extent to which these surges are transmitted into commercial facilities, industrial facilities, or residences. The IEEE paper, *A Field Study of Lightning Surges Propagating Into Residences*[12], provides an outstanding view into the effort needed to acquire even limited amounts of real-world data. This paper provides the following insights:

- When a home appliance malfunctions due to lightning, the relationship between the lightning stroke and the damage is often unclear. The purpose of their study was to complete experimental investigations on lightning surges that flow into residences. SPDs were not installed in these residences.
- Lightning surge waveform detectors were installed in 49 residences and monitored for four years (2003 to 2006). During the four-year observation period, lightning surge waveforms were obtained for a total of 18 lightning stroke events.
- Damage occurred to appliances in 4 of the 18 events. The most severe damage occurred when lightning appeared to have hit an antenna. In this case, currents of 1 kA or greater were recorded at all the measurement points, and many appliances were damaged.
- The home appliances, typically having built-in lightning protective devices with a peak current of 1 kA or higher, broke down at a current peak value of approximately 1 kA or higher, according to the observations.
- The analysis of observation data found that in some cases a ground potential rise causes a lightning surge to flow from the ground of another residence or the ground of a distribution system into the distribution system and, in turn, to flow into another residence.

Notice that the above effort took four years of monitoring at 49 residences to produce recordings of 18 surge events, of which four were severe enough to cause damage to appliances. This illustrates the difficulty of acquiring actual surge data.

4.3 Who Has Data on Surges, Surge Effects, and SPDs

4.3.1 *Surge Data – Lightning Surges*

Vaisala[13] owns and operates the National Lightning Detection Network (NLDN) that provides accurate lightning data information across the USA. And, Vaisala can provide lightning location reports that provide individual cloud-to-ground lightning strikes and the intensity of strike at a specific location on the date of loss. This capability represents the largest and most complete source of lightning surge location and intensity.

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12 Teru Miyazaki, et al, *A Field Study of Lightning Surges Propagating Into Residences*, IEEE Transactions on Electromagnetic Compatibility, Vol. 52, No. 4, November 2010.

13 http://www.vaisala.com/en/services/dataservicesandsolutions/lightningdata/Pages/default.aspx

Data for lightning surges that extend to the inside of facilities is not readily available. Published papers and IEEE C62.41.1 provide information regarding the expected surge levels within a facility or residence, but extensive data is not available.

4.3.2 *Surge Data – Switching Surges*

Switching-related surge data, either internally or externally generated, is sparse. The added difficulty with this data is that these surges often do not cause immediate failure of electrical and electronic equipment; the damage occurs as a cumulative effect.

4.3.3 *Surge Effects – Manufacturers*

Although manufacturers produce SPDs and do a great job of educating consumers regarding their products, very little failure data associated with surges appears to be available from them. NEMA maintains the Surge Protection Institute[14] and they have completed surveys in 2013 and 2014 regarding failures of electrical and electronic equipment caused by surges. Although the sample size is relatively small, the survey results are helpful with respect to historical failures of life safety equipment. Refer to Section 2.2.1 for more information.

4.3.4 *Surge Effects – Consulting Firms*

Many engineering consulting firms assist with evaluations of surge damage in support of insurance claims. However, this data is not compiled in a readily usable manner nor is the data accessible in many cases. Surge data is not typically available.

4.3.5 *Surge Effects – Insurance Claims*

The largest documented source of surge effects is contained within the insurance claim documents for damage caused by surges. The Insurance Information Institute in collaboration with State Farm® produces annual reports of insurance claims associated with lightning-induced damage (refer to Section 2.2.2 for more information). The information contained in these claim reports likely provides additional detail regarding surge effects and the types of damage caused.

4.4 Data Acquisition Plan

There are challenges in obtaining usable data applicable to residential applications, such as:

- Confirming that equipment failures were a direct result of a surge event.
- Establishing any median and upper bounds to actual surge levels since this is not recorded inside facilities.
- Defining the protection improvement realized by applying SPDs.

Given the scarcity of real data relating to surges and the effects of surges, the approach described below is recommended.

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[14] *Refer to* *http://www.nemasurge.org*.

4.4.1 *Purpose of Data to Be Obtained*

The purpose of the recommended data acquisition approach is to produce real data regarding damage and injuries caused by surges. This information is intended to assist the NFPA 70 code-making committees with additional technical data to support a decision to require or not require SPDs for the variety of electrical applications proposed in past NFPA 70 update cycles (refer to Section 1.2).

4.4.2 *Lightning Stroke Data*

The starting point for this project is to acquire the nationwide lightning stroke data for the continental USA for 2013 (or 2014 if the project starts in 2015). This information can tie back to insurance claim data and possibly provide surge current values for the locations of interest.

4.4.3 *Insurance Information Institute Claim Data*

The Insurance Information Institute is proposed to manage the insurance industry claim data. Their involvement assures that the insurance industry claim reports can remain confidential while allowing access to additional data that might be contained in the claim reports.

The Insurance Information Institute already publishes annual summaries of the number of lightning-related insurance claims and the claim amount. Additional information of interest that might be available in the claim data includes:

- Date and location of surge event (to establish geographical correlations).
- Electronic equipment and appliances damaged.
- Life safety equipment damaged – smoke detectors, CO or CO_2 detectors, or other equipment.
- Fires caused by surge effects.
- Personal injuries associated with the surge event.
- Presence of or lack of installed SPDs.

Life safety equipment damage, fires caused by surge events, and personal injuries are of particular interest for code-making efforts.

Although the annual Insurance Information Institute survey has historically focused on residential claims, the survey for this project should include commercial and industrial claims also. NEMA assistance and direction with this effort will be helpful.

4.4.4 *NEMA Participation*

NEMA Low Voltage Surge Protective Devices Section (5-VS) participation is recommended for the following:

- Assisting with project scope, including commercial and industrial users.

- Reviewing the project checklist for the type of information to be obtained from the insurance industry.
- Reviewing failure data report summaries.
- Considering recommended SPD design principles, including the specification of surge protection in low-lightning flash density areas versus high-lightning flash density areas. Should NFPA elect to require SPDs in dwelling units or other applications, then minimum surge protection current limits should also be addressed, similar to the method provided in NFPA 780. As SPD surge current rating increases (and the degree of protection), the SPD cost also increases.

4.4.5 *Why Not Another Test Program?*

The IEEE paper, *A Field Study of Lightning Surges Propagating Into Residences*, illustrates the difficulty with obtaining real data during surge events. Although this study produced very useful results, it took a 4-year period at 49 homes to obtain data for 18 surge events, of which four surge events caused damage to appliances and electronic equipment. This is considered a typical outcome to be expected. A test program sponsored by the Fire Protection Research Foundation is not recommended.

A

REFERENCES

Appendix A provides a list of references used in the development of this report.

A.1 Industry Standards

IEEE 1100, *Powering and Grounding Electronic Equipment.*

IEEE 1692, *IEEE Guide for the Protection of Communication Installations from Lightning Effects.*

IEEE C62.41.1, *Guide On The Surge Environment In Low-Voltage (1000V And Less) AC Power Circuits.*

IEEE C62.41.2, *Recommended Practice On Characterization Of Surges In Low-Voltage (1000V And Less) AC Power Circuits.*

IEEE C62.45, *Recommended Practice On Surge Testing For Equipment Connected To Low-Voltage (1000V And Less) AC Power Circuits.*

IEEE C62.50, *IEEE Standard for Performance Criteria and Test Methods for Plug-in (Portable) Multiservice (Multiport) Surge-Protective Devices for Equipment Connected to a 120 V/240 V Single Phase Power Service and Metallic Conductive Communication Line(s).*

NFPA 70, *National Electrical Code®*, 2014 Edition.

NFPA 780, *Standard for the Installation of Lightning Protection Systems*, 2014 Edition .

UL 497 series, *Protectors for Fire Alarm Signaling Circuits.*

UL 1283, *Electromagnetic Interference Filters.*

UL 1449, Third Edition, *Surge Protective Devices*, September 29, 2006.

A.2 NFPA Documents

1. *National Electrical Code® Committee Report on Proposals – 2013 Annual Revision Cycle*, National Fire Protection Association, 2012.
2. Marty Ahrens, *Lightning Fires and Lightning Strikes*, National Fire Protection Association, Fire Analysis and Research Division, June 2013.

A.3 IEEE Documents

1. *How to Protect Your House and Its Contents from Lightning, IEEE Guide for Surge Protection of Equipment Connected to AC Power and Communication Circuits*, by Richard L. Cohen and others, ISBN 0-7381-4634-X, 2005.

2. Lightning and Insulator Subcommittee of the T&D Committee, *Parameters of Lightning Strokes: A Review*, IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005.

3. Teru Miyazaki, et al, *A Field Study of Lightning Surges Propagating Into Residences*, IEEE Transactions on Electromagnetic Compatibility, Vol. 52, No. 4, November 2010.

4. Jinliang He, et al, *Evaluation of the Effective Protection Distance of Low-Voltage SPD to Equipment*, IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005.

5. Shozo Sekioka, et al, *Simulation Model for Lightning Overvoltages in Residences Caused by Lightning Strike to the Ground*, IEEE Transactions on Power Delivery, Vol. 25, No. 2, January 2010.

6. Joseph Randolph, *Lightning Surge Damage to Ethernet and POTS Ports Connected to Inside Wiring*, IEEE, 2014.

7. Vladimir A. Rakov, *Direct Lightning Strikes to the Lightning Protective System of a Residential Building: Triggered-Lightning Experiments*, IEEE Transactions on Power Delivery, Vol. 17, No. 2, January 2002.

Note: The IEEE Power & Energy Society sponsors the Surge Protective Devices Committee, which provides information associated with their standards. Refer to http://pes-spdc.org.

A.4 NIST Documents

1. NIST Special Publication 960-6, *Surges Happen! How to Protect the Appliances in Your Home*, 2001.

Note: The NIST website provides many historical documents available in the public domain related to surge protection. Although this information is over 10 years old, it is still useful as a reference source. Refer to http://www.nist.gov/pml/div684/spd.cfm.

A.5 NEMA Documents

1. NEMA 2013 *U.S. Surge Protection Damage Survey.*

2. NEMA *Surge Damage Survey Results – Wave 2*, March 2014.

Note: The NEMA Surge Protection Institute maintains a website devoted to low voltage SPDs. Refer to http://www.nemasurge.org.

A.6 Insurance Industry Documents

1. *Lightning Sparks Concern For Insurance Industry; Homeowners Claims Rise Sharply Over Last Five Years*, Insurance Information Institute, March 2010.

2. *Thunderstruck! Average Lightning Claim Costs Up by 25 Percent, But Number of Claims Continues to Fall*, Insurance Information Institute, June 2013.

3. *Number, Cost of Homeowners Insurance Claims From Lightning Fell In 2013; Dry Conditions, Fewer Powerful Thunderstorms A Contributing Factor*, Insurance Information Institute, June 2014.

4. *Lightning,* Insurance Information Institute, August 2014.

5. *Protect Your Property From Power Surges*, State Farm website.

6. *Guidelines for Providing Surge Protection at Commercial Institutional and Industrial Facilities*, The Hartford Steam Boiler Inspection and Insurance Company.

7. *Approval Standard for Transient Voltage Surge Suppression Devices*, FM Approvals.

A.7 Manufacturer's Documents

1. Emerson Network Power Report SL-30119, *Surge Protection Reference Guide*, November 2011.

A.8 Miscellaneous Documents

1. A. Ametani,, et al, *Surge Voltages and Currents into a Customer due to Nearby Lightning*, International Conference on Power Systems Transients (IPST"07) June 2007.

2. Schneider Electric Data Bulletin DB03A, *Surge Protection: Measured Lightning Stroke Data*.

3. Al Martin, *Lightning Induced GPR, Why it's a problem, characteristics and simulation*, In Compliance, June 2012.

4. Thomas Key, et al, *Update on a Consumer-Oriented Guide for Surge Protection*, Proceedings, PQA'99 Conference, May 1999.

5. François D. Martzloff, et al, *The Role and Stress of Surge-Protective Devices in Sharing Lightning Current*, EMC Europe 2002, September 2002.

6. Arshad Mansoor, et al, *The Dilemma of Surge Protection vs. Overvoltage Scenarios: Implications for Low-Voltage Surge-Protective Devices*, Proceedings, 8th Annual Conference on Harmonics and Quality of Power, October 1998.

7. Air Force Manual 32-1181, *Design Standards for Interior Electrical Systems*.

B

ACRONYMS

Appendix B provides a list of the abbreviations and acronyms used in this report.

EMI – Electromagnetic interference.

FPRF – Fire Protection Research Foundation.

GDT – Gas discharge tube.

GPR – Ground potential rise.

Hz – Hertz.

III – Insurance Information Institute.

kA – Thousands of amperes.

khz – Kilo-hertz.

L–G – Line-to-ground.

L–L – Line-to-line.

MCOV – Maximum continuous operating voltage.

MOV – Metal oxide varistor.

N–G – Neutral-to-ground.

NEMA – National Electrical Manufacturers Association.

NLDN – National Lightning Detection Network.

NFPA – National Fire Protection Association.

NIST – National Institute of Standards and Technology.

pu – Per unit.

SAD – Silicon avalanche diode.

SCCR – Short circuit current rating.

SPD – Surge protective device.

TOV – Temporary overvoltage.

TVSS – Transient voltage surge suppressor (no longer used – replaced by SPD).

UL – Underwriter's Laboratories.

µsec – Micro-second.

VPR – Voltage protection rating.

E7365

Date Submitted	11/20/2018	**Section**	3111	**Proponent**	Bryan Holland
Chapter	31	**Affects HVHZ**	No	**Attachments**	No

TAC Recommendation Pending Review
Commission Action Pending Review

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

7345, 7347, 7348

Summary of Modification

This proposed modification updates requirement for solar energy systems in the FBC-B.

Rationale

This proposed modification deletes the current requirements in Section 3111 and replaces them with the updated rules in 3111 of the 2018 IBC that have been correlated and harmonized with current industry standards and other applicable references. This change is similar to those proposed under Mods 7345, 7347, and 7348 for inclusion into the FBC-R. This change will also coordinate the FBC-B with the FFPC.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will not impact the local entity relative to code enforcement.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building and property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public by coordinating the FBC-B with the FFPC for life, fire, and property safety related to solar energy system installations.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves and strengthens the code by updating the rules for solar energy systems in the FBC-B.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

~~SECTION 3111~~

~~PHOTOVOLTAIC PANELS AND MODULES~~

~~3111.1 General. Photovoltaic panels and modules shall comply with the requirements of this code and the Florida Fire Prevention Code.~~

~~3111.1.1 Rooftop-mounted photovoltaic panels and modules. Photovoltaic panels and modules installed on a roof or as an integral part of a roof assembly shall comply with the requirements of Chapter 15 and the Florida Fire Prevention Code.~~

SECTION 3111

SOLAR ENERGY SYSTEMS

3111.1 General. Solar energy systems shall comply with the requirements of this section.

3111.1.1 Wind resistance. Rooftop-mounted photovoltaic panels and modules and solar thermal collectors shall be designed in accordance with Section 1609.

3111.1.2 Roof live load. Roof structures that provide support for solar energy systems shall be designed in accordance with Section 1607.13.5.

3111.2 Solar thermal systems. Solar thermal systems shall be designed and installed in accordance with the Florida Building Code-Plumbing, the Florida Building Code-Mechanical, and the Florida Fire Prevention Code.

3111.2.1 Equipment. Solar thermal systems and components shall be listed and labeled in accordance with ICC 900/SRCC 300 and ICC 901/SRCC 100.

3111.3 Photovoltaic solar energy systems. Photovoltaic solar energy systems shall be designed and installed in accordance with this section, the Florida Fire Prevention Code, NFPA 70 and the manufacturer's installation instructions.

3111.3.1 Equipment. Photovoltaic panels and modules shall be listed and labeled in accordance with UL 1703. Inverters shall be listed and labeled in accordance with UL 1741. Systems connected to the utility grid shall use inverters listed for utility interaction.

3111.3.2 Fire classification. Rooftop-mounted photovoltaic systems shall have a fire classification in accordance with Section 1505.9. Building-integrated photovoltaic systems shall have a fire classification in accordance with Section 1505.8.

3111.3.3 Building-integrated photovoltaic systems. Building-integrated photovoltaic systems that serve as roof coverings shall be designed and installed in accordance with Section 1507.18.

3111.3.4 Access and pathways. Roof access, pathways and spacing requirements shall be provided in accordance with Section 1204 of the Florida Fire Prevention Code.

3111.3.5 Ground-mounted photovoltaic systems. Ground-mounted photovoltaic systems shall be designed and installed in accordance with Chapter 16 and the Florida Fire Prevention Code.

3111.3.5.1 Fire separation distances. Ground-mounted photovoltaic systems shall be subject to the fire separation distance requirements determined by the local jurisdiction.

E7205

13

Date Submitted	11/6/2018	**Section**	405.6.3	**Proponent**	Bryan Holland
Chapter	4	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **Yes** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposed modification revises the voltage drop requirement to include "customer-owned service conductors" in addition to feeder conductors and branch circuit conductors.

Rationale

The current requirement for voltage drop does not include customer-owned service conductors which in long runs can result in significant voltage drop. The term “conductors” has been added to feeder and branch circuit to add clarity. A definition of "voltage drop" is being added to harmonize the Florida Energy Code with the IECC and ASHRAE 90.1 Standard.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will have no impact to the local entity relative to code enforcement.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will ensure customer-owned service conductors are included in the voltage drop calculation to prevent unnecessary losses in the complete premises wiring systems.

Impact to industry relative to the cost of compliance with code

This proposed modification could result in an increased cost of compliance if the designer chooses to increase the customer-owner service conductors in response to excess voltage drop.

Impact to small business relative to the cost of compliance with code

This proposed modification should not have an impact on small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected with the health, safety, and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves the code by adding a needed definition and revising the prescriptive language of the section to include all conductors on the premises-wiring side of the electrical installation.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

1st Comment Period History

E7205-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

C405.6.3 Voltage drop. ~~The conductors for feeders and branch circuits combined shall be sized for a maximum of 5 percent voltage drop total.~~ The total voltage drop across the combination of customer-owned service conductors, feeder conductors, and branch circuit conductors shall not exceed 5 percent.

Add to Section C202 Definition:

VOLTAGE DROP. A decrease in voltage caused by losses in the wiring systems that connect the power source to the load.

E7206

Date Submitted 11/6/2018
Chapter 4
Section 405.6.1
Affects HVHZ No
Proponent Bryan Holland
Attachments No
TAC Recommendation Pending Review
Commission Action Pending Review

Comments

General Comments Yes
Alternate Language No

Related Modifications

Summary of Modification

This proposed modification revises the section to clarify that compliance with Section 8 Power of the ASHRAE Standard 90.1 is required by Section 405.6.1

Rationale

The purpose of this proposed modification is to align the code with DS 2016-033 and further clarify that Section 8 Power of the ASHRAE Standard 90.1 is the part being referenced by C405.6 Electric power. The revised language will assist those designing, installing, or enforcing the requirements of the Florida Energy Code.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will assist the local entity when enforcing the requirement of the Florida Energy Code by clarifying exactly what requirements in the ASHRAE Standard 90.1 are applicable to C405.6.1 compliance.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will ensure building and property owners have electric distribution systems installed in compliance with both C405.6 of the FBC-EC and Section 8 of ASHRAE Standard 90.1.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance with the code.

Impact to small business relative to the cost of compliance with code

This proposed modification will have no impact to small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public by ensuring electrical power distribution in buildings meet the requirements of the code.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves the code by clarifying the section and giving a pointer to the specific section of ASHARE Standard 90.1 that is applicable.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code by clarifying the rule.

1st Comment Period History

E7206-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

C405.6 Electrical power (Mandatory).

C405.6.1 Applicability.

This section applies to all building power distribution systems. The provisions for electrical distribution for all sections of this code are subject to ~~the design conditions~~ the requirements of Section 8 Power in ASHRAE Standard 90.1.

E7207

15

Date Submitted	11/7/2018	**Section**	328	**Proponent**	Bryan Holland
Chapter	3	**Affects HVHZ**	No	**Attachments**	Yes

TAC Recommendation Pending Review
Commission Action Pending Review

Comments

General Comments Yes **Alternate Language** No

Related Modifications

7208

Summary of Modification

This proposed modification will add mandatory surge protection requirements to buildings under the scope of the FBC-R.

Rationale

This revision is intended to address the recognized need for surge protection to protect the sensitive electronics and systems found in most modern appliances, safety devices (such as AFCI, GFCI and smoke alarms) and equipment used in dwellings. Additionally, the expanding use of distributed energy resources (DER) within electrical systems often results in more opportunity or greater exposure for the introduction of surges into the system.

Electronic life-saving equipment such as fire alarm systems, IDCI's, GFCI's, AFCI's and smoke alarms, may be damaged when a surge occurs due to lighting, internal local switching as well as external utility switching. Other equipment is also damaged when subjected to surge. In many cases, electronic devices and equipment can be damaged and rendered inoperable by a surge and yet this damage is undetected by the owner. It is practical to require a SPD to provide a general level of protection. In almost all new service installations, as well as service upgrades, no consideration is given to providing a general level of protection to the "whole structure" which would include those devices that cannot be afforded a cord connected Type 3 SPD protection. R328.4 is included to require that when a service is upgraded, an SPD is to be installed.

Studies by recognized authorities including NEMA, IEEE, and UL, all substantiate the fact that surges can and do cause significant damage. Nationwide Insurance organizations recognize the need for effective surge protection as well and have published recommendations that include point-of-use surge protectors and installation of surge protection at service equipment.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will require additional enforcement requirements related to electrical services. The impact will be minor.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will increase the cost of compliance to building and property owners where the cost of providing a mandatory SPD is passed-on to the consumer.

Impact to industry relative to the cost of compliance with code

SPDs are available with a large variety of ratings, configurations, and options. The cost can be as low as $25 per device to several hundred-dollars where higher levels of protection or other performance features are selected.

Impact to small business relative to the cost of compliance with code

This proposed modification will increase the cost to small business owners where the cost of providing a mandatory SPD is passed-on to the consumer.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification will enhance the health, safety, and welfare of the general public by reducing the negative impacts of transient surges to a building's premises wiring system and equipment.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification strengthens and improves the code by closing an essential life and property saving protection gap in the current code.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against any material, product, method, or system of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code by adding life and property saving surge protection.

1st Comment Period History

E7207-G1

Proponent	Vincent Della Croce	**Submitted**	1/8/2019	**Attachments**	No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

Section R328

Surge Protection

R328.1 Surge Protective Device.

All services supplying buildings under the scope of this code shall be provided with a surge protective device (SPD).

R328.2 Location.

The surge protective device shall be an integral part of the service equipment or shall be located immediately adjacent thereto.

Exception: The surge protective device shall not be required to be located in the service equipment if located at each next level distribution equipment downstream toward the load.

R328.3 Type.

The surge protective device shall be a Type 1 or Type 2 SPD.

R328.4 Replacement.

Where service equipment is replaced, all of the requirements of this section shall apply.

National Electrical Manufacturers Association

A NEMA Low Voltage Surge Protective Devices Section White Paper
VSP 1-2017

Susceptibility of Electrical and Electronic Components to Surge Damage

Published by

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Foreword

This is a new NEMA white paper based on member-supported testing. To ensure that a meaningful publication was developed, draft copies were distributed to groups within NEMA that have an interest in this topic. Their comments and suggestions provided vital input prior to final NEMA approval and resulted in a number of substantive changes in this publication. To remain up to date with advancing technology, this publication will be periodically reviewed by the Low Voltage Surge Protective Devices Group of the NEMA Commercial Products Division.

Proposed or recommended revisions should be submitted to:

> Senior Technical Director, Operations
> National Electrical Manufacturers Association
> 1300 North 17th Street, Suite 900
> Rosslyn, Virginia 22209

This white paper was developed by the Low Voltage Surge Protective Devices Group of the NEMA Commercial Products Division. Approval of this white paper does not necessarily imply that all members of the Product Group voted for its approval or participated in its development.

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Leviton Manufacturing	Chula Vista, CA
Littelfuse, Inc.	Chicago, IL
Mersen USA	Newburyport, MA
MVC-Maxivolt	Amarillo, TX
Pentair Engineered Electrical & Fastening Solutions	Solon, OH
Phoenix Contact	Middletown, PA
Raycap, Inc.	Post Falls, ID
Schneider Electric USA	Salt Lake City, UT
Siemens Industry, Inc.	Norcross, GA
Southwire Company	Clearwater, FL
Space Age Electronics	Sterling, MA
Surge Suppression, LLC	Brooksville, FL
Thomas & Betts, a member of the ABB Group	Richmond, VA

The National Electrical Manufacturers Association (NEMA) provides information to assist with answering various questions related to the application and use of surge protective devices.

Executive Summary

The NEMA Low Voltage Surge Protection Devices, 05VS, has been asked to provide an overview of electrical and electronic equipment surge susceptibility. This overview will help the electrical community, engineers, consumers, and technicians understand the various transient conditions to which electrical and electronic equipment may be subjected. The intent is not to evaluate individual companies' equipment as to safety or product performance, but to create awareness and offer guidance based on real-world testing on protection. This will be helpful in preventing problems with products. While there are many documents, papers, standards, web sites, and other media that talk about the harmful effects of transient impulses practical and empirical data is not readily available. Some of the explanations for this lack of data are the variable conditions electrical equipment is subjected to events such as electrical equipment failure, electronic equipment process interruption, insulation breakdown in electric conductors and electronic circuits, electronic component breakdown, premature aging of electrical and electronic components, etc. The standards community has many test procedures and evaluation practices for a prescribed environment. The challenge is that these environments are normally under standard test conditions, for example, 25°C. There are two are issues that are not covered under these standard test conditions.

a. What is the upset capability of the equipment?
b. What level of voltage or current would cause damage to equipment?

Quantitative data on how big or how many transient impulses are required to significantly reduce the life of or cause failure of an electrical or electronic device is almost nonexistent. Reasons for this lack of available information are the variable conditions under which an electrical device is subjected, i.e., at one location normal operating voltage might have a range of 110 to 135 Vac. Other locations may have more consistent supply voltage, but how many times does it fluctuate? When it does change, how long was the unstable condition? How large was the transient condition? When a system is influenced by another device or system, how large is the impact on the rest of the equipment?

The 05VS section understands that every possible combination of events and test equipment cannot be tested. The burden placed upon manufactures and consumers would be impractical. For instance, what happens when a transient impulse occurs to an electrical device when it is at its maximum operating temperatures, upper and lower boundaries? As every electrical device has its own unique set of environmental conditions, a frequent request is, "How many surges does it take to damage my equipment" or "How much longer will my equipment last with and without surge protection?"

Another missing piece of information is data on the cumulative effect of transient impulses. The average person, unless taught otherwise, often believes that surge damage is a one-time event. When lightning strikes and a piece of equipment is damaged, the damage may be attributed to a transient impulse. But when a piece of equipment fails due to the accumulation of numerous smaller magnitude surges, the failure is attributed to the age of equipment, poor quality of the equipment, or a hundred other unexplained conditions.

For this paper, the term "surge" and "transient" are used interchangeably.

Scope

The purpose of this paper is to present the test results of actual devices in a real-world surge environment. This white paper will generate some information on the surge susceptibility for various electrical components. This white paper is not meant to be an exhaustive study, nor a complete test spectrum. It is merely a means to provide useful information to the electrical community, both for those who design electronic and electrical equipment and for those who install and use electronic and electrical equipment. The tests were performed in certified testing laboratories. The tests were completed using standardized test sequences and parameters. The test specimens used were off-the-shelf devices; they were not modified or altered in any way. The electrical products used were selected to represent a broad spectrum of common electrical components familiar to all users of electrical appliances.

The results obtained by this testing can be used as a guide to the reaction of electrical devices under various conditions. Some devices might show malfunctions, and some may experience upset events caused by surge events in actual installations. Upset conditions will be a concern if any other electronics are controlling a critical safety component. For example, a control transformer with an upset output could cause process failure for equipment being run by the transformer.

Test Methodology

A variety of waveforms were selected to represent surge conditions. These waveforms are based on the standard waveforms found in the current edition of IEEE C62.41.2 with the addition of some intermediate waveforms from an earlier version of this standard. They are a representation of impulse events created by interruptions in the electrical system. Most equipment is designed to handle minor variations in nominal operating voltages. However, surges can range in impact and adversity and may affect nearly all equipment under certain conditions. Here are some of the standard waveforms for equipment surge susceptibility. While most equipment has a nominal level of intrinsic resistibility, based on environment, application, and installation, additional or redundant levels of surge protection may be recommended.

The following standard waveforms were used in the testing protocol:

a) Category C Low / Category B Combination Wave (6,000 V / 3,000 A)
b) Category C Low / Category B Combination Wave (4,000 V / 2,000 A)
c) Category B Combination Wave (2,000 V / 1,000 A)
d) Category B Ring Wave (6,000 V / 500 A)
e) Category B Ring Wave (4,000 V / 333 A)
f) Category B Ring Wave (2,000 V / 167 A)
g) Category A Ring Wave (6,000 V / 200 A)
h) Category A Ring Wave (4,000 V / 133 A)
i) Category A Ring Wave (2,000 V / 67 A)

Note: See IEEE Std. C62.41.2 TM-2002 especially Clause 6.2; Tables 2, 3 and 4; and the notes associated with those tables for further explanation of the surge test levels selected.

The 6,000 V combination wave was developed to represent a variety of surge events. These events may be externally or internally generated electrical surges, such as when a utility capacitor bank is switched into or out of an electrical system. Internal events can come from inductive load switching. This surge is not meant to be a replication of lightning impulses, but rather a representation of the energy produced from an impulse during normal electrical operating conditions. For additional information on lightning impulses, please see NFPA 780 *Standard for the Installation of Lightning Protection Systems.*

These tests were designed to determine the number and magnitude of surges some common electrical devices used in residential, commercial and industrial applications could withstand before failure. Each sample was tested starting with the highest magnitude IEEE C62.41.2 waveform from the list above, the 6,000 V / 3,000 A Category C Low Combination Wave. If the sample could withstand 300 surges, the test was stopped.

If the sample failed before 300 surges in this category were applied, then the surge generator was re-calibrated to output the next lower surge waveform. This continued until the sample withstood 300 surges.

The following common electrical and electronic devices were tested:

a) Incandescent Bulb
    - Common 120 V, 60 W screw-base bulb
b) Compact Fluorescent Bulb
    - Common 120 V, 60 W (equivalent) screw-base bulb
c) Electronic Ballast & Fluorescent Bulb
    - Common 120 V electronic ballast with two 25 W, 36 inch fluorescent tubes
d) LED Bulb
    - Common 120 V, 60 W (equivalent) screw-base bulb
e) Control Transformer
    - Industrial 50 VA, 120 V to 24 V transformer
f) Variable Frequency Drive (VFD)
    - Industrial 120 V single-phase, 0.33 HP VFD
g) Uninterruptable Power Supply (UPS)
    - Common 120 V, 500 VA, off-line UPS

The test procedure was designed to subject the test samples to a range of surges of different types and magnitudes representing real-world applications. The testing started with IEEE Category C and then proceeded to Categories B and A (decreasing in severity). If the sample failed during the first series of test surges, a new sample was tested with surges of the next lower level until the test sample passed 300 surges without issue.

> Note: that the test samples were not directly connected to the surge generator. The samples were connected through a 10 meters (30 feet) length of cable. This is a better representation of a practical and actual electrical installation.

The following steps were taken to conduct the test on each device:

a) The open circuit voltage waveform and short circuit current waveform were measured to verify the test waveform.
b) The sample to be tested was attached to the output of the generator using a 10 meters cable (12-2 non-metallic sheathed cable).
c) Apply the highest combination surges from Table 1 to the first test sample. Perform up to 300 strikes unless the sample fails. The impulses are injected at 60 second intervals and are applied at the peak of the AC sine wave (90 degrees of the power frequency).
d) If the sample fails, apply the surge waveform in the next column to the right in Table 1 in 60 second intervals at 90 degrees of the power frequency for up to 300 strikes or until the device fails and record results.
e) Continue testing with the test waveform in the next column to the right in Table 1 until one sample passes the test of 300 surges.

Test Results

Table 1 contains the compiled results of the surge susceptibility testing. The first column describes the device being tested. The devices tested were all commercially available products manufactured by a variety of companies. The second column lists the number of the sample being tested. This is followed by the nine different surge waveforms used in the testing, starting with the highest voltage and current waveforms on the left and working to the lowest magnitude waveforms on the right.

The number in the columns under the different test waveforms are the number of surges of that surge type when the sample failed. None of the samples survived more than one of Category C Low Combination Wave (6,000 V / 3,000 A) waveform. When a number “1” appears in a column, then the test sample failed on the first surge in that category. When there is a “300” in a column under one of the test waveforms, then the test sample survived 300 of those waveforms without damage. At that point, the testing was stopped, as the sample would have passed all the surge waveforms to the next lowest value (to the right in Table 1).

Table 1: Test Results

Sample	Sample Number	Category C Low / Category B Combination Wave			Category B Ring Wave			Category A Ring Wave		
		6 kV 3,000 A	4 kV 2,000 A	2 kV 1,000 A	6 kV 500 A	4 kV 333 A	2 kV 167 A	6 kV 200 A	4 kV 133 A	2 kV 67 A
Incandescent Bulb	1	1								
	2		1							
	3			1						
	4				1					
	5					1				
	6						1			
	7							44		
	8								300	
Compact Fluorescent Bulb	1	1								
	2		1							
	3			1						
	4				300					
Electronic Ballast & Fluorescent Bulb	1	1								
	2		1							
	3			1						
	4				300					
LED Bulb	1	1								
	2		1							
	3			1						
	4				300					
50 VA Control Transformer	1				53					
VFD 0.33 HP	1	1								
	2				300					
	3*				20, L-G					
500 VA UPS	1				300					

Note: All VFD surges were performed Line to Neutral in positive polarity except for VFD sample number 3 which was tested Line to Ground.

Conclusions

Table 1 in this document shows the surge test results for some common products. They cover a range of products from an incandescent light bulb to an uninterruptible power supply. These are common devices that are connected to an electrical supply and are exposed to everyday electrical surges that can be damaged by these events. The surges applied in this testing are at the same levels to be expected in common electrical installations.

As documented in the test results, the surge environment can produce a variety of effects. Surge damage can be experienced in a single event or as the result of an accumulation of surges. For example, in the case of an incandescent light bulb, the damage can be immediate or from repeated surges as shown by the quantity of the 44 surges in the Category A environment (i.e., test sample 7 in the table above). The application of a quality surge protective device can prevent damage to common electrical or electronic products. Surge protection is just as effective when used in commercial and industrial environments.

Electrical equipment is subject to surge damage, and these results show conclusively that everyday electrical devices are damaged by surges of the level expected in a normal electrical distribution system. The application of a surge protective device within a home or facility can alleviate the effects and save the cost or replacement for many electrical or electronic devices. For additional information on surge protection and its applications, visit www.NEMASurge.org.

§

Data Assessment for Electrical Surge Protection Devices

Phase 1
Final Report

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FOREWORD

Every year there are widespread anecdotal reports of homeowners' property damage to electrical and electronic equipment resulting from electrical surges. The revision cycle of the 2011 edition of NFPA 70, *National Electrical Code®* (NEC®) included several proposals (e.g. NEC 4-53 and NEC 4-127) to add new requirements for a Surge Protective Device for all dwelling units. These proposals were rejected by the respective Code Making Panel (i.e., CMP-4) due to a lack of reliable data to support such requirements.

The goal of this project is to develop a data collection plan to assess loss related to electrical surge in homes, and address the potential impact electrical surge protection devices would have in mitigating these losses. The deliverables from this project represent a Phase I study in support of a potential second phase (not included in the scope of this effort).

The Research Foundation expresses gratitude to the report authors Eddie Davis, Nick Kooiman, and Kylash Viswanathan, all with Hughes Associates, Inc. Likewise, appreciation is expressed to the Project Technical Panelists and all others who contributed to this research effort for their on-going guidance. Special thanks are expressed to the project sponsors Eaton Corporation and the National Electrical Manufacturers Association for providing the funding for this phase 1 project.

The content, opinions and conclusions contained in this report are solely those of the authors.

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Data Assessment for Electrical Surge Protective Devices

Prepared for:

The Fire Protection Research Foundation
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Project Number: 1ELD62001.001
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EXECUTIVE SUMMARY

Purpose

The Fire Protection Research Foundation sponsored this project to address electrical surge protection for residential dwelling units. The goal of the project is to develop a data collection plan to assess loss related to electrical surges in homes, and address the potential impact electrical surge protection devices (SPDs) would have in mitigating these losses. The deliverables from this project represent a Phase I study (this report) in support of a potential second phase (not included in the scope of this effort).

Report Content

This report provides information regarding:

- Surge phenomena and their sources.
- Surge protection methods.
- Surge protection strategies recommended by various sources.
- Industry standards and their recommendations.
- Available data associated with electrical surges and their impact.
- Recommended data collection in support of code-making efforts.

Surge Protection

Sources of Surges

A surge is a transient wave of voltage or current. The duration is not tightly specified but is usually less than a few milliseconds. The following are typical sources of surges:

- Lightning.
- Utility switching, including capacitor switching.
- Equipment switching and switching inductive loads within a facility.

Protection against surges is referred to as *surge protection*, and includes protection against both surge voltages and currents. The devices used to protect against surges are referred to as *surge* *protective devices*, or SPDs. A surge of duration longer than a few milliseconds is referred to as a swell or temporary overvoltage (TOV) and requires a different type of protection design; SPDs can fail if exposed to long duration TOVs.

Surge Effects

Surges can cause equipment damage. Large surges damage equipment and other components in the electrical distribution system. Smaller surges can cumulatively damage equipment and can cause nuisance equipment tripping. Both surge voltage and current can be damaging. In the case of lightning strokes, the surge can be carried into a facility via all of the connected conductive paths.

There is a limit on how high of a voltage can be transmitted into a facility or residence. Above a certain level, a high voltage will result in flashover in the insulation system of electrical equipment and conductors. A flashover can cause insulation damage, electric shock, and fire.

NEMA surveys of facility managers confirmed catastrophic failure or damage of electrical or electronic equipment due to a lightning event or voltage surge and premature failure of electrical or electronic equipment, including failure of life safety equipment.

The Insurance Information Institute report for 2013 identified 114,740 insurer-paid lightning claims for residential locations. The average lightning paid-claim amount was $5,869.

Residential Surge Protection

Residential surge protection has long been viewed as an important safety consideration and guidance has been issued by IEEE and NIST to help homeowners protect their house and its contents. This protection has often been described as being similar to an insurance policy, partly because there is not an NFPA code requirement for SPD installation in residences. Today's residences often contain electronic equipment throughout, including appliances, computers, security systems, life safety equipment, automation systems for internet-enabled applications, and home entertainment systems.

Industry Standards

SPDs are routinely used in facilities that are potentially exposed to voltage or current surges from nearby lightning, utility switching, or other sources; and there are many manufacturers of SPDs and these manufacturers often offer guidance regarding SPD installation ratings and recommended applications. However, industry codes and standards provide limited guidance regarding selection, rating, and application.

One limitation with surge protection design is that there is no industry standard that describes what is an acceptable level of surge protection for standard facilities or residential locations. Although industry codes and standards are available that establish standardized surge criteria and assist with the application of specific surge protector types, these standards do not provide adequate design guidance that ensures a facility is properly protected against surges. There is no existing industry guidance for surge protection of residential facilities.

Refer to Section 3 for an overview of the available industry standards.

Data Acquisition Plan

Surge Data and Its Effects

Lightning strokes, either direct, nearby, or some distance away can cause voltage and current surges into a facility. Information is available regarding lightning strokes and their intensity. But, less information is available regarding the extent to which these surges are transmitted into commercial facilities, industrial facilities, or residences. Section 4.2 describes the difficulty associated with obtaining this data.

Available Data

Vaisala owns and operates the National Lightning Detection Network (NLDN) that provides accurate lightning data information across the USA. And, Vaisala can provide lightning location reports that provide individual cloud-to-ground lightning strikes and the intensity of strike at a specific location on the date of loss. This capability represents the largest and most complete source of lightning surge location and intensity.

Data for lightning surges that extend to the inside of facilities is not readily available. Published papers and IEEE C62.41.1 provide information regarding the expected surge levels within a facility or residence, but extensive data is not available.

Switching-related surge data, either internally or externally generated, is sparse. The added difficulty with this data is that these surges often do not cause immediate failure of electrical and electronic equipment; the damage occurs as a cumulative effect.

The largest documented source of surge effects is contained within the insurance claim documents for damage caused by surges. The Insurance Information Institute in collaboration with State Farm® produces annual reports of insurance claims associated with lightning-induced damage.

Data Acquisition Plan

There are challenges in obtaining usable data applicable to residential applications, such as:

- Confirming that equipment failures were a direct result of a surge event.
- Establishing any median and upper bounds to actual surge levels since this is not recorded inside facilities.
- Defining the protection improvement realized by applying SPDs.

Given the scarcity of real data relating to surges and the effects of surges, the approach described below is recommended.

The purpose of the recommended data acquisition approach is to produce real data regarding damage and injuries caused by surges. This information is intended to assist the NFPA 70 code-making committees with additional technical data to support a decision to require or not require SPDs for the variety of electrical applications proposed in past NFPA 70 update cycles (refer to Section 1.2).

The starting point for this project is to acquire the nationwide lightning stroke data for the continental USA for 2013 (or 2014 if the project starts in 2015). This information can tie back to insurance claim data and possibly provide surge current values for the locations of interest.

The Insurance Information Institute is proposed to manage the insurance industry claim data. Their involvement assures that the insurance industry claim reports can remain confidential while allowing access to additional data that might be contained in the claim reports.

The Insurance Information Institute already publishes annual summaries of the number of lightning-related insurance claims and the claim amount. Additional information of interest that might be available in the claim data includes:

- Date and location of surge event (to establish geographical correlations).
- Electronic equipment and appliances damaged.
- Life safety equipment damaged – smoke detectors, CO or CO_2 detectors, or other equipment.
- Fires caused by surge effects.
- Personal injuries associated with the surge event.
- Presence of or lack of installed SPDs.

Life safety equipment damage, fires caused by surge events, and personal injuries are of particular interest for code-making efforts.

Although the annual Insurance Information Institute survey has historically focused on residential claims, the survey for this project should include commercial and industrial claims also. NEMA assistance and direction with this effort will be helpful.

NEMA Low Voltage Surge Protective Devices Section (5-VS) participation is recommended for the following:

- Assisting with project scope, including commercial and industrial users.
- Reviewing the project checklist for the type of information to be obtained from the insurance industry.
- Reviewing failure data report summaries.
- Considering recommended SPD design principles, including the specification of surge protection in low-lightning flash density areas versus high-lightning flash density areas. Should NFPA elect to require SPDs in dwelling units or other applications, then minimum surge protection current limits should also be addressed, similar to the method provided in NFPA 780. As SPD surge current rating increases (and the degree of protection), the SPD cost also increases.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

INTRODUCTION

1.1 Project Overview

The Fire Protection Research Foundation sponsored this project to address electrical surge protection for residential dwelling units. The goal of the project is to develop a data collection plan to assess loss related to electrical surges in homes, and address the potential impact electrical surge protection devices (SPDs) would have in mitigating these losses. The deliverables from this project represent a Phase I study (this report) in support of a potential second phase (not included in the scope of this effort).

The project includes the following activities that are documented in this report:

- Literature review – review of literature to include fundamental factors contributing to electrical surges, existing data associated with losses, case studies of SPD effectiveness, and overview of SPD designs.
- Preliminary data collection plan – develop a preliminary data collection plan that will address the identified data gaps. When implemented, the data collection plan should provide a comprehensive review of electrical surge related losses in homes in the United States and address the potential impact of electrical surge protection devices in mitigating these losses.
- Final report – to be issued after review of the draft report.

1.2 NFPA 70 Committee Report on Proposals – 2013

Each update cycle for NFPA 70, *National Electrical Code®*, includes numerous proposals for changes throughout the document. In particular, the installation of SPDs has been proposed for virtually all low-voltage (600 volts or less) electrical distribution equipment. Because of the breadth of these recommendations, the proposals and their reasons for rejection are summarized here. Although this Fire Protection Research Foundation report is focused on SPDs for residential dwelling units, the proposals for SPDs cover a much broader set of electrical distribution equipment.

The *National Electrical Code® Committee Report on Proposals – 2013 Annual Revision Cycle*[1] provides a summary of all proposals and their disposition in support of the 2014 edition of NFPA 70. With respect to the application of SPDs, the following proposals were submitted:

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[1] The *National Electrical Code® Committee Report on Proposals – 2013 Annual Revision Cycle*. The 2010 version provided similar recommendations.

- Proposal 4-65 Log #3318 NEC-P04 – New Article 225.41 Surge Protection. A Type 1 or Type 2 listed SPD shall be installed on all outside branch circuits and feeders and shall be located at the point where the outside branch circuits and feeders receive their supply.

- Proposal 4-143 Log #3319 NEC-P04 – Article 230.67 Surge Protection. A Type 1 or Type 2 listed SPD shall be installed on all services.

- Proposal 4-143a Log #3504 NEC-P04 – Article 230.67 Dwelling Unit Surge Protection.
(A) Surge Protective Device. All dwelling units shall be provided with a surge protective device (SPD) installed in accordance with Article 285.
(B) Location. The surge protective device shall be an integral part of the service disconnecting means or shall be located immediately adjacent thereto.
(C) Type. The surge protective device shall be a Type 1 or Type 2 SPD.
(D) Replacement. Where service equipment is upgraded, all of the requirements of this section shall apply.

- Proposal 5-244 Log #3320 NEC-P05 – New Article 285.2 Required uses. A listed SPD shall be installed in or on the following equipment that is rated at 1000 volts or less.
(1) Switchboards and panelboards
(2) Motor control centers
(3) Industrial control panels
(4) Control Panels for elevators, dumbwaiters, escalators, moving walks, platform & stairway chairlifts
(5) Power distribution units supplying information technology equipment in information technology rooms
(6) Solar photovoltaic (PV) combiner boxes, recombiner boxes, and inverters
(7) Roof-top air conditioning and refrigerating equipment
(8) Adjustable-speed drive systems
(9) Burglar alarm panels
(10) Fire alarm panels
(11) Critical Operations Power Systems
(12) Small Wind Electric Systems

- Proposal 9-117 Log #3321 NEC-P09 – Article 408.6 Surge Protection. A listed SPD shall be installed in or on all switchboards and panelboards.

- Proposal 11-14 Log #3322 NEC-P11 – Article 409.70 Surge Protection. A listed SPD shall be installed in or on all industrial control panels.

- Proposal 11-42 Log #3323 NEC-P11 – New Article 430.92 Surge Protection. A listed SPD shall be installed in or on all motor control centers.

- Proposal 11-55 Log #3324 NEC-P11 – New Article 430.121 Surge Protection. A listed SPD shall be installed in or on all adjustable-speed drive systems.

- Proposal 11-84 Log #3325 NEC-P11 – New Article 440.9 Surge Protection. A listed SPD shall be installed in or on all roof-top air-conditioning and refrigerating equipment.

- Proposal 12-49 Log #3326 NEC-P12 – New Article 620.56 Surge Protection. A listed SPD shall be installed in or on control panels for elevators, dumbwaiters, escalators, moving walks, platform and stairway chairlifts.

- Proposal 12-140 Log #3327 NEC-P12 – New Article 645.18 Surge Protection. A listed SPD shall be installed in or on all switchboards, panelboards, and power distribution units supplying information technology equipment in information technology rooms.

- Proposal 12-169 Log #3328 NEC-P12 – New Article 670.6 Surge Protection. A listed SPD shall be installed in or on all industrial machinery.

- Proposal 4-254 Log #3329 NEC-P04 – New Article 690.12 Surge Protection. A listed SPD shall be installed in or on all solar photovoltaic (PV) combiner boxes, recombiner boxes, and inverters.

- Proposal 13-98 Log #3330 NEC-P13 – New Article 700.8 Surge Protection. A listed SPD shall be installed in or on all emergency systems switchboards and panelboards.

  Note: Although the *Committee Report on Proposals* lists the Final Action as Reject, the 2014 edition of NFPA 70 does include a new Article 700.8 that states:

  700.8 Surge Protection
  A listed SPD shall be installed in or on all emergency systems switchboards and panelboards.

- Proposal 4-405 Log #3331 NEC-P04 – New Article 705.13 Surge Protection. A Type 1 listed SPD shall be installed at the point of connection of all interconnected electric power production sources.

- Proposal 3-131 Log #3332 NEC-P03 – New Article 725.36 Surge Protection. A listed SPD shall be installed in or on all burglar alarm control panels.

- Proposal 3-179 Log #3333 NEC-P03 – New Article 760.36 Surge Protection. A listed SPD shall be installed in or on all fire alarm control panels.

The NFPA 70 Panel rejected the above proposals on various bases, including:

- *Surge protection is permitted to be installed and should not be required, as surge probabilities vary by locality, and different types of electrical loads have differing surge protection requirements. Surge protection must also be periodically maintained or replaced. The user should make the decision to install this protection.*

- *While the use of SPD's is appropriate in many instances, it is not always needed in every installation. System designers should apply SPD's where needed. Equipment manufacturers frequently provide integrated surge protection when it is deemed appropriate. The substantiation provided does not warrant the imposition of this new requirement.*

- *Surge protective devices have proven to provide benefits for components and systems against the damages of voltage surges, but the substantiation for this proposal does not document that such protection would specifically benefit HVAC equipment installed on a roof. In addition this may not work with high resistance, impedance or ungrounded systems. The NFPA FPRF is working on a project in this area which may provide information in the future.*

- *CMP-13 acknowledges that surges may result in failures. However, the proposal does not state what type or level of protection should be required. Further substantiation through a formal research report that presents evidence of the type of SPD and the level of protection required would present the opportunity for the panel to reconsider the proposal.*

Miscellaneous changes were made to the 2014 edition of NFPA 70 Article 285, *Surge-Protective Devices (SPDs), 1000 Volts or Less*, but these changes do not affect the locations where surge protection has been required.

1.3 Report Content

This report provides information regarding:

- Surge phenomena and their sources.
- Surge protection methods.
- Surge protection strategies recommended by various sources.
- Industry standards and their recommendations.
- Available data associated with electrical surges and their impact.
- Recommended data collection in support of code-making efforts.

2

SURGE PROTECTION FUNDAMENTALS

Section 2 provides an overview of electrical surges and protection against the effects of these destructive surges.

2.1 Sources of Surges

A surge is a transient wave of voltage or current. The duration is not tightly specified but is usually less than a few milliseconds. The following are typical sources of surges:

- Lightning.
- Utility switching, including capacitor switching.
- Equipment switching and switching inductive loads within a facility.

The following summarizes the effects of these various surge sources.

Table 2-1
Sources of Surges

Source of Surge	Peak Voltage Magnitude	Frequency of Occurrence	Comments
Lightning	<1,000 volts to >40,000 volts with average of about 20,000 volts	Weekly to rarely, depending on location	Magnitude depends on proximity of stroke to facility and coupling of stroke to facility electrical system. Voltages within a facility above 6,000 volts are unlikely due to flashover.
Utility Capacitor and System Switching	Up to 1,300 volts on a 480 volt system	Never to several times a day, depending on utility	Capacitors might or might not be installed nearby.
Facility Equipment Switching	Up to 2,000 volts on a 480 volt system	Many times a day	Magnitude is small compared to lightning-induced transients, but switching can occur frequently.

Protection against surges is referred to as *surge protection*, and includes protection against both surge voltages and currents. The devices used to protect against surges are referred to as *surge protective devices*, or SPDs. A surge of duration longer than a few milliseconds is referred to as a swell or temporary overvoltage (TOV) and requires a different type of protection design; SPDs can fail if exposed to long duration TOVs.

2.1.1 *Lightning Surges*

Lightning-induced surges into an electrical system are caused by lightning strokes to the ground, towers, or structures. A lightning stroke can produce peak discharge currents ranging from a few thousand amperes to 200,000 amperes, or higher. This lightning discharge current is developed within a few microseconds and typically discharges most of its energy within a millisecond. The location where a lightning stroke will occur is not completely predictable; cloud-to-ground strokes have been recorded almost 20 miles from the base of the source cloud.

The frequency of lightning strokes varies with geographical location. Figure 2-1 shows the Vaisala lightning flash density map for the United States. Lightning strokes are a rare occurrence in Portland Oregon while they can be a routine event in Orlando Florida.

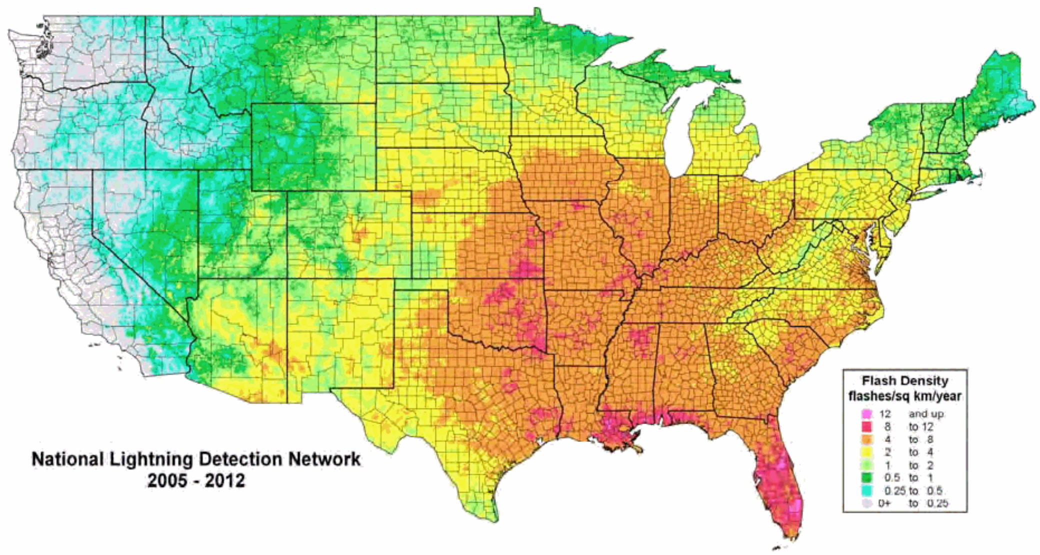

Figure 2-1
Lightning Flash Density Map
Courtesy Vaisala

A single intense storm can produce thousands of lightning strokes. Schneider Electric Data Bulletin DB03A, *Surge Protection: Measured Lightning Stroke Data*, describes a July 2000 storm in Tampa Florida that recorded 33,863 lightning strokes during a 14 hour period. Both positive and negative polarity strokes were detected,[2] with the following recorded surge currents:

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[2] A lightning stroke is a lightning discharge between a thundercloud and the ground and commonly referred to as cloud-to-ground lightning. The most common type of lightning stroke is referred to as a negative lightning stroke and usually originates near the bottom of the cloud with a large concentration of negative charge in the cloud base. The term *negative lightning* means that there is a net transfer of negative charge from the cloud to the ground. Positive lightning strokes represent only about 5% of the lightning strokes and tend to originate in the more positively charged top of the cloud.

Positive Lightning Stroke Surge Currents

- 95% – less than 30 kA
- 98% – less than 60 kA

Negative Lightning Stroke Currents

- 82% – less than 30 kA
- 98% – less than 60 kA

For this Tampa Florida storm, notice that the above results show that 2% of the lightning strokes produced surge currents greater than 60 kA. A few lightning strokes approached 200 kA. But, over 80% of the lightning strokes produced surge currents less than 60 kA.

This data correlates reasonably well with a report from the IEEE Lightning and Insulator Subcommittee of the T&D Committee that showed a 50% probability of less than about 20 kA, a 95% probability of less than about 60 kA, and a 99% probability of less than about 100 kA.[3]

A lightning-induced surge is a high magnitude impulsive transient of very short duration, typically measured in microseconds or milliseconds. But, during this short period, significant system damage can occur. Figure 2-2 shows an example.

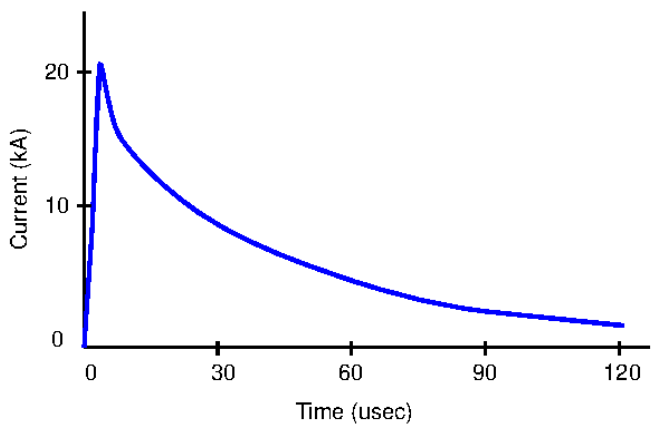

Figure 2-2
Typical Lightning Surge Current

Lightning-induced surges can be introduced into the electrical distribution system by any of the following methods, either alone or in combination:[4]

[3] Refer to Lightning and Insulator Subcommittee of the T&D Committee, *Parameters of Lightning Strokes: A Review*, IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005, for the actual range of values.

- Direct lightning strokes to the service entrance, either at low voltage lines or on the high voltage windings of service entrance transformers.
- Nearby strokes that induce voltages in distribution transformer secondary circuits.
- Strokes near the service entrance that induce surges onto the electrical system.
- Strokes to a building that induce surges in the system ground with respect to power supplies.
- Surges that cause surge protector operation, thereby placing a surge on the ground and neutral wire common to the low voltage system.

The greatest number of lightning-caused surges that will be seen originate on the high voltage side of the distribution transformer. Far less often, the surges will be caused by a local stroke impinging on the facility, service entrance transformer, or nearby equipment. Most surges, regardless of whether they originate on the primary or secondary side of the transformer are not from a direct stroke; usually, the surge is caused by a stroke to the pole, tower, ground wire, or nearby object with the surge electromagnetically coupled into the distribution or service conductors. Once into the electrical system wiring, surges on the high side of the transformer are coupled into the secondary and transmitted throughout a facility.

2.1.2 *Utility Switching*

Utility switching is a broad term that applies to how utility configurations are occasionally changed. Each switching operation can produce a transient that can momentarily exceed equipment voltage ratings. Although the transients are not as large in magnitude as a nearby lightning stroke, switching transients can cause cumulative damage to electrical equipment. And, if switching results in a temporary overvoltage (TOV), it can also cause SPD failure.

Capacitor switching is a special case of utility switching. Capacitors might also be switched periodically by large industrial power customers. Capacitor switching can be a common every-day event, occurring several times each day in some locations, as a utility adjusts system voltage and compensates for inductive loads.

Capacitor switching causes a surge voltage by the following process. The voltage across a capacitor is zero before it is switched into the circuit. As a capacitor is switched, there is a momentary short circuit across the capacitor as the system voltage is applied to the zero voltage of the capacitor. At the capacitor location, the bus voltage momentarily experiences a step change to zero volts. After the initial step change, the voltage recovers and then overshoots as the system eventually return to its steady state value. Thereafter, the system oscillates until damping returns the voltage to its steady-state value. During the initial oscillation period, the peak transient voltage can approach 200 percent of the normal peak system voltage (common peak surge voltages can range from 150 percent to 180 percent of normal). Another factor contributing to the transient is the inrush current as the capacitor energizes; this inrush current

[4] IEEE C62.41.1, *Guide On The Surge Environment In Low-Voltage (1000V And Less) AC Power Circuits*, uses the terms "direct flash", "near flash", and "far flash" to distinguish between lightning strokes and how they induce a surge on a facility.

can have a resonant frequency anywhere from 300 hz to 1,000 hz depending on the installed inductance and capacitance, which adds to the system oscillations. Figure 2-3 shows an example of a capacitor switching transient.

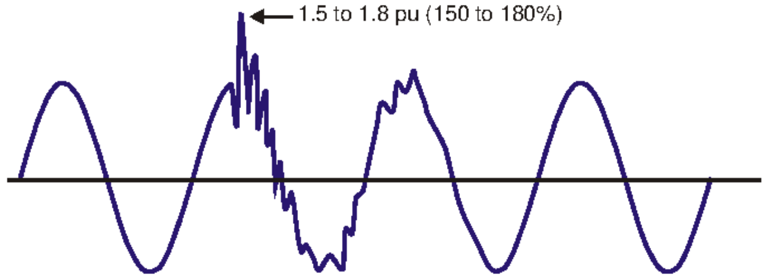

Figure 2-3
Voltage Waveform for Capacitor Switching Transient

Capacitors inside a facility can resonate with the switching-induced oscillations, thereby magnifying the peak voltage and extending the period until the voltage returns to normal. Magnification of the switching transient can occur if the utility switched capacitor bank is much larger than the facility capacitor bank and there is little resistive load (mostly motor load) to provide a damping mechanism.

2.1.3 *Facility Internal Switching*

Switched equipment in a facility electrical system or residence results in the inductive release of energy that creates a momentary voltage surge. Even minor switching, such as deenergizing lighting loads, can cause a significant inductive surge in the system. This type of switching accounts for the overwhelming majority of switching transients. However, the magnitude of this type of surge is much smaller than for lightning-induced surges.

2.2 Surge Effects

Surges can cause equipment damage.[5] Large surges damage equipment and other components in the electrical distribution system. Smaller surges can cumulatively damage equipment and can cause nuisance equipment tripping. Both surge voltage and current can be damaging. In the case of lightning strokes, the surge can be carried into a facility via all of the connected conductive paths. The following figures show examples of damage caused by surges.

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[5] Refer to IEEE 1100, *Powering and Grounding Electronic Equipment*, for additional information regarding the effects of surges.

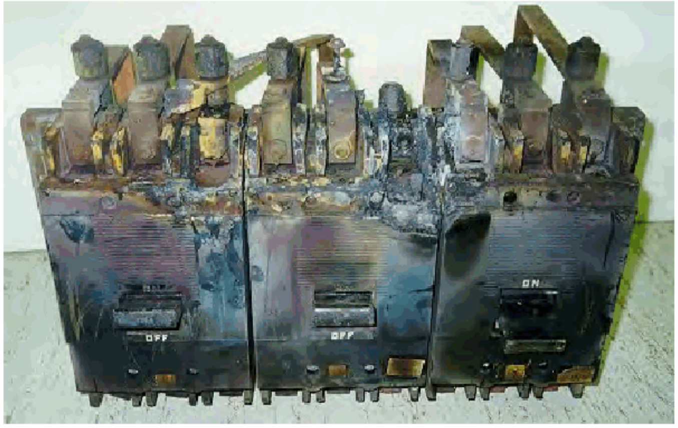

Figure 2-4
Circuit Breaker Failure Caused by Surge Voltage

Figure 2-5
Copper Busbar Melted by Surge Current

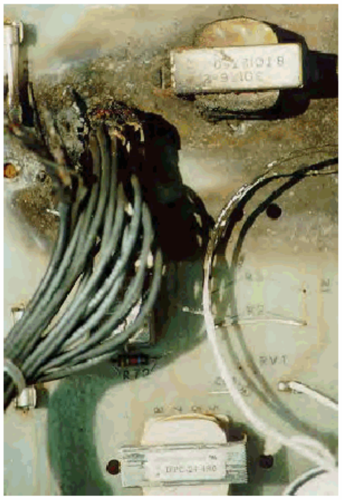

Figure 2-6
Circuit Board Damage Caused by Surge Voltage

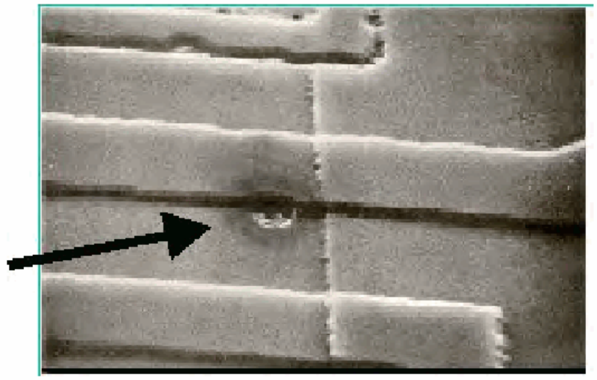

Figure 2-7
Micro Circuit Damage Caused by Surge Voltage

Electronic equipment is susceptible to surge transients. Computers and internet-enabled devices are not only at risk in the power supply but can also be damaged by surges that propagate into the equipment via the communications link.

There is a limit on how high of a voltage can be transmitted into a facility or residence. Above a certain level, a high voltage will result in flashover in the insulation system of electrical equipment and conductors. A flashover can cause insulation damage, electric shock, and fire.

2.2.1 *NEMA Surveys*

The NEMA Low Voltage Surge Protective Devices Section (5-VS) sponsored surveys of surge damage in 2013 and 2014.[6] The surveys were targeted towards facility managers and attempted to accomplish the following:

- Determine if SPDs are installed.
- Obtain failure data for electrical or electronic equipment due to a lightning event or voltage surge.
- Determine the frequency of damage incidents.
- Address the type of equipment damaged.
- Summarize the cost of damage.

The following summarizes the 2014 survey results:

- 100 respondents completed the survey.

[6] NEMA 2013 *U.S. Surge Protection Damage Survey* and NEMA *Surge Damage Survey Results – Wave 2*. Refer to http://www.nemasurge.org for reports.

- A plurality (48%) of respondents noted that their facility had experienced unexplained process interruptions. Catastrophic failure or damage of electrical or electronic equipment due to a lightning event or voltage surge and premature failure of electrical or electronic equipment were both frequently reported (41%) events. More than a third (38%) noted the occurrence of lockup of computer or industrial process systems.

- For most respondents (61%), it cost less than $10,000 to repair the damage resulting from voltage surges, but a sizable number (16%) reported damage costing in excess of $50,000 to fix.

- Nearly 95% of those who reported having experienced a surge event resulting in equipment damage indicated that they subsequently purchased surge protection. Virtually all of those who did so, purchased immediately or within three months of the event.

- Over 65% reported downtimes associated with voltage surges of 6 hours or more.

- Respondents reported damage or loss of function of the following types of life safety equipment because of voltage surges:

  - Smoke detector (34.7%)
  - CO2 detector (18.7%).
  - Fire alarm system (41.3%).
  - Security system (49.3%).
  - Ground fault circuit interrupters (22.7%).
  - Emergency lighting (32.0%)
  - Emergency generators or backup power (33.3%).
  - Fire pumps (12.0%).
  - Elevators or escalators (24.0%).
  - Safety interlocking systems on machines (26.7%)

  Of the respondents, only 14.7% stated that no life safety equipment was damaged or lost function.

- When asked if anyone had been injured, either directly or indirectly, as a result of a voltage surge, 10.7% replied yes.

The NEMA survey is significant in that it shows the effect of surges on life safety equipment and the potential impact to personnel in a facility.

2.2.2 *Insurance Information Institute Surveys*

The Insurance Information Institute[7] provides periodic reports of homeowner insurance claims associated with lightning-induced damage. Their report for 2013, produced in collaboration with State Farm®, included the following:

- There were 114,740 insurer-paid lightning claims in 2013, down 24% from 2012.
- The average lightning paid-claim amount was also down in 2013, slipping by 8.3% to $5,869 from $6,400 in 2012.
- The decline in lightning damage last year is consistent with data from the National Weather Service, which recorded 137 days in 2013 with lightning causing property damage, while 160 such days were recorded in 2012—a 14 percent decrease.
- Despite the drop in the number of paid claims in 2013, the average cost per claim rose nearly 122% from 2004-2013. The average cost per claim has generally continued to rise, in part because of the huge increase in the number and value of consumer electronics in homes.

2.3 Surge Protective Devices (SPDs)

2.3.1 *Typical Configuration*

Most SPDs in use for the applications covered by this report use metal oxide varistors (MOVs) to accomplish surge suppression in the electrical power system. MOVs exhibit nonlinear resistance characteristics as a function of voltage. Within the MOV voltage rating, the resistance usually exceeds 10,000,000Ω, but the resistance drops to less than 0.1Ω when the MOV is exposed to an overvoltage, such as a transient voltage spike due to a nearby lightning stroke. It is this characteristic that makes MOVs an effective protection element.

The MOV is essentially a matrix of zinc oxide grain boundaries that have a nonlinear resistance characteristic. The series combination of the boundaries defines the MOV voltage rating, the parallel combination defines the total current that can be passed, and the bulk volume determines how much energy that it can absorb. When an MOV is energized with an AC voltage, resistive and reactive current flows through the highly capacitive disc.

Most SPDs are connected in parallel with the circuit and operate when a transient voltage exceeds the voltage protection rating. Parallel surge protectors have little interaction with the circuit under normal conditions.

A different technology is commonly used for communications lines, referred to as a gas discharge tube (GDT), which is a spark gap type of surge suppression device. When subjected to a surge voltage, the gas discharge tube sparks over, thereby causing an arc to ground. The hermetically sealed tubes used today can have a precise and repeatable turn-on voltage. Gas discharge tubes consist of a spark gap in series with a resistance or varistance to limit the discharge current to safe levels.

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[7] Their reports are accessible at http://www.iii.org/.

2.3.2 *SPD Classification*

UL 1449 classifies SPDs by type depending, in part, on their location in the system and their level of internal protection:

- Type 1 – Permanently connected SPDs intended for installation between the secondary of the service transformer and the line side of the service equipment overcurrent device, as well as the load side, including watt-hour meter socket enclosures and intended to be installed without an external overcurrent protective device. They must have overcurrent protective devices either installed internally on the SPD or included with it. While these are primarily intended for installation before the main service disconnect, Type 1 SPDs can be installed in Type 2 and Type 4 locations such as distribution panels, end-use equipment. Residential installations are often Type 1, installed near the incoming meter.

- Type 2 – Permanently connected SPDs intended for installation on the load side of the service equipment overcurrent device; including SPDs located at the branch panel. While some will have internal overcurrent protective components, Type 2 SPDs can rely on the service entrance overcurrent disconnect device for over current protection. These SPDs can be installed in service equipment, distribution panels, and end-use equipment.

- Type 3 – Point of utilization SPDs, installed at a minimum conductor length of 10 meters (30 feet) from the electrical service panel to the point of utilization, for example cord connected, direct plug-in, receptacle type and SPDs installed at the utilization equipment being protected.

- Type 4 – Component SPDs, including discrete components as well as component assemblies.

Permanently installed self-contained SPDs are usually Type 1 or Type 2.

2.3.3 *SPD Ratings*

SPDs are tested and rated in accordance with UL 1449. The following ratings are normally provided for each model and size of SPD:

- Nominal voltage and frequency.

- Maximum continuous overvoltage (MCOV) – defines the voltage at which the SPD will start conducting to ground. Continuous operation above the MCOV will lead to SPD failure.

- Voltage protection rating (VPR) – a UL 1449 rating of the limiting voltage measured during the transient-voltage surge suppression test using the combination wave generator at a setting of 6kV, 3kA. A lower VPR is better.

- Surge current rating – the maximum surge current that an SPD is rated to carry without excessive overheating and consequent premature breakdown or combustion risk. The surge current rating is expressed in thousands of amps (kA) and is an indicator of how many MOVs are installed in parallel inside the device. SPDs are readily available rated for as low as ≤20 kA up to ≥600 kA. SPD price tends to increase as surge current rating increases.

- Protection modes – line-to-line, line-to-ground, line-to-neutral, neutral-to-ground.
- Short circuit current rating (SCCR).
- Surge life – expected number of surges that the SPD can withstand.

Other important attributes include monitoring and design for the environment at the installation location.

2.4 Residential Surge Protection

Residential surge protection has long been viewed as an important safety consideration and guidance has been issued in the past to help homeowners protect their house and its contents[8]. This protection has often been described as being similar to an insurance policy, partly because there is not an NFPA code requirement for SPD installation in residences. Today's residences often contain electronic equipment throughout, including appliances, computers, security systems, life safety equipment, automation systems for internet-enabled applications, and home entertainment systems.

2.4.1 *Design*

SPDs used in residential applications are typically designed for 240/120 volts with the electrical power neutral bonded to ground at the service entrance. A permanently-installed SPD can be installed at the incoming meter (Type 1) or at the service entrance (Type 2). Type 3 SPDs can still be installed at the point of use for electronic equipment also.

The IEEE document, *How to Protect Your House and Its Contents from Lightning, IEEE Guide for Surge Protection of Equipment Connected to AC Power and Communication Circuits*, provides an excellent overview of the design and installation considerations for SPDs. A permanently-installed SPD should be installed by a qualified electrician and should consider quality of the grounding system, lead length for connections, overcurrent protection, and disconnect capability. Installation in accordance with NFPA 70 is a requirement.

2.4.2 *General Cost*

Prices vary widely for SPDs. An SPD intended for residential use (240/120 volts) and rated for 50 kA surge current can cost as little as $125 and as much as $500. Integrated protection to protect the incoming power lines as well as the phone/internet communication lines can cost an additional $100. A reasonable level of protection can typically be realized for about $500.

One consideration is how high of a surge current rating to specify. Cost tends to increase as the surge current rating increases because of the additional MOV modules that are required. The cost can be considerably higher for three-phase circuits, partly because there are more protection

[8] Key documents include *How to Protect Your House and Its Contents from Lightning, IEEE Guide for Surge Protection of Equipment Connected to AC Power and Communication Circuits*, by Richard L. Cohen and others, ISBN 0-7381-4634-X, 2005 and NIST Special Publication 960-6, *Surges Happen! How to Protect the Appliances in Your Home*, 2001. Some insurance companies also provide guidance on their websites.

modes to consider compared to a single-phase application and partly because the surge current rating might be higher. For residential applications, a surge current rating above 30 kA likely is adequate for 80% to 90% of lightning strokes.[9] A surge current rating above 60 kA likely is adequate for virtually all lightning strokes. In lightning-prone areas (refer to Figure 2-1), a higher surge current rating can also provide a longer SPD life if it is exposed to repeated surges.

[9] Lightning strokes produce the largest surges.

3

INDUSTRY STANDARDS

Section 3 provides an overview of industry codes and standards that apply to SPDs.

SPDs are routinely used in facilities that are potentially exposed to voltage or current surges from nearby lightning, utility switching, or other sources; and there are many manufacturers of SPDs and these manufacturers often offer guidance regarding SPD installation ratings and recommended applications. However, industry codes and standards provide limited guidance regarding selection, rating, and application.

One limitation with surge protection design is that there is no industry standard that describes what is an acceptable level of surge protection for standard facilities or residential locations. Although industry codes and standards are available that establish standardized surge criteria and assist with the application of specific surge protector types, these standards do not provide adequate design guidance that ensures a facility is properly protected against surges. There is no existing industry guidance for surge protection of residential facilities.

3.1 NFPA Codes and Standards

3.1.1 *NFPA 70*

NFPA 70 distinguishes between surge arresters for applications over 1,000 volts (Article 280) and SPDs for applications 1,000 volts or less (Article 285). Each Article provides installation requirements.

NFPA 70[10] requires SPDs for the following applications:

- Article 501.35, Surge Protection – required Class I Division 1 and 2 locations.
- Article 694, Wind Electric Systems. Article 694.7(D) requires, "*A surge protective device shall be installed between a small wind electric system and any loads served by the premises electrical system. The surge protective device shall be permitted to be a Type 3 SPD on a dedicated branch circuit serving a small wind electric system or a Type 2 SPD located anywhere on the load side of the service disconnect.*"
- Article 700, Emergency Systems. New Article 700.8, Surge Protection, was added in 2014 and requires, "*A listed SPD shall be installed in or on all emergency systems switchboards and panelboards.*"

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[10] The *National Electrical Code® Handbook* provides additional discussion of surge protection requirements.

- Article 708, Critical Operations Power Systems (COPS). Article 708.20(D) requires, "*Surge protection devices shall be provided at all facility distribution voltage levels*".

- If surge protection is provided, Article 646, Modular Data Centers, requires that SPDS are listed, labeled, and installed in accordance with Article 285.

Article 285 provides requirements regarding the installation of SPDs, but it provides limited guidance for when a SPD is required or recommended ratings. The NFPA 70 Handbook also avoids discussion regarding the application of SPDs. In other words, NFPA 70 provides guidance regarding SPD installation, but provides no information regarding SPD selection and rating.

3.1.2 *NFPA 780*

NFPA 780[11], *Standard for the Installation of Lightning Protection Systems*, is more specific regarding the application of SPDs for lightning protection systems. This standard provides detailed requirements for the application of SPDs in support of a lightning protection system, including SPD rating information. Key requirements include:

- SPDs shall be installed at all power service entrances.

- The SPD shall protect against surges produced by a 1.2/50 µs and 8/20 µs combination waveform generator.

- SPDs at the service entrance shall have a nominal discharge current (I_n) rating of at least 20 kA 8/20 µs per phase.

- Signal, data, and communications SPDs shall have a maximum discharge current (I_{max}) rating of at least 10 kA 8/20 µs when installed at the entrance.

- The published voltage protection rating (VPR) for each mode of protection shall be selected to be no greater than those given in Table 4.20.4 for the different power distribution systems to which they can be connected. The maximum allowed VPR per mode of protection varies from 600 to 1,800 volts, depending on the service voltage and connection type.

- The maximum continuous operating voltage (MCOV) of the SPD shall be selected to ensure that it is greater than the upper tolerance of the utility power system to which it is connected.

- SPDs at grounded service entrances shall be wired in a line-to-ground (L–G) or line-to-neutral (L–N) configuration. Additional modes, line-to-line (L–L), or neutral-to-ground (N–G) shall be permitted at the service entrance. For services without a neutral, SPD elements shall be connected line-to-ground (L–G). Additional line-to-line (L–L) connections shall also be permitted.

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[11] NFPA 780, *Standard for the Installation of Lightning Protection Systems*, 2014 Edition.

- Installation of surge suppression hardware shall conform to the requirements of NFPA 70, *National Electrical Code*. SPDs shall be located and installed so as to minimize lead length. Interconnecting leads shall be routed so as to avoid sharp bends or kinks.

Although NFPA 780 only applies to lightning protection systems, it provides clear SPD design, rating, and installation guidance for these systems.

3.2 IEEE Standards

IEEE has historically taken the lead with respect to characterizing the surge environment. The following sections discuss key IEEE documents that apply to SPDs.

3.2.1 *IEEE C62.41.1*

IEEE C62.41.1, *Guide On The Surge Environment In Low-Voltage (1000V And Less) AC Power Circuits*, provides comprehensive information about surges and the environment in which they occur. This guide form the basis for IEEE surge testing criteria and is recommended for any review of surge characteristics. IEEE C62.41.1 is also valuable as a source of recorded data of surge events. Temporary over-voltages are also discussed, including their potential impact on SPDs.

3.2.2 *IEEE C62.41.2*

IEEE C62.41.2, *Recommended Practice On Characterization Of Surges In Low-Voltage (1000V And Less) AC Power Circuits*, presents recommendations for selecting surge waveforms, and the amplitudes of surge voltages and currents used to evaluate equipment immunity and performance of SPDs. The following figures show the surges recommended by IEEE C62.41.2 for consideration.

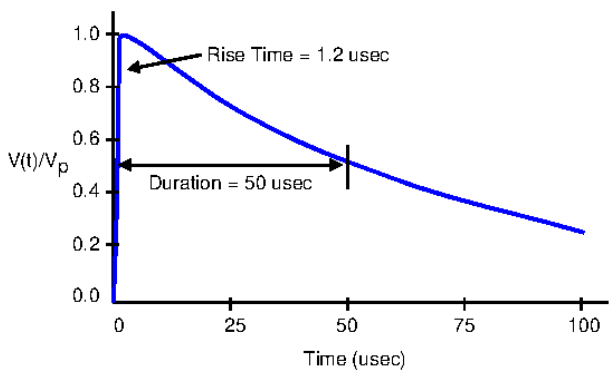

Figure 3-1
Combination Wave—1.2 x 50 µsec, Open Circuit Voltage

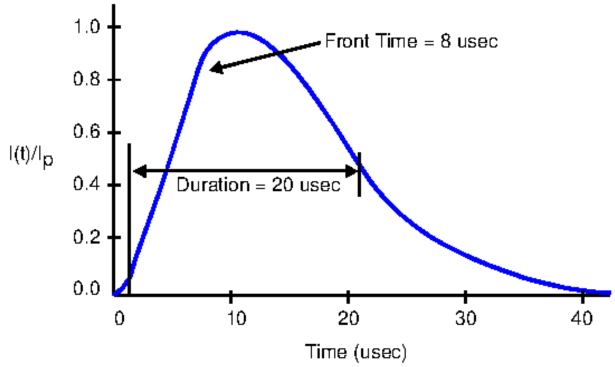

Figure 3-2
Combination Wave—8 x 20 µsec, Short Circuit Current

The second type of IEEE C62.41.2 surge voltage is called a 100 khz ring wave with a waveform below.

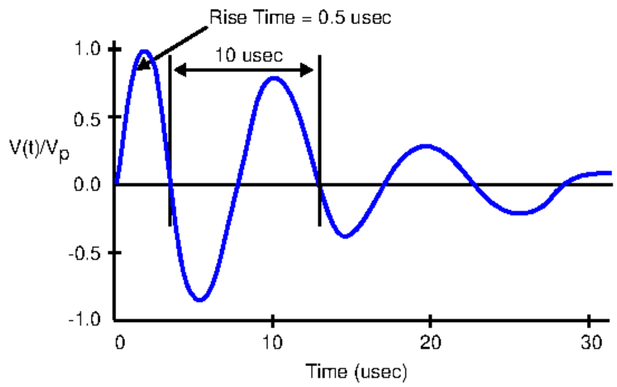

Figure 3-3
100 khz Ring Wave—Open Circuit Voltage

The combination and ring waves are intentionally generic in shape, in that peak magnitudes are not provided. Voltage and current values are assigned according to distance into the distribution system.

3.2.3 *IEEE C62.45*

IEEE C62.45, *Recommended Practice On Surge Testing For Equipment Connected To Low-Voltage (1000V And Less) AC Power Circuits*, describes surge testing procedures using simplified waveform representations (described in IEEE C62.41.2) to obtain reliable measurements and enhance operator safety.

3.2.4 *IEEE 1100*

IEEE 1100, *Powering and Grounding Electronic Equipment*, provides guidance regarding SPDs. Unfortunately, the information provided in IEEE 1100 is dated and does not reflect the current SPD products that arevavailable; much of the information provided is over 15 years old. But, IEEE 1100 provides a good discussion of surge effects and protecting against surges.

3.2.5 *IEEE 1692*

IEEE 1692, *IEEE Guide for the Protection of Communication Installations from Lightning Effects*, provides design guidelines to help prevent lightning damage to communications equipment within structures.

3.3 UL Documents

3.3.1 *UL 1449*

In the USA, SPDs are manufactured and specified in accordance with UL 1449, Third Edition, *Surge Protective Devices*, which was issued on September 29, 2006 with an effective date of September 29, 2009. This revision to UL 1449 changed how surge protective devices (SPDs) are named, tested, and rated. UL 1449 listing is specifically required by NFPA 780 and SPD listing (presumably to UL 1449) is required by NFPA 70. UL 1449 defines the performance requirements for an SPD; however, it does not address the engineering application of SPDs. UL also addresses additional related product performance criteria in UL 1283, *Electromagnetic Interference Filters*, and the UL 497 series, *Protectors for Fire Alarm Signaling Circuits*.

UL 1449, Third Edition, improved the harmonization of methods with IEC 61643 series, *Low Voltage Surge Protective Devices*, but there still remain some differences in approach between the UL and IEC test methods.

UL 1449, Third Edition, changed testing and rating requirements such that an SPD listed to UL 1449, Second Edition, cannot be compared to an SPD listed to UL 1449, Third Edition; the differences are too significant. Some of the key changes include:

- New performance tests use more surge current, resulting in higher let-through voltages. The older tests were performed at 500 amperes and 6,000 volts. The new tests are performed at 3,000 amperes and 6,000 volts.

- Test results for the new performance tests in the Third Edition are higher than the equivalent tests in the Second Edition, which has resulted in manufacturers changing their product literature. With a surge current of 6 times the Second Edition level, the Third Edition results for let-through voltage must be higher (the let-through voltage or clamping voltage was referred to as suppressed voltage rating in the Second Edition and is referred to as voltage protection rating in the Third Edition).

- Terminology has changed.

- UL 1449 is now ANSI-approved.

3.3.2 *UL 497*

The UL 497 series, *Protectors for Fire Alarm Signaling Circuits*, provides performance standards and testing procedures for enclosures, corrosion protection, field wiring connections, and components of SPDs, as well as product labeling and installation instructions.

3.3.3 *UL 1283*

UL 1283, *Electromagnetic Interference Filters*, provides requirements for electromagnetic interference (EMI) filters. It addresses filters installed on, or connected to, 600 V or lower voltage circuits and 50-60 Hz frequency. These filters are used to attenuate unwanted radio frequency (RF) signals, such as noise or interference generated from electromagnetic sources. They consist of capacitors and inductors used alone or in combination with each other and may be provided with resistors.

4

DATA ACQUISITION PLAN

Section 4 provides an overview of the recommended data acquisition plan for SPDs.

4.1 Type of Desired Data

In order to address fully the potential application of SPDs as a code requirement, the following types of data would be especially helpful:

Installations With SPDs Installed

- Characterization of surge events that were successfully diverted without damage to electronic equipment, electrical equipment, or the structure.
- Characterization of surge events that occurred with subsequent damage to electronic equipment, electrical equipment, or the structure.
- Characterization of surge events that resulted in damage or loss of function to life safety equipment.

Installations Without SPDs Installed

- Characterization of surge events that did not cause damage to electronic equipment, electrical equipment, or the structure.
- Characterization of surge events that occurred with subsequent damage to electronic equipment, electrical equipment, or the structure.
- Characterization of surge events that resulted in damage or loss of function to life safety equipment.

Surge Characterization

- Real data recording of lightning-induced surges.
- Real data recording of switching-induced surges, either internally generated (appliances or motors turning on or off) or externally generated (such as capacitor switching).

The problem lies in acquiring the above data, which is the goal of this project. The above information does not really exist, except in a few limited scope studies and in insurance claim documents. Refer to the following sections for more information.

4.2 Data to Characterize the Nature of Surges

Lightning strokes, either direct, nearby, or some distance away can cause voltage and current surges into a facility. Information is available regarding lightning strokes and their intensity. But, less information is available regarding the extent to which these surges are transmitted into commercial facilities, industrial facilities, or residences. The IEEE paper, *A Field Study of Lightning Surges Propagating Into Residences*[12], provides an outstanding view into the effort needed to acquire even limited amounts of real-world data. This paper provides the following insights:

- When a home appliance malfunctions due to lightning, the relationship between the lightning stroke and the damage is often unclear. The purpose of their study was to complete experimental investigations on lightning surges that flow into residences. SPDs were not installed in these residences.
- Lightning surge waveform detectors were installed in 49 residences and monitored for four years (2003 to 2006). During the four-year observation period, lightning surge waveforms were obtained for a total of 18 lightning stroke events.
- Damage occurred to appliances in 4 of the 18 events. The most severe damage occurred when lightning appeared to have hit an antenna. In this case, currents of 1 kA or greater were recorded at all the measurement points, and many appliances were damaged.
- The home appliances, typically having built-in lightning protective devices with a peak current of 1 kA or higher, broke down at a current peak value of approximately 1 kA or higher, according to the observations.
- The analysis of observation data found that in some cases a ground potential rise causes a lightning surge to flow from the ground of another residence or the ground of a distribution system into the distribution system and, in turn, to flow into another residence.

Notice that the above effort took four years of monitoring at 49 residences to produce recordings of 18 surge events, of which four were severe enough to cause damage to appliances. This illustrates the difficulty of acquiring actual surge data.

4.3 Who Has Data on Surges, Surge Effects, and SPDs

4.3.1 *Surge Data – Lightning Surges*

Vaisala[13] owns and operates the National Lightning Detection Network (NLDN) that provides accurate lightning data information across the USA. And, Vaisala can provide lightning location reports that provide individual cloud-to-ground lightning strikes and the intensity of strike at a specific location on the date of loss. This capability represents the largest and most complete source of lightning surge location and intensity.

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[12] Teru Miyazaki, et al, *A Field Study of Lightning Surges Propagating Into Residences*, IEEE Transactions on Electromagnetic Compatibility, Vol. 52, No. 4, November 2010.

[13] http://www.vaisala.com/en/services/dataservicesandsolutions/lightningdata/Pages/default.aspx

Data for lightning surges that extend to the inside of facilities is not readily available. Published papers and IEEE C62.41.1 provide information regarding the expected surge levels within a facility or residence, but extensive data is not available.

4.3.2 *Surge Data – Switching Surges*

Switching-related surge data, either internally or externally generated, is sparse. The added difficulty with this data is that these surges often do not cause immediate failure of electrical and electronic equipment; the damage occurs as a cumulative effect.

4.3.3 *Surge Effects – Manufacturers*

Although manufacturers produce SPDs and do a great job of educating consumers regarding their products, very little failure data associated with surges appears to be available from them. NEMA maintains the Surge Protection Institute[14] and they have completed surveys in 2013 and 2014 regarding failures of electrical and electronic equipment caused by surges. Although the sample size is relatively small, the survey results are helpful with respect to historical failures of life safety equipment. Refer to Section 2.2.1 for more information.

4.3.4 *Surge Effects – Consulting Firms*

Many engineering consulting firms assist with evaluations of surge damage in support of insurance claims. However, this data is not compiled in a readily usable manner nor is the data accessible in many cases. Surge data is not typically available.

4.3.5 *Surge Effects – Insurance Claims*

The largest documented source of surge effects is contained within the insurance claim documents for damage caused by surges. The Insurance Information Institute in collaboration with State Farm® produces annual reports of insurance claims associated with lightning-induced damage (refer to Section 2.2.2 for more information). The information contained in these claim reports likely provides additional detail regarding surge effects and the types of damage caused.

4.4 Data Acquisition Plan

There are challenges in obtaining usable data applicable to residential applications, such as:

- Confirming that equipment failures were a direct result of a surge event.
- Establishing any median and upper bounds to actual surge levels since this is not recorded inside facilities.
- Defining the protection improvement realized by applying SPDs.

Given the scarcity of real data relating to surges and the effects of surges, the approach described below is recommended.

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[14] *Refer to http://www.nemasurge.org.*

4.4.1 *Purpose of Data to Be Obtained*

The purpose of the recommended data acquisition approach is to produce real data regarding damage and injuries caused by surges. This information is intended to assist the NFPA 70 code-making committees with additional technical data to support a decision to require or not require SPDs for the variety of electrical applications proposed in past NFPA 70 update cycles (refer to Section 1.2).

4.4.2 *Lightning Stroke Data*

The starting point for this project is to acquire the nationwide lightning stroke data for the continental USA for 2013 (or 2014 if the project starts in 2015). This information can tie back to insurance claim data and possibly provide surge current values for the locations of interest.

4.4.3 *Insurance Information Institute Claim Data*

The Insurance Information Institute is proposed to manage the insurance industry claim data. Their involvement assures that the insurance industry claim reports can remain confidential while allowing access to additional data that might be contained in the claim reports.

The Insurance Information Institute already publishes annual summaries of the number of lightning-related insurance claims and the claim amount. Additional information of interest that might be available in the claim data includes:

- Date and location of surge event (to establish geographical correlations).
- Electronic equipment and appliances damaged.
- Life safety equipment damaged – smoke detectors, CO or CO_2 detectors, or other equipment.
- Fires caused by surge effects.
- Personal injuries associated with the surge event.
- Presence of or lack of installed SPDs.

Life safety equipment damage, fires caused by surge events, and personal injuries are of particular interest for code-making efforts.

Although the annual Insurance Information Institute survey has historically focused on residential claims, the survey for this project should include commercial and industrial claims also. NEMA assistance and direction with this effort will be helpful.

4.4.4 *NEMA Participation*

NEMA Low Voltage Surge Protective Devices Section (5-VS) participation is recommended for the following:

- Assisting with project scope, including commercial and industrial users.

- Reviewing the project checklist for the type of information to be obtained from the insurance industry.
- Reviewing failure data report summaries.
- Considering recommended SPD design principles, including the specification of surge protection in low-lightning flash density areas versus high-lightning flash density areas. Should NFPA elect to require SPDs in dwelling units or other applications, then minimum surge protection current limits should also be addressed, similar to the method provided in NFPA 780. As SPD surge current rating increases (and the degree of protection), the SPD cost also increases.

4.4.5 *Why Not Another Test Program?*

The IEEE paper, *A Field Study of Lightning Surges Propagating Into Residences*, illustrates the difficulty with obtaining real data during surge events. Although this study produced very useful results, it took a 4-year period at 49 homes to obtain data for 18 surge events, of which four surge events caused damage to appliances and electronic equipment. This is considered a typical outcome to be expected. A test program sponsored by the Fire Protection Research Foundation is not recommended.

A

REFERENCES

Appendix A provides a list of references used in the development of this report.

A.1 Industry Standards

IEEE 1100, *Powering and Grounding Electronic Equipment.*

IEEE 1692, *IEEE Guide for the Protection of Communication Installations from Lightning Effects.*

IEEE C62.41.1, *Guide On The Surge Environment In Low-Voltage (1000V And Less) AC Power Circuits.*

IEEE C62.41.2, *Recommended Practice On Characterization Of Surges In Low-Voltage (1000V And Less) AC Power Circuits.*

IEEE C62.45, *Recommended Practice On Surge Testing For Equipment Connected To Low-Voltage (1000V And Less) AC Power Circuits.*

IEEE C62.50, *IEEE Standard for Performance Criteria and Test Methods for Plug-in (Portable) Multiservice (Multiport) Surge-Protective Devices for Equipment Connected to a 120 V/240 V Single Phase Power Service and Metallic Conductive Communication Line(s).*

NFPA 70, *National Electrical Code®*, 2014 Edition.

NFPA 780, *Standard for the Installation of Lightning Protection Systems*, 2014 Edition .

UL 497 series, *Protectors for Fire Alarm Signaling Circuits.*

UL 1283, *Electromagnetic Interference Filters.*

UL 1449, Third Edition, *Surge Protective Devices*, September 29, 2006.

A.2 NFPA Documents

1. *National Electrical Code® Committee Report on Proposals – 2013 Annual Revision Cycle*, National Fire Protection Association, 2012.

2. Marty Ahrens, *Lightning Fires and Lightning Strikes*, National Fire Protection Association, Fire Analysis and Research Division, June 2013.

A.3 IEEE Documents

1. *How to Protect Your House and Its Contents from Lightning, IEEE Guide for Surge Protection of Equipment Connected to AC Power and Communication Circuits*, by Richard L. Cohen and others, ISBN 0-7381-4634-X, 2005.

2. Lightning and Insulator Subcommittee of the T&D Committee, *Parameters of Lightning Strokes: A Review*, IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005.

3. Teru Miyazaki, et al, *A Field Study of Lightning Surges Propagating Into Residences*, IEEE Transactions on Electromagnetic Compatibility, Vol. 52, No. 4, November 2010.

4. Jinliang He, et al, *Evaluation of the Effective Protection Distance of Low-Voltage SPD to Equipment*, IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005.

5. Shozo Sekioka, et al, *Simulation Model for Lightning Overvoltages in Residences Caused by Lightning Strike to the Ground*, IEEE Transactions on Power Delivery, Vol. 25, No. 2, January 2010.

6. Joseph Randolph, *Lightning Surge Damage to Ethernet and POTS Ports Connected to Inside Wiring*, IEEE, 2014.

7. Vladimir A. Rakov, *Direct Lightning Strikes to the Lightning Protective System of a Residential Building: Triggered-Lightning Experiments*, IEEE Transactions on Power Delivery, Vol. 17, No. 2, January 2002.

Note: The IEEE Power & Energy Society sponsors the Surge Protective Devices Committee, which provides information associated with their standards. Refer to http://pes-spdc.org.

A.4 NIST Documents

1. NIST Special Publication 960-6, *Surges Happen! How to Protect the Appliances in Your Home*, 2001.

Note: The NIST website provides many historical documents available in the public domain related to surge protection. Although this information is over 10 years old, it is still useful as a reference source. Refer to http://www.nist.gov/pml/div684/spd.cfm.

A.5 NEMA Documents

1. NEMA 2013 *U.S. Surge Protection Damage Survey*.

2. NEMA *Surge Damage Survey Results – Wave 2*, March 2014.

Note: The NEMA Surge Protection Institute maintains a website devoted to low voltage SPDs. Refer to http://www.nemasurge.org.

A.6 Insurance Industry Documents

1. *Lightning Sparks Concern For Insurance Industry; Homeowners Claims Rise Sharply Over Last Five Years*, Insurance Information Institute, March 2010.

2. *Thunderstruck! Average Lightning Claim Costs Up by 25 Percent, But Number of Claims Continues to Fall*, Insurance Information Institute, June 2013.

3. *Number, Cost of Homeowners Insurance Claims From Lightning Fell In 2013; Dry Conditions, Fewer Powerful Thunderstorms A Contributing Factor*, Insurance Information Institute, June 2014.

4. *Lightning,* Insurance Information Institute, August 2014.

5. *Protect Your Property From Power Surges*, State Farm website.

6. *Guidelines for Providing Surge Protection at Commercial Institutional and Industrial Facilities*, The Hartford Steam Boiler Inspection and Insurance Company.

7. *Approval Standard for Transient Voltage Surge Suppression Devices*, FM Approvals.

A.7 Manufacturer's Documents

1. Emerson Network Power Report SL-30119, *Surge Protection Reference Guide*, November 2011.

A.8 Miscellaneous Documents

1. A. Ametani,, et al, *Surge Voltages and Currents into a Customer due to Nearby Lightning*, International Conference on Power Systems Transients (IPST"07) June 2007.

2. Schneider Electric Data Bulletin DB03A, *Surge Protection: Measured Lightning Stroke Data*.

3. Al Martin, *Lightning Induced GPR, Why it's a problem, characteristics and simulation*, In Compliance, June 2012.

4. Thomas Key, et al, *Update on a Consumer-Oriented Guide for Surge Protection*, Proceedings, PQA'99 Conference, May 1999.

5. François D. Martzloff, et al, *The Role and Stress of Surge-Protective Devices in Sharing Lightning Current*, EMC Europe 2002, September 2002.

6. Arshad Mansoor, et al, *The Dilemma of Surge Protection vs. Overvoltage Scenarios: Implications for Low-Voltage Surge-Protective Devices*, Proceedings, 8th Annual Conference on Harmonics and Quality of Power, October 1998.

7. Air Force Manual 32-1181, *Design Standards for Interior Electrical Systems*.

B

ACRONYMS

Appendix B provides a list of the abbreviations and acronyms used in this report.

EMI – Electromagnetic interference.

FPRF – Fire Protection Research Foundation.

GDT – Gas discharge tube.

GPR – Ground potential rise.

Hz – Hertz.

III – Insurance Information Institute.

kA – Thousands of amperes.

khz – Kilo-hertz.

L–G – Line-to-ground.

L–L – Line-to-line.

MCOV – Maximum continuous operating voltage.

MOV – Metal oxide varistor.

N–G – Neutral-to-ground.

NEMA – National Electrical Manufacturers Association.

NLDN – National Lightning Detection Network.

NFPA – National Fire Protection Association.

NIST – National Institute of Standards and Technology.

pu – Per unit.

SAD – Silicon avalanche diode.

SCCR – Short circuit current rating.

SPD – Surge protective device.

TOV – Temporary overvoltage.

TVSS – Transient voltage surge suppressor (no longer used – replaced by SPD).

UL – Underwriter's Laboratories.

μsec – Micro-second.

VPR – Voltage protection rating.

E7345

Date Submitted	11/20/2018	**Section**	324	**Proponent**	Bryan Holland
Chapter	3	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposed modification updates the requirements for solar energy systems.

Rationale

This proposed modification updates the rules for solar energy systems be completely deleting the current R324 of the FBC-R and replacing with R324 of the 2018 IRC, which represents the most current industry practices and related standards. This update also harmonizes the FBC-R with the NFPA 70, NFPA 1, and NFPA 101 (FFPC) as these rules are already required within those standards.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will not impact the local entity relative to code enforcement as these rules are standard practice for all solar energy installations.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building and property owners as these rules already exist in other applicable codes and standards.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public by updating out-of-date rules for solar energy systems with the most current industry standards and practices.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves and strengthens the code by completely updating the rules related to solar energy systems with those already in practice by industry today.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

~~SECTION 324~~

~~SOLAR ENERGY SYSTEMS~~

~~R324.1 General. Solar energy systems shall comply with the provisions of this section.~~

~~R324.2 Solar thermal systems. Solar thermal systems shall be designed and installed in accordance with Chapter 23 and the Florida Fire Prevention Code.~~

~~R324.3 Photovoltaic systems. Photovoltaic systems shall be designed and installed in accordance with Sections R324.3.1 through R324.6.1 and NFPA 70. Inverters shall be listed and labeled in accordance with UL 1741. Systems connected to the utility grid shall use inverters listed for utility interaction.~~

~~R324.3.1 Equipment listings. Photovoltaic panels and modules shall be listed and labeled in accordance with UL 1703.~~

~~R324.4 Rooftop-mounted photovoltaic systems. Rooftopmounted photovoltaic panel systems installed on or above the roof covering shall be designed and installed in accordance with Section R909.~~

~~R324.4.1 Roof live load. Roof structures that provide support for photovoltaic panel systems shall be designed for applicable roof live load. The design of roof structures need not include roof live load in the areas covered by photovoltaic panel systems. Portions of roof structures not covered by photovoltaic panels shall be designed for roof live load. Roof structures that provide support for photovoltaic panel systems shall be designed for live load, LR, for the load case where the photovoltaic panel system is not present.~~

~~R324.5 Building-integrated photovoltaic systems. Building-integrated photovoltaic systems that serve as roof coverings shall be designed and installed in accordance with Section R905.~~

~~R324.5.1 Photovoltaic shingles. Photovoltaic shingles shall comply with Section R905.16.~~

~~R324.6 Ground-mounted photovoltaic systems. Ground-mounted photovoltaic systems shall be designed and installed in accordance with Section R301.~~

~~R324.6.1 Fire separation distances. Ground-mounted photovoltaic systems shall be subject to the fire separation distance requirements determined by the local jurisdiction.~~

SECTION 324

SOLAR ENERGY SYSTEMS

R324.1 General. Solar energy systems shall comply with the provisions of this section.

R324.2 Solar thermal systems. Solar thermal systems shall be designed and installed in accordance with Chapter 23 and the Florida Fire Prevention Code.

R324.3 Photovoltaic systems. Photovoltaic systems shall be designed and installed in accordance with Sections R324.3.1through R324.7.1, NFPA 70 and the manufacturer's installation instructions.

R324.3.1 Equipment listings. Photovoltaic panels and modules shall be listed and labeled in accordance with UL 1703. Inverters shall be listed and labeled in accordance with UL 1741. Systems connected to the utility grid shall use inverters listed for utility interaction.

R324.4 Rooftop-mounted photovoltaic systems. Rooftop-mounted photovoltaic panel systems installed on or above the roof covering shall be designed and installed in accordance with this section.

R324.4.1 Structural requirements. Rooftop-mounted photovoltaic panel systems shall be designed to structurally support the system and withstand applicable gravity loads in accordance with Chapter 3. The roof on which these systems are installed shall be designed and constructed to support the loads imposed by such systems in accordance with Chapter 8.

R324.4.1.1 Roof load. Portions of roof structures not covered with photovoltaic panel systems shall be designed for dead loads and roof loads in accordance with Sections R301.4 and R301.6. Portions of roof structures covered with photovoltaic panel systems shall be designed for the following load cases:

1. Dead load (including photovoltaic panel weight) plus snow load in accordance with Table R301.2(1).

2. Dead load (excluding photovoltaic panel weight)plus roof live load or snow load, whichever is greater, in accordance with Section R301.6.

R324.4.1.2 Wind load. Rooftop-mounted photovoltaic panel or module systems and their supports shall be designed and installed to resist the component and cladding loads specified in Table R301.2(2), adjusted for height and exposure in accordance with Table R301.2(3).

R324.4.2 Fire classification. Rooftop-mounted photovoltaic panel systems shall have the same fire classification as the roof assembly required in Section R902.

R324.4.3 Roof penetrations. Roof penetrations shall be flashed and sealed in accordance with Chapter 9.

R324.5 Building-integrated photovoltaic systems. Building-integrated photovoltaic systems that serve as roof coverings shall be designed and installed in accordance with Section R905.

R324.5.1 Photovoltaic shingles. Photovoltaic shingles shall comply with Section R905.16.

R324.5.2 Fire classification. Building-integrated photovoltaic systems shall have a fire classification in accordance with Section R902.3.

R324.6 Roof access and pathways. Roof access, pathways and setback requirements shall be provided in accordance with Sections R324.6.1 through R324.6.2.1. Access and minimum spacing shall be required to provide emergency access to the roof, to provide pathways to specific areas of the roof, provide for smoke ventilation opportunity areas, and to provide emergency egress from the roof.

Exceptions:

1. Detached, nonhabitable structures, including but not limited to detached garages, parking shade structures, carports, solar trellises and similar structures, shall not be required to provide roof access.

2. Roof access, pathways and setbacks need not be provided where the code official has determined that rooftop operations will not be employed.

3. These requirements shall not apply to roofs with slopes of two units vertical in 12 units horizontal (17-percent slope) or less.

R324.6.1 Pathways. Not fewer than two pathways, on separate roof planes from lowest roof edge to ridge and not less than 36 inches (914 mm) wide, shall be provided on all buildings. Not fewer than one pathway shall be provided on the street or driveway side of the roof. For each roof plane with a photovoltaic array, a pathway not less than 36 inches wide (914 mm) shall be provided from the lowest roof edge to ridge on the same roof plane as the photovoltaic array, on an adjacent roof plane, or straddling the same and adjacent roof planes. Pathways shall be over areas capable of supporting fire fighters accessing the roof. Pathways shall be located in areas with minimal obstructions such as vent pipes, conduit, or mechanical equipment.

R324.6.2 Setback at ridge. For photovoltaic arrays occupying not more than 33 percent of the plan view total roof area, not less than an 18-inch (457 mm) clear setback is required on both sides of a horizontal ridge. For photovoltaic arrays occupying more than 33 percent of the plan view total roof area, not less than a 36-inch (914 mm) clear setback is required on both sides of a horizontal ridge.

R324.6.2.1 Alternative setback at ridge. Where an automatic sprinkler system is installed within the dwelling in accordance with NFPA 13D or Section P2904, setbacks at ridges shall comply with one of the following:

1. For photovoltaic arrays occupying not more than 66 percent of the plan view total roof area, not less than an 18-inch (457 mm) clear setback is required on both sides of a horizontal ridge.

2. For photovoltaic arrays occupying more than 66 percent of the plan view total roof area, not less than a 36-inch (914 mm) clear setback is required on both sides of a horizontal ridge.

R324.6.2.2 Emergency escape and rescue opening. Panels and modules installed on dwellings shall not be placed on the portion of a roof that is below an emergency escape and rescue opening. A pathway not less than 36 inches (914 mm) wide shall be provided to the emergency escape and rescue opening.

R324.7 Ground-mounted photovoltaic systems. Ground-mounted photovoltaic systems shall be designed and installed in accordance with Section R301.

R324.7.1 Fire separation distances. Ground-mounted photovoltaic systems shall be subject to the fire separation distance requirements determined by the local jurisdiction.

E7350

Date Submitted	11/20/2018	**Section**	329	**Proponent**	Bryan Holland
Chapter	3	**Affects HVHZ**	No	**Attachments**	No
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **No** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposed modification adds a new section on Stationary Storage Battery Systems to the code.

Rationale

This proposed modification does not mandate that ESS or stationary storage battery systems be installed, but rather includes basic safety requirements that should be applied if such systems are to be installed and used. The proposed rules are harmonized with an correlate to the applicable provisions of the NFPA 70, NFPA 855, related UL product safety standards, and the FFPC (NFPA 1, NFPA 101).

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will not impact the local entity relative to code enforcement.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will not change the cost of compliance to building and property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact industry.

Impact to small business relative to the cost of compliance with code

This proposed modification will not change the cost of compliance or impact small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification is directly connected to the health, safety, and welfare of the general public by including life, fire, and property safety requirements to the code when an ESS or battery systems is elected to be installed.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves and strengthens the code by providing rules for an emerging and growing industry.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

SECTION R328

STATIONARY STORAGE BATTERY SYSTEMS

R328.1 General. Stationary storage battery system shall comply with the provisions of this section.

R328.2 Equipment listings. Stationary storage battery systems shall be listed and labeled for residential use in accordance with UL 9540.

Exceptions:

1. Where approved, repurposed unlisted battery systems from electric vehicles are allowed to be installed outdoors or in detached sheds located not less than 5 feet (1524 mm) from exterior walls, property lines and public ways.

2. Battery systems that are an integral part of an electric vehicle are allowed provided that the installation complies with Section 625.48 of NFPA 70.

3. Battery systems less than 1 kWh (3.6 megajoules).

R328.3 Installation. Stationary storage battery systems shall be installed in accordance with the manufacturer's instructions and their listing, if applicable, and shall not be installed within the habitable space of a dwelling unit.

R328.4 Electrical installation. Stationary storage battery systems shall be installed in accordance with NFPA 70. Inverters shall be listed and labeled in accordance with UL 1741 or provided as part of the UL 9540 listing. Systems connected to the utility grid shall use inverters listed for utility interaction.

R328.5 Ventilation. Indoor installations of stationary storage battery systems that include batteries that produce hydrogen or other flammable gases during charging shall be provided with ventilation in accordance with Section M1307.4.

E7645

Date Submitted	12/3/2018	**Section**	324	**Proponent**	John Hall
Chapter	3	**Affects HVHZ**	No	**Attachments**	Yes
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **Yes** | **Alternate Language** **No**

Related Modifications

The location and numbering of this modification will be dependent upon any action taken on modification #7475.

Summary of Modification

The modification provides for solar ready features to facilitate the instalation of solar PV and solar thermal systems without resort to destructive methods.

Rationale

Solar photovoltaic and solar thermal systems are becoming more cost competitive in the marketplace. Adoption of this technology has many societal benefits. A serious hindrance to the adoption of solar technology is the destructive means required to install them on existing structures. This mod seeks to overcome this hindrance.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

There will be no cost impact relative to enforcement of the code due to this proposed modification. The inspection activity will be performed during already required inspections that are regularly scheduled.

Impact to building and property owners relative to cost of compliance with code

There will be a cost impact to building and property owners for compliance. The requirements are minimal and the associated cost is negligible.

Impact to industry relative to the cost of compliance with code

There will be no cost impact to industry for compliance. The modification is only applicable to one- and two-family dwellings and townhouses.

Impact to small business relative to the cost of compliance with code

There will be no cost impact to small business for compliance. The modification is only applicable to one- and two-family dwellings and townhouses.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The proposed modification has a reasonable and substantial connection with the health, safety, and welfare of the general public by fostering adoption of solar technology that will reduce harmful emissions from use of fossil fuels.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The proposed modification improves the code by making provision for non-destructive installation of solar systems on existing structures.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The proposed modification does not discriminate against any materials, products, methods, or systems of construction as none are specified. The modification allows use of any existing code approved methods and materials for compliance.

Does not degrade the effectiveness of the code

The proposed modification does not degrade the effectiveness of the code. The implementation of the code is enhanced through the provision of features that simplify addition of solar systems to existing structures.

1st Comment Period History

E7645-G1

Proponent	Stevie Freeman-Monte	**Submitted**	1/29/2019	**Attachments**	No

Comment:

I support this proposed code modification.

SECTION 324

SOLAR ENERGY SYSTEMS

R324.1 General. Solar energy systems shall comply with the provisions of this section.

R324.2 Solar thermal systems. Solar thermal systems shall be designed and installed in accordance with Chapter 23 and the *Florida Fire Prevention Code.*

R324.3 Photovoltaic systems. Photovoltaic systems shall be designed and installed in accordance with Sections R324.3.1 through R324.7.1, NFPA 70 and the manufacturer's installation instructions.

R324.3.1 Equipment listings. Photovoltaic panels and modules shall be listed and labeled in accordance with UL 1703. Inverters shall be *listed* and *labeled* in accordance with UL 1741. Systems connected to the utility grid shall use inverters *listed* for utility interaction.

R324.4 Rooftop-mounted photovoltaic systems. Rooftop-mounted *photovoltaic panel systems* installed on or above the roof covering shall be designed and installed in accordance with this section.

R324.4.1 Structural requirements. Rooftop-mounted *photovoltaic panel systems* shall be designed to structurally support the system and withstand applicable gravity loads in accordance with Chapter 3. The roof on which these systems are installed shall be designed and constructed to support loads imposed by such systems in accordance with Chapter 8.

R324.5 Building-integrated photovoltaic systems. Building-integrated photovoltaic systems that serve as roof coverings shall be designed and installed in accordance with Section R905.

R324.5.1 Photovoltaic shingles. Photovoltaic shingles shall comply with Section R905.16.

R324.5.2 Fire Classification. *Building-integrated photovoltaic systems* shall have a fire classification in accordance with Section R902.3.

R324.6 Ground-mounted photovoltaic systems. Groundmounted photovoltaic systems shall be designed and installed in accordance with Section R301.

R324.6.1 Fire separation distances.

Ground-mounted photovoltaic systems shall be subject to the *fire separation distance* requirements determined by the local *jurisdiction*.

<u>**R324.7 Solar-ready zone.** New detached one- and two-family dwellings, and townhouses with not less than 600 square feet (55.74 m2) of roof area oriented between 90 degrees and 270 degrees of true north shall comply with Sections R324.9 through R324.17.</u>

<u>**Exceptions:**</u>

New residential buildings with a permanently installed on-site renewable energy system.

A building where all areas of the roof that would otherwise meet the requirements of Section R324.8 are in full or partial shade for more than 70 percent of daylight hours annually.

Solar-ready zone. A section or sections of the roof or building overhang designated and reserved for the future installation of a solar photovoltaic or solar thermal system.

R324.7.1 Construction document requirements for solar ready zone. Construction documents shall indicate the solar-ready zone.

R324.7.2 Solar-ready zone area. The total solar ready zone area shall be not less than 300 square feet (27.87m2) exclusive of mandatory access or set back areas as required by the *Florida Fire Prevention Code*. New townhouses three stories or less in height above grade plane shall have a solar-ready zone area of not less than 150 square feet (13.94 m2). The solar-ready zone shall be composed of areas not less than 5 feet (1524 mm) in width and not less than 80 square feet (7.44 m2) exclusive of access or set back areas as required by the *Florida Fire Prevention Code*.

R324.7.3 Obstructions. Solar-ready zones shall be free from obstructions, including but not limited to vents, chimneys, and roof-mounted equipment.

R324.7.4 Shading. The solar-ready zone shall be set back from any existing or new, permanently affixed object on the building or site that is located south, east or west of the solar zone a distance not less than two times the object's height above the nearest point on the roof surface. Such objects include, but are not limited to, taller portions of the building itself, parapets, chimneys, antennas, signage, rooftop equipment, trees and roof plantings.

R324.7.5 Capped roof penetration sleeve. A capped roof penetration sleeve shall be provided adjacent to a solar-ready zone. The capped roof penetration sleeve shall be sized to accommodate the future photovoltaic system conduit, but shall have an inside diameter of not less than 11/4 inches (32 mm).

R324.7.6 Roof load documentation. The structural design loads for roof dead load and roof live load shall be clearly indicated on the construction documents.

R324.7.7 Interconnection pathway. Construction documents shall indicate pathways for routing of conduit or plumbing from the solar-ready zone to the electrical service panel or service hot water system.

R324.7.8 Electrical service reserved space. The main electrical service panel shall have a reserved space to allow installation of a dual pole circuit breaker for future solar electric installation and shall be labeled "For Future Solar Electric." The reserved space shall be positioned at the opposite (load) end from the input feeder location or main circuit breaker location.

> **Exception.** A listed enclosure on the supply side of the electrical service main disconnecting means providing access for future interconnection of a solar photovoltaic power production source shall be permitted. The listed enclosure shall be labeled "For Future Solar Electric." The label shall comply with NFPA 70 110.21(B).

R324.7.9 Construction documentation certificate. A permanent certificate, indicating the solar-ready zone and other requirements of this section, shall be posted near the electrical distribution panel, water heater or other conspicuous location by the builder or registered design professional.

Fiscal Impact Assumptions Mod 7645

1. Electrical inspections will be required during the course of construction of a new dwelling. The inspections required by this modification will be performed during the regularly scheduled rough inspection.
2. The modification will result in negligible cost to the owner. The modification requires only three physical items to be installed, a capped roof penetration sleeve of a minimum inside diameter of 1.25 inches, a two pole space in the electrical panel, and labels indicating the location of the solar ready roof zone and the electrical panel space or supply side enclosure if provided.
3. The space in the electrical panel can be substituted with a listed enclosure on the supply side of the service main disconnecting means. This option would eliminate the need for additional space in the electrical panel.
4. All remaining requirements are for location of items to allow clear space on the roof for the system.

LUND UNIVERSITY

Residential solar photovoltaics deployment: barriers and drivers in space

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List of abbreviations:

IRR = Internal rate of return

PPA = Power purchase agreement

PV = (Solar) photovoltaics

TGC = tradable green certificates

TIS = Technological innovation system

TPO = Third-party ownership

Keywords: Solar photovoltaics (PV), renewable energy, sustainability transitions, technology deployment, diffusion of innovations, barriers, drivers, space, technological innovation system (TIS), technology adoption, business model, peer effects

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Abstract

In order to support a sustainability transition in the energy sector, actors need knowledge about barriers and drivers to the deployment of clean energy technologies. Solar photovoltaics (PV) is a renewable energy technology that is technically mature and on the verge of becoming economically competitive in numerous regions around the world. Not least in the residential segment, PV has considerable potential. Even after residential PV has reached economic competitiveness, however, the technology might still face important barriers in the sociotechnical system in which it is to be deployed.

This thesis aims at adding knowledge about barriers and drivers to the deployment of residential PV systems. The research takes a sociotechnical systems perspective and demonstrates how the *technological innovation systems* (TIS) framework can be amended by the *business models* and the *diffusion of innovations* frameworks to study the deployment of a mature technology in a catching-up market, treating technology development and production as a 'black box'. The research is largely based on case studies and uses various modes of data collection and analysis. The bulk of the research was performed in Swedish settings on the national and local levels, although the United States, Germany and Japan were also studied. Studying these different contexts, the thesis builds knowledge about barriers and drivers on different spatial scales. The researched focused on the period between 2009 and 2014.

The results highlight various barriers and drivers in the studied contexts. On the national level, the Swedish sociotechnical system for PV deployment has been immature and infested by various institutional barriers. Swedish subsidies for PV deployment have been flawed with uncertainties, complexities and discontinuations, and there have been important uncertainties regarding the future development of the institutional set-up. The results also demonstrate how barriers in different national contexts have been decisive for what kinds of business models for PV deployment that have been viable. On the local level in Sweden, the results show how actors such as local electric utilities and private individuals have influenced homeowners to adopt PV through information dissemination and social influence (peer effects). The results can inform policymakers, firms and other actors as to how to support PV deployment.

Populärvetenskaplig sammanfattning

Klimatförändringarna är en av vår tids största utmaningar. För att utsläppen av koldioxid ska minska behöver teknologier för förnybar energi snabbt ersätta energi baserad på fossila bränslen. För att olika aktörer – såsom lagstiftare, företag, ideella organisationer och privatpersoner – ska kunna stödja en sådan omställning behövs kunskap om olika hinder och drivkrafter som motverkar respektive främjar (eller skulle kunna främja) spridningen av teknologi för förnybar energi.

Denna avhandling handlar om spridning av *solceller*. Avhandlingens mål är att identifiera och utvärdera hinder och drivkrafter som påverkar hur mycket solceller som installeras. Fokus ligger främst på solcellsanläggningar för privatpersoner i Sverige, vilket i regel innebär solceller placerade på villatak. Trots Sveriges geografiska läge på förhållandevis solfattiga breddgrader finns god potential för användning av solceller även i Sverige. Avhandlingen tar ett sociotekniskt systemperspektiv och analyserar samtida hinder och drivkrafter relaterade till regelverk, styrmedel, affärsmodeller, social påverkan och ekonomi. En rad fallstudier genomfördes, och data samlades in genom bland annat enkäter och intervjuer med nyckelaktörer. Genom fallstudier fokuserade på såväl det nationella som det lokala planet bygger avhandlingen kunskap om hinder och drivkrafter på olika geografiska nivåer.

Arbetet genomfördes som fyra delstudier, vilka har publicerats (eller ska publiceras) i vetenskapliga tidskrifter. Den första delstudien tog ett helhetsperspektiv på hinder och drivkrafter på nationell nivå i Sverige. Analysen återger ett underutvecklat sociotekniskt system för byggnadsanknutna solceller i Sverige och pekar på en rad problem vad gäller den institutionella stabiliteten. Brister i de ekonomiska styrmedlen har medfört osäkerheter och försämrad investeringsvilja inom installatörsbranschen samt en lång kö för privatpersoner att få ansökningar om bidrag beviljade. Stora osäkerheter har rått vad gäller den framtida utformningen av styrmedel och skatteregler. I vissa fall har det varit oklart hur befintliga regler ska tillämpas då dessa inte varit anpassade för mikroproduktion av elektricitet utan utvecklats för centraliserad storskalig elproduktion.

I den andra delstudien analyserades olika typer av affärsmodeller som nått framgång på tre stora solcellsmarknader (USA, Tyskland och Japan). En affärsmodell är det sätt på vilket företag skapar värde åt sig själva och sina kunder. Studien gick ut på att identifiera faktorer som skiljer sig åt mellan marknaderna och som skulle kunna förklara varför en viss affärsmodell nått framgång på en marknad men inte på en annan. De studerade marknaderna skiljer sig åt markant vad gäller vilka typer av affärsmodeller som nått framgång. Till exempel har leasing av solcellssystem varit mycket populärt i USA men nästintill obefintligt i Tyskland och Japan. Resultaten visade på att faktorer som husägares tillgång till kapital, sparkvoter, flyttmönster, egenskaper hos den nationella byggsektorn samt utformning av bidragssystem kan ha ett stort förklaringsvärde. Resultaten kan användas för att stödja spridning av solceller i Sverige och annorstädes, t.ex. genom att informera lagstiftare om hur institutionella hinder mot vissa typer av affärsmodeller kan avlägsnas, eller genom att informera entreprenörer om hur affärsmodeller kan anpassas för olika nationella kontexter.

Den tredje delstudien gick ut på att förklara skillnader i antalet solcellsinstallationer per capita mellan svenska kommuner. Intervjuer med lokala aktörer samt en enkät skickad till personer som skaffat solceller användes för att identifiera lokala faktorer i fem kommuner med särskilt hög solcellstäthet (antal installationer per capita). Resultaten pekar på att den troligen enskilt viktigaste förklaringen till den höga solcellstätheten i de studerade kommunerna är att lokala aktörer aktivt främjat solceller. Framförallt verkar lokala elnätsbolag som marknadsfört och spridit information kring solceller ha haft en stor effekt.

Den fjärde delstudien handlade om social påverkan mellan privatpersoner. En rad utländska studier har tidigare visat att varje ny solcellsinstallation ökar sannolikheten för ytterligare installationer i dess absoluta närhet, vilket indikerar att grannar påverkar varandra att skaffa solceller. Kunskapen om *hur* denna påverkan gått till har dock varit låg. En enkät skickades till solcellsägare, och uppföljande intervjuer genomfördes med utvalda respondenter. Resultaten tydde på att påverkan främst skett genom förhållandevis nära sociala nätverk (mellan släkt och vänner snarare än mellan grannar utan någon närmare relation), samt att den information som förmedlats och som ansetts viktig främst varit en *bekräftelse* på att anläggningen är enkel att använda, levererar elektricitet som förväntat och är driftsäker, samt att inga obehagliga överraskningar är att vänta. Kontakt mellan privatpersoner har således fungerat som ett komplement till professionell rådgivning, där solcellsägande privatpersoner förmedlat en trygghet som ökat deltagarnas benägenhet att skaffa solceller trots att de saknat proffsens detaljkunskaper.

I sin helhet visar avhandlingen på en rad viktiga hinder och drivkrafter för spridning av solceller. Dessa hinder och drivkrafter kopplar till såväl nationella styrmedel och regelverk som till lokala informationsinsatser och social påverkan. Genom att öka kunskaperna om hinder och drivkrafter på olika geografiska nivåer bidrar avhandlingen till bättre förutsättningar för olika aktörer att underlätta spridning av solceller.

List of papers

This thesis is based on the following four research papers (articles). The full papers can be found at the end of the thesis.

Paper 1:

Palm, A., 2015. An emerging innovation system for deployment of building-sited solar photovoltaics in Sweden. Environmental Innovation and Societal Transitions 15, 140-157.

Paper 2:

Strupeit, L., Palm, A., 2016. Overcoming barriers to renewable energy diffusion: business models for customer-sited solar photovoltaics in Japan, Germany and the United States. Journal of Cleaner Production 123, 124-136.

This paper was produced by my colleague Lars Strupeit and me in close collaboration. As regards research design, the credit goes mainly to Lars. Data collection was split between us, with me responsible for one case (Japan) and Lars for the other two cases. The literature review, data analysis and writing were performed by the two of us in close collaboration.

Paper 3:

Palm, A., 2016. Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market. Energy Research & Social Science 14, 1-12.

Paper 4:

Palm, A., 2016. Peer effects in residential solar photovoltaics adoption – a mixed methods study of Swedish users. Submitted to Energy Research & Social Science.

Content

1. Introduction

To cope with the challenge of climate change, the need for a transition to a low-carbon energy system is urgent (IPCC, 2014). Such a transition is likely to not only involve the introduction of new energy technologies, but also changes of a more social character, involving institutions, consumption behaviour, knowledge and business models (Geels, 2002; Grübler, 2003; IPCC, 2014; Kemp et al., 1998). Sociotechnical transitions of this kind have occurred several times throughout history in different sectors, but they normally take decades (Grübler, 1996), not only because of the time required to develop and refine new technological artefacts, but also because of various barriers in the sociotechnical environment in which the technology is to be deployed. Not least in the energy sector, such barriers are often severe (Unruh, 2000).

Common barriers to the dissemination of new technology include high costs, technical flaws and poor compatibility with existing infrastructure (Geels, 2002; Grübler, 1996; Kemp et al., 1998). Key reasons that new technology tends to be expensive are that production typically takes place on a relatively small scale, and that processes of learning regarding efficient production are yet to occur (Grübler, 2003; Kemp and Soete, 1992). Long periods of experimentation and learning are typically required to bring down costs and refine the performance of a new technology (Grübler, 2012; Kemp and Soete, 1992; Rosenberg, 1994).

Even after a new technology has reached economic and technical competitiveness, important barriers of a more social character typically remain, obstructing deployment of the technology. Organisational and institutional support for new energy technologies is often lacking, while existing (competing) technologies have built up such support over a long period (Bergek et al., 2008a; Geels, 2002; Grübler, 2012; Hekkert et al., 2007; Unruh, 2000). Existing institutions are often poorly aligned to new, radical innovations as the institutions were often adapted for another technological regime, and incumbent companies with vested interests in preserving the status quo will often use their (superior) financial resources and networks to hold new competitors back, e.g. through lobbying (Unruh, 2000). Besides, consumers tend to be somewhat suspicious of new technologies, and complexities and uncertainties (perceived or real, technical or institutional) can often deter potential adopters (Kemp et al., 1998; Rogers, 1983).

There is also an important spatial dimension to the dissemination of innovations. Understanding the preconditions for a transition requires an understanding of how different phenomena relate to geographical places and scales (Coenen et al., 2012; Hansen and Coenen, 2015). The spatial dimension of sustainability transitions has, nevertheless, remained underexplored (Coenen et al., 2012; Hansen and Coenen, 2015). For example, local aspects related to consumers and market formation have only been sporadically considered in the transitions literature (Hansen and Coenen, 2015).

There are various strategies that different actors can use to facilitate a transition. Various policy interventions can be used, based on economic instruments, regulatory approaches or information dissemination (IPCC, 2014). Firms can develop innovative business models that fit certain characteristics of a new technology (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013). Information campaigns and lobbying can be run by non-profit organisations or others. Individuals can influence each other through social networks. Such activities can make a new technology disseminate more quickly. To enable different actors to facilitate a transition in an informed manner, a thorough understanding of the sociotechnical system in which the technology is to be deployed is needed.

This thesis is about the deployment of one specific renewable energy technology, namely *solar photovoltaics* (PV). The aim is to identify and assess *barriers* and *drivers* that obstruct and facilitate PV deployment. The thesis takes the *spatial* dimension into consideration, recognising that geographical place and scale might matter in different ways for different barriers and drivers. The scope is limited to the residential sector, i.e. to PV systems situated on the premises of private homeowners. Only grid-connected applications are considered. The thesis adopts a systemic, sociotechnical view of technology deployment, recognising that deployment depends on an interplay between aspects such as institutions, perceptions, social influence, economy infrastructure and artefacts (Bergek et al., 2008a; Geels, 2002; Grübler, 2003; Hekkert et al., 2007; Hughes, 1993; Markard et al., 2012; Unruh, 2000).

The research behind the thesis has been presented to the research community in four papers. Three of them have been published in different peer-reviewed academic journals, and the fourth is under revision. The papers are summarised one by one in section 3, and the full papers are provided as appendices.

Box 1. Background: PV technology

What is a PV system?

A PV system consists of a number of PV modules and any necessary mounting device, wiring, power inverters etc. Each module consists of a series of solar cells encapsulated into a weather-resistant shell with a transparent surface. PV systems take advantage of the photovoltaic effect, which occurs as the semiconductive material of solar cells is exposed to sunlight.

PV development and dissemination: a brief history

After its invention in the mid-1900s, PV technology found its first significant commercial market in the space industry, where the then high cost of PV was of minor concern. Subsequent niche markets include pocket calculators, early mobile phones, remote transmission stations, parking meters and holiday cottages. As a result of cost reductions and subsidies, the residential rooftop segment gained relevance in the 1990s. Global PV installations came to be dominated by a handful of countries with ambitious subsidy schemes, including Japan, Germany and the United States. In the most recent years, the global PV market has become increasingly geographically diverse.

Technical benefits and challenges of PV

Rooftop PV systems allow adopters to produce and use their own electricity. As the production is close to the user, transmission losses are kept at a minimum. PV technology is highly modular, and PV can feasibly be applied on vastly different scales (from pocket calculators to ground-mounted solar parks). A challenge of PV is intermittency (electricity is produced only when the sun shines), and an increasing share of PV in the power systems might eventually increase the need for load management.

The efficiency of most commercial PV modules in converting solar energy into electricity is around 15%, a figure that has gradually increased from around 6% in the earliest years of PV technology. This figure might not appear too impressive at first glance, but, considering the large amounts of solar energy entering the Earth, it is more than enough from a technical perspective. The global technical potential for electricity generation is several times larger for PV than for biomass or wind power (de Vries et al., 2007).

Although solar cells can be made from a variety of different materials, the world market has been dominated by cells made of silicon, which is the Earth's second most abundant element. The lifecycle greenhouse gas emissions and other externalities of PV systems are normally small in comparison to fossil fuel based electricity generation systems. The energy payback time of silicon-based PV systems under average United States and Southern European conditions is typically around two to three years (Fthenakis and Kim, 2011), and the lifetime of PV modules can be assumed to be 25 years or more (Bazilian et al., 2013).

1.1. PV deployment: barriers, drivers and space – previous knowledge and gaps in the literature

1.1.1. Barriers and drivers to PV deployment

Residential PV deployment faces substantial challenges, including issues that are general to the deployment of new technologies as well as issues that are more specific to PV, the electricity system and the built environment. While barriers are present throughout the PV value chain, this thesis focuses on barriers at work in the *deployment* phase. Deployment is defined here as the process of putting the technology into use, involving activities occurring at and around the very end of the value chain (see section 1.3 for a more detailed definition).

From a purely technical point of view, PV has been a rather mature technology for decades, performing well in various applications (Jacobsson et al., 2004). However, PV is a radical innovation in the context of national electricity systems and the built environment (Awerbuch, 2000; Schleicher-Tappeser, 2012). Compared to established electricity generation technologies, PV is a disruptive technology as it (a) can be distributed at many points in the electrical grid rather than concentrated to a few large plants, (b) can be located at the user side of the electricity meter, and (c) produces electricity intermittently (only when the sun shines). As a radical technology that requires compatibility with other systems, PV can be expected to face substantial challenges regarding compatibility with existing institutions, practices and infrastructures when deployed in a new context (cf. Kemp et al., 1998). Although there is a fair amount of literature on barriers and drivers to PV deployment, there are various relevant research gaps, of which this thesis addresses a few.

Historically, high costs of PV-generated electricity compared to electricity bought from the grid have been a dominant barrier to residential PV and other grid-connected PV applications (Arvizu et al., 2011; Jacobsson et al., 2004). Only recently have costs of PV technology become low enough for PV to compete in grid-connected applications without subsidies. These cost reductions have largely been the result of learning and economies of scale in the production of solar cells, including input materials (Candelise et al., 2013; de La Tour et al., 2013; Jacobsson et al., 2004; Neij, 2008; Nemet, 2006; Zheng and Kammen, 2014). However, this thesis mainly studies a context (Sweden) in which limited economic profitability has remained a substantial barrier.

To overcome the cost barrier, subsidies to deployment have been a common strategy and an important driver. However, not only the sheer size of subsidies is important, but also various other design aspects. For example, the remuneration can be based on the electricity production, total cost or installed capacity of a PV system, creating somewhat different incentive structures (Haas, 2003). Regardless of which strategy is chosen, the literature stresses the importance of keeping subsidies predictable (to reduce uncertainty), user-friendly (to reduce complexity) and dynamic (to be adaptable to external changes). It is crucial to keep the economic profitability (measured for example as the *internal rate of return*, IRR) of investing in a PV system predictable. Remuneration levels should thus be continuously monitored and adapted to changing prices of PV systems (Haas, 2004, 2003; Sandén, 2005). Throughout Europe, insufficient guarantees regarding the continuation of subsidies have been a common problem (Dusonchet and Telaretti, 2010). The potential of subsidies for PV adoption to drive down costs of PV technology has also been stressed, as the subsidies provide the industry with a market in which it can sell its products and thus learn how to produce and deploy PV more efficiently (Jacobsson et al., 2004; Sandén, 2005). There has, however, been a large variation in how subsidies for PV deployment have actually been designed.

An economic barrier that is particularly tangible for PV is the relatively high *upfront* cost. That is, the total lifecycle cost of PV systems is typically highly concentrated to the initial investment. The 'fuel' is free and maintenance costs are low, and although a PV system might be a beneficial long-term investment, prospective adopters might not be able to purchase a PV system due to difficulties in raising the necessary capital (Rosoff and Sinclair, 2009; Yang, 2010). This issue can also deter potential adopters that use a high (explicit or implicit) discount rate.

As costs of PV systems have decreased over time, other barriers than poor economic profitability have gained in relative importance. For example, various complexities and uncertainties (institutional, financial, technical) will often deter potential PV adopters (Karteris and Papadopoulos, 2012; Rai et al., 2016; Rosoff and Sinclair, 2009; Shih and Chou, 2011; Simpson and Clifton, 2015). Examples of specific institutional barriers to PV deployment that have been pinpointed in the literature are a lack of reliable installer certification and standards for technical components and grid-connection (Shrimali and Jenner, 2013; Simpson and Clifton, 2015; Zhang et al., 2015), and long turnaround times and high fees in permitting (Dong and Wiser, 2013; Li and Yi, 2014). Incumbent actors in the electricity sector that have seen their revenues being threatened by the dissemination of residential PV have often tried to influence institutions to counteract PV dissemination, with some (albeit limited) success (Hess, 2016).

Barriers to PV deployment may often be rooted in the electricity and housing systems. Barriers to new technologies tend to be most severe for "systemic technologies that require change in the outside world" (Kemp et al., 1998). For PV to achieve compatibility with buildings and electricity systems, technical and institutional change in these systems might be required. Housing and energy are also typically highly regulated, meaning that various legislative barriers might be present (cf. Unruh, 2000). Systems for electricity generation and distribution can be understood as 'large technical systems' of high complexity and inertia (Hughes, 1993). In such systems, existing institutions and infrastructures often interact to obstruct the deployment of new technologies. Legislation and other institutions in the electricity sector have typically been adapted for a technological regime (cf. Geels, 2002) of centralised large-scale facilities (Unruh, 2000). Current energy systems can be understood as being in a state of 'carbon lock-in' caused by "technological and institutional co-evolution driven by path-dependent increasing returns to scale" (Unruh, 2000), impeding radical innovation in the energy sector and conserving the status quo. Furthermore, technological change is typically slower in sectors of long-lived structures (Grübler, 1996). Only rarely does new energy technology replace existing technology through the premature retiring of existing capital stock; thus, the longevity of plants and infrastructures in incumbent energy systems holds back the dissemination of new energy technologies (Grübler, 2012).

In understanding barriers and drivers to PV deployment, it is important to understand the motives for adopting a residential PV system. In developed countries, motives have mainly related to electricity bill savings, reduced environmental impact, energy independence and a general interest in new technology (Rai et al., 2016; Schelly, 2014; Zhai and Williams, 2012). In markets where PV adoption has been a poor economic investment, concern for the environment and an interest in the technology have often been important driving forces for those few adopting PV (e.g. Palm and Tengvard, 2011).

It is recognised that business model innovation (the development of new business models or the adaptation of existing ones) could serve to overcome certain barriers to PV deployment. For example, third-party ownership (TPO) business models can address the high upfront cost of PV systems, bureaucratic hassle and concerns related to operation and maintenance (Overholm, 2015). Research on how different business models for PV deployment relate to different contextual factors has, however, been scarce.

1.1.2. The spatial dimension of PV deployment

Barriers and drivers to PV deployment can be rooted in different places and extend over different geographical scales. The production of PV system components has mainly taken place in other parts of the world than where the technology has been deployed (Huang et al., 2016; Quitzow, 2015), and the part of the value chain where development and production occur has been more global by nature than have processes of deployment. Processes occurring 'upstream' in the PV value chain, such as silicon purification and wafer production, are technologically advanced and take place in a global arena. In this part of the value chain, skilled staff has been recruited from around the world and production equipment and produced goods have been traded internationally (de la Tour et al., 2011; Huang et al., 2016). The development of institutions governing the global PV industry has been shaped by an interplay between governments and firms across national borders (Bohnsack et al., 2016). Although the actual production of PV system components and input materials has been concentrated to certain places, the sociotechnical system for the generation of PV system components has thus been rather global by nature. At the subsequent steps down the value chain too, solar cells and modules are traded globally nearly as commodities. As a consequence, cost reduction and technological improvements of PV system components have been globally pervasive, thus directly reducing barriers to PV deployment around the world.

PV deployment is an inherently more local process. Installations must be performed on-site, and the geographical focus of the actors involved typically range from the local to the national scale. Deployment in any given place is typically strongly dependent on formal institutions applying to a limited geographical area (Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015), including subsidies, tax rules, building permits and rules for grid-connection.

The cost and technical performance of PV technology have thus been determined to a great extent by factors beyond the deployment context, operating at other geographical places and scales.

Although PV system installation is in itself a rather straightforward procedure, PV deployment is a complex and systemic procedure involving interaction between various actors, institutions and artefacts (Quitzow, 2015). PV deployment and production could indeed be understood as being different sociotechnical systems with different spatial characteristics, interconnected through certain linkages (cf. Bergek et al., 2015; Markard et al., 2015; Quitzow, 2015; Sandén et al., 2008). For small national deployment markets, the global PV industry could be seen as an 'external force' (cf. Sandén et al., 2008). Deployment could thus be characterised as taking place in sociotechnical 'sub-systems' (national or regional PV markets) to a global sociotechnical system for PV technology. The geographical reach of these sub-systems is presumably defined to a great extent by national borders, as the nation state is a natural upholder and enforcer of formal institutions. Although the aggregate of these sub-systems is what fuels (and is fuelled by) the global production system for PV system components, the individual sub-systems are often too small to substantially influence the global system (a counterexample is the domination of the German PV market on global demand in the early 2000s (Quitzow, 2015)).

Conventional methods for analysing technological transitions have suffered from a lack of attention to geographical aspects of the kinds described above (Coenen et al., 2012; Raven et al., 2012). The most widely used sociotechnical system approaches to understanding sustainability transitions are *technological innovation systems* (TIS) and the *multi-level perspective* (MLP) (Coenen et al., 2012; Coenen and Díaz López, 2010; Markard et al., 2012; Markard and Truffer, 2008; Weber and Rohracher, 2012). These approaches have been developed and conventionally applied to consider processes of technology development and deployment together as belonging to one and the same system. However, neither of them has been very explicit on how to deal with spatial division of labour of the kind occurring in the PV value chain (Coenen et al., 2012), although some development has occurred in this regard in parallel to the work with this thesis (Hansen and Coenen, 2015).

As stated, PV technology is mature regarding technical performance, and is reaching cost competitiveness in an increasing number of regions. Meanwhile, there are numerous potential national and regional markets around the world where PV penetration is (still) very low. These markets can be seen as potential catching-up markets, into which PV technology could be imported and deployed relatively swiftly if their internal barriers to deployment are not too severe. The potential global aggregate for PV uptake in such markets is huge, and it is thus important to understand barriers and drivers to deployment in these markets. Research on barriers and drivers to PV deployment in catching-up markets has, however, been scarce.

Various factors of a more local nature have been found to influence PV adoption rates, such as local variations in solar insolation, electricity prices (Kwan, 2012) and rules and procedures for permits, grants and grid-connection (Brudermann et al., 2013; Dong and Wiser, 2013). There is also some evidence that local organisations can overcome barriers to deployment by promoting PV through campaigns, information provision, lobbying or demonstration projects (Brudermann et al., 2013; Dewald and Truffer, 2012; Noll et al., 2014; Owen et al., 2014). As argued by Noll et al. (2014), such local initiatives are likely to have the largest impact on PV adoption rates if residential PV adoption is neither highly profitable nor clearly unprofitable. As financial aspects are neither the dominant driver nor a major barrier in such situations, the argument goes, there is more opportunity for information campaigns or seminars to make a relative difference in driving adoption rates. However, the understanding of what factors can explain local variation in PV adoption rates has been limited.

A driver with an often inherently large local component is social influence between peers, also referred to as *peer effects*. Positive word of mouth often plays an important role in overcoming barriers to the diffusion of innovations (Rogers, 1983). This is particularly true in situations where the support of a strong brand or strong marketing resources are lacking, which is often the case for small companies marketing radical innovations (Mazzarol, 2011). A number of recent studies have attempted to quantify local peer effects in terms of increased probability of additional nearby PV adoptions following previous adoptions (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). The results indicate that peer effects are stronger down to the zip code or street level (e.g. Bollinger and Gillingham, 2012). Some early attempts have also been made to separate *active* (through direct interpersonal contact) and *passive* (through passively observing PV systems) peer effects, although the results have remained rather inconclusive (e.g. Rai and Robinson, 2013). Pre-existing research on peer effects in PV adoption has focused on estimating the sheer magnitude of the effects, and the qualitative perspective has been lacking. The actual mechanisms underlying the peer effects have thus remained poorly understood.

There is some evidence that local organisations can take advantage of peer effects to reduce barriers to adoption. The findings of Noll et al. (2014) suggest that local non-profit organisations promoting residential PV in the U.S. have managed to leverage the impact of their activities through peer effects by engaging local individuals. A better understanding of how peer effects actually work could potentially inform organisations in how to exploit peer effects to boost PV uptake.

1.2. Objective

The objective of this thesis is to advance the knowledge on *the deployment of residential PV systems*. More specifically, the thesis aims at identifying and assessing *barriers* and *drivers* that obstruct or facilitate PV deployment in different geographical settings, taking the spatial dimension into account. Barriers include any factors in the sociotechnical system surrounding PV deployment that obstruct the deployment process, thus reducing the rate of PV adoptions. Correspondingly, drivers are sociotechnical factors that facilitate PV deployment, thus increasing adoption rates. Such barriers and drivers may relate to for example institutions, firms, economy, human behaviour, infrastructure or technology. Studying different national and local contexts, the thesis aims at building knowledge on barriers and drivers on different spatial scales. The thesis aims at answering four different research questions, one for each paper:

- RQ1 (paper 1): What barriers are present in the Swedish sociotechnical system for residential PV deployment?

- RQ2 (paper 2): How have different kinds of business models been successfully designed by firms to overcome country-specific barriers to residential PV deployment in different national contexts?
- RQ3 (paper 3): What local factors can explain geographically uneven adoption rates (as measured on the municipal level) of residential PV systems within Sweden?
- RQ4 (paper 4): How has social influence between peers (peer effects) reduced barriers to PV adoption among Swedish homeowners?

The thesis is largely based on case study methodology. Important modes of data collection were interviews and surveys, although data were gathered in various other ways as well. Both qualitative and quantitative methods were used.

The target audience includes actors that might have an interest in stimulating PV dissemination. These include policymakers, firms and non-profit organisations.

1.3. Scope

This thesis focuses on a particular part of the PV value chain, namely on *deployment*. Deployment is defined here as the process of putting the technology into use, and involves various activities taking place at and around the very end of the PV value chain, such as PV system marketing, sales, installation and adoption decision making among (potential) users. Deployment is thus the last set of processes in a series of events that lead to a PV system being commissioned. Processes taking place further upstream in the value chain, such as technology production and development, are outside the scope.

Although the terms 'deployment' and 'dissemination' are often used interchangeably, 'deployment' is in this thesis used to signal that it is activities at the end of the value chain that are alluded to. The term 'dissemination' is used here to describe the increased uptake of an innovation (e.g. the number of PV systems per capita) without alluding to any particular part(s) of the value chain. Dissemination is thus regarded here as an outcome of the combination of technology development, production and deployment.

With a focus on deployment, there is little reason to delimit the scope to PV systems based on any particular kind of solar cells. Although crystalline silicon solar cells dominate PV markets worldwide, other kinds of solar cells are in principle not excluded from the analysis. Other cell types can be produced with very different methods using different materials, but once encapsulated into modules they can typically be treated more or less as equivalents for residential applications. The deployment focus thus allows the researcher to regard PV modules as 'black boxes' converting sunlight into electricity regardless of the characteristics of its internal processes.

As regards different applications, the focus is on the ***residential*** segment, i.e. on systems situated in connection to and providing electricity to a particular household. Thus, larger ground-mounted installations, industrial applications and most applications on multi-family dwellings are not considered. Although people renting their homes are in principle not excluded, the current state of affairs in PV markets around the world (including the studied contexts) implies that the adopter category of interest is that of private homeowners.

Regarding ***geography***, most of the research focused on Sweden, either the whole country (paper 1) or more local entities (papers 3 and 4). Only in paper 2 was the focus on markets outside Sweden, namely Germany, Japan and the United States. Paper 2 does, nevertheless, provide important lessons for Swedish actors regarding the future development of the Swedish market as this paper studies more developed markets. Papers 3 and 4 differ from the other papers in that they have a *local* focus. All research was conducted in developed countries only. Practically all households in the studied contexts are connected to the electrical grid, and the thesis thus considers grid-connected PV applications only.

Sweden was chosen as the main setting for three key reasons. First, residential PV as an investment in Sweden has been neither clearly unprofitable nor very profitable in recent years. When PV adoption offers limited (but not too poor) prospects of economic gains, various non-economic factors are presumably more likely to have a relatively high impact on adoption rates (cf. Noll et al., 2014), which makes such factors more easily observable. This makes Sweden a potentially fruitful case for studying non-economic barriers to deployment. Second, there has been a lack of research on barriers to PV deployment in catching-up markets. The aggregate of (potential) catching-up PV markets around the world offers a huge potential for PV uptake, and understanding barriers in such contexts is thus of utmost importance. Third, data for Sweden were relatively accessible as the researcher was based there and is a native speaker of the language. Paper 2 went outside the Swedish context because there was not enough empirical data to be found on the topic of interest (business models for PV deployment) within Sweden. A better understanding of business models can nevertheless be useful to support PV deployment in Sweden and other catching-up markets.

Regarding ***time***, the research focuses mainly on phenomena that occurred between 2009 (when a subsidy for residential PV was launched in Sweden) and 2014. During that period and up until the time of writing this chapeau (late 2016), the studied PV markets, as well as other PV markets around the world and the global PV industry, have developed substantially. There is, nevertheless, little reason to believe that the findings of this thesis (with perhaps some minor exceptions) are less relevant at the time of finishing the thesis than a few years earlier. First, as observed by the researcher, most of the barriers to deployment in Sweden identified throughout the research remain at the time of finishing the thesis and are thus still relevant targets for policy. Second, even if the studied contexts have changed, there are numerous markets around the world that will likely face challenges similar to those encountered in the studied cases, and that can learn important lessons from them.

All papers except paper 4 adopt a systemic perspective in their respective context, considering a variety of interacting factors in PV deployment. Paper 4, being narrower in scope, focuses exclusively on social influence between peers in PV adoption.

1.4. Limitations

Some limitations of this thesis need to be recognised. First, the generalisability (external validity) of the findings is limited by the fact that the bulk of the research was focused on the Swedish context. Generalisability might be largest to similar cases, e.g. to developed countries with PV markets that are in an early stage of development and where the economic profitability of adopting a PV system is limited.

Second, the perspectives of all relevant actors are not always present. Due to restrictions in time available to the researcher, primary data could not be collected through interviews or surveys for all actors but were collected only from actors that were deemed the most relevant. In paper 1, the actors interviewed were general experts, installers and electricity companies, while primary data were not gathered for adopters and policymakers. In paper 2, primary data were obtained from companies using the business models of interest and from industry experts, but not from the companies' customers or from companies using other business models. Also in paper 3, a deeper understanding could possibly have been obtained through interviews with adopters that responded to the survey.

Third, the number of cases in the comparative case studies (papers 2 and 3) was constrained by limitations in the amount of time available to the researcher rather than by theoretical saturation (cf. Glaser and Strauss, 1967). With more cases added, the internal and external validity could have been increased, and additional insights could potentially have been reached.

Fourth, data could have been gathered to support more elaborate statistical analyses. For paper 3, data could have been collected to perform statistical analyses comparing a larger number of municipalities with regard to how various aspects correlate with PV adoption rates. For paper 4, a larger sample with secured representativeness would have made more elaborate statistical analyses possible.

2. Methodology

This section starts with a description of three theoretical frameworks that were used to guide the research. Then, the overall research design, which is based on case studies and various methods for data collection and analysis, is presented. Lastly, the interdisciplinary nature of the research is discussed briefly.

2.1. Theoretical frameworks

The research conducted for this thesis was guided by a variety of theoretical frameworks and concepts. However, three theoretical frameworks were particularly important. The rationale for choosing these frameworks is described below, after which the frameworks are outlined one by one.

As the thesis aims at identifying barriers and drivers throughout sociotechnical systems for PV deployment, the theoretical framework, or set of frameworks, used must reflect the 'whole' system. There are existing frameworks that fit this purpose quite well. In particular, the *technological innovation systems* (TIS) framework (e.g. Bergek et al., 2008a; Hekkert et al., 2007) and the *multi-level perspective* (MLP) (e.g. Geels, 2002) have been developed to analyse the development and deployment of new technologies from a sociotechnical systems perspective. These two frameworks have become dominant as analytical tools to understand (various barriers and drivers to) sustainability transitions, and, even though they have been developed rather independently of each other, they are largely focused on the same real-world phenomena and share several key concepts (Coenen et al., 2012; Markard and Truffer, 2008). Although these frameworks were not developed for any particular technology or sector, they have very often been applied to renewable technologies in the energy sector (Markard et al., 2012; Markard and Truffer, 2008).

Yet, there are differences between these two frameworks. The TIS framework is apt for studying barriers and drivers at different stages of a technology's development (Bergek et al., 2015, 2008a; Markard et al., 2012), while the MLP framework is relatively more focused on niche applications *or* regimes and less so on intermediate stages of development (Markard and Truffer, 2008). The MLP framework is more apt to explain broader transformative changes than the TIS framework, which is more focused on technology-specific matters (Markard et al., 2015; Weber and Rohracher, 2012). These differences hint that the TIS framework might be a more appropriate choice for the purpose of studying the deployment of a mature technology (PV) in an application that is not to be considered a niche (the residential application) but that has become mainstream in other geographical contexts and is expected to become mainstream also in the country or region of interest. Thus, the thesis uses the TIS framework as a starting point to analyse barriers to PV deployment (paper 1).

The wide scope of the TIS framework implies that it is not as detailed in all parts of the studied sociotechnical system. To further understand barriers and drivers to PV deployment, papers 2-4 analyse specific parts of the deployment systems. The research designs of papers 2-4 thus required the identification of the most relevant parts of these systems, as well as the identification or construction of theoretical frameworks that zoomed in on these parts.

Ideally, the TIS framework would provide adequate guidance to other frameworks that could be applied when studying certain phenomena in greater depth. This is the case for some phenomena that are within the scope of the TIS framework; for example, the TIS framework assigns significant importance to institutions, and accordingly the TIS literature refers to central literature on institutional theory, particularly to literature that deals with relationships between institutions and technological change. However, when it comes to other phenomena that occur in the TIS framework, such as the different actors involved in technology deployment and some of the 'functions' (key processes), the TIS literature does not connect as well to other literature streams. Neither does it provide guidance to any subsystems that might be analysed.

A useful analysis has, nevertheless, been performed by Foxon (2011), who identified a set of key coevolving systems relevant when analysing sustainability transitions, namely *ecosystems*, *technologies*, *institutions*, *business strategies* and *user practices*. Of these systems, *ecosystems* are regarded as external in this thesis. Also *technologies* are largely regarded as an external force, as the focus is on the deployment of artefacts that are in themselves technically mature and imported from another system. *Institutions* are crucial to a systemic analysis of barriers to deployment but are, as stated, quite well covered by the TIS framework, and paper 1 accordingly provides a thorough institutional analysis. Thus, potential areas for further studies remaining after the completion of paper 1 are *business strategies* and *user practices*. Business strategies have also been identified as crucial in bringing sustainable products to the market within the *business models* literature (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013; Mont et al., 2006; Reim et al., 2015; Tukker, 2004). Furthermore, Schot et al. (2016) have made a strong case for dealing in greater depth with the role of users in the technological transitions literature.

Suitable frameworks for studying business strategies and user practices are the *business models framework* (Amit and Zott, 2001; Shafer et al., 2005) and Rogers' (1983) *diffusion of innovations* framework, respectively. Thus, these frameworks were used for papers 2-4. These frameworks fit within the scope of the TIS framework as they zoom in on real-world phenomena covered by the TIS literature. Both frameworks could be positioned relatively easily within the TIS literature as they clearly relate to core TIS concepts. What the TIS framework intends to capture by stressing the importance of firms and the function 'entrepreneurial experimentation' has a large overlap with what is described in the business models literature. The business models literature, being solely devoted to this topic, is nevertheless much more detailed on the phenomena of interest. In a similar manner, the role of users and the functions 'legitimation', 'knowledge development and diffusion' and 'market formation' of the TIS framework have a large overlap with what is dealt with in Rogers' diffusion of innovations framework.

2.1.1. Framework 1: Technological innovation systems (TIS)

The technological innovation systems (TIS) framework was developed to analyse the development, production and deployment of new technologies from a sociotechnical systems perspective (Bergek et al., 2008a; Hekkert et al., 2007). Its most common application has been to identify and assess barriers and drivers to technology dissemination in order to derive policy recommendations, often with the purpose of understanding how increased uptake of renewable energy technologies could be supported (e.g. Dewald and Truffer, 2011; Dewald and Fromhold-Eisebith, 2015; Jacobsson and Bergek, 2011; Quitzow, 2015; Sandén et al., 2008; Suurs, 2009; Suurs and Hekkert, 2009).

The TIS literature is a branch of a wider innovation systems literature, including other innovation systems approaches such as *national*, *regional* and *sectoral* innovation systems. An innovation system belonging to any of these categories can be understood as a complex system of actors and institutions involved in the development, production and deployment of new technology. Originally, the innovation systems literature focused on *national* innovation systems, which are not restricted to one particular technology but deal with the general innovative capability of a country (Lundvall, 2010). Subsequently, literature emerged on sector-specific innovation systems (Malerba, 2009) and, narrowing down, on innovation systems for specific technologies – that is, on TISs. The innovation systems literature emerged largely as a result of a frustration among certain scholars regarding how (mainstream) economics dealt with economic development; the argument was that it neglected processes of learning, institutions and technological change, and wrongfully assumed a static equilibrium (Sharif, 2006).

The rate and direction of technological change can be understood as being determined more by competition between innovation systems than between technologies (Hekkert et al., 2007). A major external force of a TIS for PV deployment is the incumbent system for electricity production, which could be understood as a sectoral innovation system, or as a sociotechnical *regime* (Geels, 2002). As stated, such incumbent systems/regimes could be expected to be locked in through various technological and institutional mechanisms, making it difficult for new and competing technologies to gain ground (Unruh, 2000).

In this thesis (paper 1), the TIS approach was used somewhat differently than in most previous TIS studies as it was applied to the *deployment* phase exclusively. Earlier TIS studies (as most other innovation system studies) have been predominantly used to study processes of development, production and deployment together as occurring in one and the same system, or they have paid less attention to deployment than to development and production (Dewald and Truffer, 2011). However, due to spatially different characteristics between different parts of the PV value chain (see section 1.1.2), a pure deployment focus was deemed the most appropriate for the present research (see also section 2.1.1.3).

In recent (post-2007/2008) TIS literature (Bergek et al., 2008a; Hekkert et al., 2007), a TIS is normally divided into one 'structural' and one 'functional' (more dynamic) part. These are outlined below, and it is briefly explained how they may relate to technology deployment. A brief account of how to think about geographical system boundaries in relation to the value chain follows, as this was an important issue in paper 1.

2.1.1.1. The structure of a TIS

The 'structure' of a TIS is normally thought of in terms of the following three categories of elements:

- *Actors*: Any organisations or individuals relevant for the development or deployment of the technology. With a deployment focus, core actors include, for example, installers and suppliers of turnkey systems and components, policymakers and (potential) adopters.
- *Networks*: Linkages between actors through which information is exchanged. In deployment, associations for installers and suppliers are frequently of high importance, as well as informal networks between adopters. Advocacy coalitions may attempt to influence policy though political networks (Bergek et al., 2008b).
- *Institutions:* Any humanly devised rules (formal or informal) affecting the development or deployment of the technology, such as laws, standards, practices or collective mind frames. For deployment, technology standards

(Ma, 2010) and popular perceptions (legitimacy) (Jacobsson and Bergek, 2004) are examples of institutions that are often important. Although institutions often facilitate deployment, pre-existing institutions may also prohibit or complicate the deployment of a new technology, often unintentionally.

While a TIS is in its early stages, the institutional set-up is usually badly aligned to the emerging technology as institutions are either not in place or are maladapted to the technology. The alignment of institutions to new technology is, however, notoriously an arduous process (Unruh, 2000), further complicated by the fact that firms "compete not only in the market but also over the nature of the institutional set-up" (Bergek et al., 2008a), a competition in which incumbent firms are often in a stronger position than the small newcomers that might represent the new technology. Furthermore, key actors might be missing or might not have gained the relevant knowledge, and networks are often lacking.

With a focus on deployment, these three categories of structural components are all likely to be as important as when the TIS framework is used to study development and deployment together. However, the deployment focus allows the researcher to focus his or her resources on those actors, networks and institutions that are the most relevant for deployment, thus creating room for a more in-depth analysis of those elements.

2.1.1.2. Functions of a TIS

Functions represent key processes that should occur in a TIS in order for the system to perform well. Functions have been described as constituting "an intermediate level between the components of a [TIS] and the performance of the system" (Jacobsson and Bergek, 2004) and as "emergent properties of the interplay between actors and institutions" (Markard and Truffer, 2008). The exact number of functions that should occur is somewhat arbitrary, and various sets of functions have been presented. The following set has (with some variation) gained recognition in the recent TIS literature (Bergek et al., 2008a; Hekkert et al., 2007):

- *Knowledge development and diffusion*, encompassing different processes of learning among key actors. As regards deployment, firms, policy makers and (potential) adopters need to gain an understanding of how to install, market, regulate, support and use the technology.
- *Guidance of the search*, capturing incentives for firms and other organisations to enter and participate in the TIS. The strength of this function is to a great extent determined by present and future *market formation* (see below) as perceived by relevant actors, not least when it comes to the deployment phase.

- *Entrepreneurial experimentation*, including various creative activities of firms. As regards deployment, innovation and variation regarding what applications and business models are employed can be important indicators of the strength of this function.
- *Market formation*, referring to activities that contribute to the creation of demand for the technology. Market formation is a crucial part of the deployment process and a prerequisite for dissemination. Barriers to market formation are often found in the institutional set-up (for example as a lack of standards or misaligned legislation) or in a poor price/performance.
- *Legitimation*, referring to changes in the social acceptance of a technology, or how good or desirable the technology is perceived to be. Legitimation through lobbying performed by activists and interest organisations was decisive for the implementation of deployment supporting schemes for PV in Germany (Bergek et al., 2008a; Jacobsson and Lauber, 2006).
- *Resource mobilisation*, reflecting the availability of human and financial capital necessary for the TIS to perform well. As regards the deployment of renewable energy technologies, the mobilisation of capital for subsidy schemes has often been crucial.

By identifying and strengthening poorly performing functions, policy interventions can facilitate the dissemination of a desirable technology (e.g. a renewable energy technology). This can be achieved by strengthening or adding drivers, or by weakening or removing barriers (Bergek et al., 2008a).

The functions have often been used to study feedback loops between production and deployment. When the TIS framework is applied to the deployment phase exclusively, such feedback loops will not be made visible. With a deployment focus, there is also a possibility that the relative importance between functions might differ from when the TIS framework is applied to a larger part of the value chain, as some functions might be more directly related to earlier stages of the value chain and others to deployment processes (e.g. 'market formation').

2.1.1.3. The spatial dimension and the case for deployment-focused TIS studies

Setting spatial system boundaries in TIS studies can be more or less complicated depending on the case at hand. While some technologies have their value chain assembled more or less entirely within one single country, others have their value chain distributed over different geographical places and scales. As stated by Hekkert et al. (2007), a technology is "hardly ever embedded in just the institutional infrastructure of a single nation or region, since – especially in modern society – the relevant knowledge base for most technologies originates from various geographical areas all over the world". The question of what part(s) of the value chain that are in focus thus has implications for the choice of spatial scope of the study.

A need for more elaborate approaches to geographical system boundary setting and spatial differentiation in TIS studies has been identified in recent publications (Binz et al., 2014; Coenen et al., 2012). The general trend towards increased global division of labour and specialisation in value chains (Antràs et al., 2012; Baldwin and Robert-Nicoud, 2014; Hummels et al., 2001; Los et al., 2015; Timmer et al., 2013) suggests that this need, if anything, will increase as technologies increasingly have their value chains distributed over different geographical places and scales. In parallel to the work with this thesis, empirical and conceptual work has been carried out by other scholars to make the TIS framework more elaborate regarding spatial differentiation (Bergek et al., 2015; Binz et al., 2014; Dewald and Fromhold-Eisebith, 2015; Gosens et al., 2015; Huang et al., 2016; Quitzow, 2015; Wieczorek et al., 2015). Empirical studies using geographically differentiated TIS approaches have been performed for PV (Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015), membrane bioreactors (Binz et al., 2014) and wind power (Wieczorek et al., 2015). A spatially differentiated TIS analysis, in which deployment and production are treated as (partly) different sociotechnical systems between which linkages exist, has been proposed in recent publications (Bergek et al., 2015; Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015). Such analyses could often be useful, but they are resource-intensive as the researcher has to gather and analyse data from different contexts. It is thus important that the researcher knows what to focus his or her resources on and what can be left out of the analysis. Thus, there is a case for elaborating upon whether and under what circumstances the TIS framework can be applied to deployment exclusively, treating technology development and production as a 'black box'.

PV is an example of a technology whose whole value chain does not naturally fit into one and the same geographically defined TIS. As described in section 1.1.2, the development and production of PV system components take place in a global arena, and this part of the value chain is thus better understood as pertaining to a global TIS (although it might, for pragmatic reasons, make sense to define a national TIS for these processes if the purpose is to derive policy recommendations for a particular government), while the deployment of PV is an inherently much more local activity. This can make it somewhat problematic to attempt to squeeze development, production and deployment of PV into one and the same TIS, although the TIS framework is originally intended to study all these processes together. In paper 1, this dilemma was elaborated upon, and it was demonstrated that the TIS framework is useful to study deployment separately in cases where it does not make sense to include more upstream parts of the value chain in the same TIS as deployment.

Two macro trends hint that TIS analyses focused on deployment will be increasingly needed. First, an increasing global division of labour and specialisation suggests that the production and trade of artefacts will increasingly take place in a global arena, while processes of deployment may remain more localised (which has been the case for PV, see section 1.1.2). In those cases, individual end user markets will often be small in relation to the global production system, and a pure deployment focus in TIS studies may be feasible. Second, there is an increasing availability of mature renewable energy technologies that can be deployed in new regions. This availability creates a case for more deployment-focused TIS analyses to study barriers and drivers in these catching-up markets, thus informing actors in how to facilitate a sustainability transition. Furthermore, as technologies mature, their global production systems are likely to increase in size in both absolute terms and in relation to more localised deployment systems, in which case it can be feasible to treat technology development and production as a 'black box' in relation to deployment.

2.1.2. Framework 2: Business models

In order for a technological transition to take place, not only technical but also organisational innovation is required. Not least *firms*, who are usually key actors in technology deployment, might need new strategies to overcome barriers to the deployment of radical innovations. In order to profit from a new technology, firms will often need new strategies for how to provide value for their customers and capture value for themselves – that is, new ***business models*** are needed. In paper 2, an analysis was made of why different kinds of business models for PV deployment have reached success in different national contexts.

A business model is, simply put, a representation of how firms create value for themselves and their customers. Customers may be private individuals, other firms or other organisations, and value may be provided in the form of services, products or a combination of both. In two widely cited papers, business models have been described as "the design of transaction content, structure, and governance so as to create value through the exploitation of business opportunities" (Amit and Zott, 2001), and the "firm's underlying core logic and strategic choices for creating and capturing value within a value network" (Shafer et al., 2005). The business models concept became prevalent around the mid-1990s in connection with the rise of the Internet (Shafer et al., 2005; Zott et al., 2011). A deployment focus is common in business model analyses, although focus can equally well be on products that are to be further processed before a finished product can be deployed.

Although there is no precise, agreed definition of a business model, the following elements are central to most definitions (M. Richter, 2013):

- *Value proposition:* the products or services offered to customers.
- *Customer interface:* the overall interaction with customers, including customer relations, customer segmentation and distribution channels.
- *Infrastructure:* the company's inner structure for value creation, including assets, know-how and partnerships.
- *Revenue model:* the relationship between the costs and revenues of the value proposition.

It is recognised in the literature that business model innovation (the development of new business models or the adaptation of existing ones) can facilitate the deployment of new technologies (Boons and Lüdeke-Freund, 2013). A new technology might not only come with some inherent attributes that call for a new or changed business model, but also the newness in itself might entail barriers that could be addressed through business model innovation. Uncertainties and incompatibilities with existing institutions could potentially be addressed through business models designed to transfer risks and transaction costs from the customer to the company, or to neutralise particular institutional barriers.

In the present thesis (paper 2), the analysis went beyond the conventional business models framework to also consider various contextual country-specific factors. This allowed the research to identify how various barriers have influenced the viability of different business models for PV deployment in different geographical contexts.

2.1.3. Framework 3: Diffusion of innovations

In the *diffusion of innovations* literature, the (potential) adopters are in focus, as well as those influencing or trying to influence their decision to adopt or reject an innovation. Thus, this framework is deployment-focused by nature, although it does not capture the full set of actors (or other factors) relevant for deployment. This section outlines the diffusion of innovations framework as presented by Rogers (1983). Rogers' framework gathers insights from a broad set of literature and has gained wide recognition. His main contribution was to put existing research together into a comprehensible yet robust package. The framework is by no means restricted to sustainability innovations or innovations in the energy sector, but is general to innovations that are or can be adopted by individuals. Elements of the diffusion of innovations framework were used throughout this thesis, particularly in papers 3 and 4.

Rogers (1983, p. 5) defined diffusion as *"the process by which an innovation is communicated through certain channels over time among the members of a social system"*. The framework focuses on processes of decision making, how different personality types relate to the inclination to adopt an innovation, and how different attributes of innovations might influence their adoption rates. Rogers used the terms 'diffusion' and 'dissemination' interchangeably. In this thesis, 'dissemination' is used as a general term for the uptake of an innovation (e.g. in terms of adoption rates), while 'diffusion' is used for processes more specifically related to communication or exchange of ideas, or to signal adherence to the work of Rogers. In this thesis, 'diffusion' differs from 'deployment' in that 'deployment' involves more aspects than just interpersonal communication (the difference between 'dissemination' and 'deployment' has been accounted for in section 1.3).

A key feature of the framework is the categorisation of potential adopters by some key characteristics and their role in diffusion processes. Rogers promotes a categorisation of potential adopters into five ideal types (although he concedes that in reality there are no sharp boundaries between these groups):

- *Innovators* are the first to adopt innovations. The innovator is venturesome and eager to try new ideas, leading him or her to seek social relationships with other like-minded outside their local peer group. Innovators are often seen upon with some suspicion by their peers, being perceived as 'too' innovative, but they can still facilitate the diffusion process by bringing new ideas into their social system.
- *Early adopters* are somewhat less innovative than innovators. They are more integrated into their local social system than innovators, and are more influential on the attitudes of their local peers. Being both relatively respected and innovative (but not *too* innovative), they are effective role models and have the highest level of *opinion leadership* (see below) among the categories.
- The *early majority* adopts innovations just slightly earlier than the average individual. This group is an important link between early and late adopters, providing interconnectedness supporting the diffusion process. Once a person belonging to this category has started contemplating adoption, his or her decision period is longer than that of earlier adopters.
- The *late majority* adopts innovations slightly later than the average individual. Adoption often comes as the result of economic necessity or social pressure. Persons in this category tend to maintain a sceptical attitude towards new ideas in general, and practically all uncertainty about the innovation must have disappeared before they choose to adopt.
- *Laggards* are the last to adopt an innovation. They are suspicious of new ideas, and their attitudes are often aligned with the practices of previous generations. Often, however, a precarious economic situation is a partial reason for the late adoption.

The decision to adopt (and keep using) an innovation is described by Rogers as an *innovation-decision process* consisting of the following five stages:

- *Knowledge,* in which awareness of the existence of the innovation and understanding of how it works are gained.
- *Persuasion*, in which a favourable or unfavourable attitude towards the innovation is formed.
- *Decision*, involving activities leading to a choice regarding whether to adopt or reject the innovation.
- *Implementation*, in which the innovation is put into use.
- *Confirmation*, in which reinforcement of an earlier adoption decision is sought, sometimes leading to a reversal of the adoption.

Innovations have different *attributes*, which are highly influential on the rate at which they diffuse in a social system. Attributes can be generalised into the following five categories, which, according to Rogers, taken together normally explain most of the variance in the rate of adoption between innovations:

- *Relative advantage* as compared to existing alternatives. In the case of residential PV, the existing alternative would for most prospective adopters be electricity from another source or another financial investment.
- *Compatibility* with for example norms, beliefs and infrastructure. As an example, residential PV benefits from a widespread belief in the perils of climate change, but may be in conflict with permitting or tax rules.
- *Complexity* as perceived by potential adopters. Although residential PV systems are typically relatively easy to acquire and use (at least from a technical point of view), potential adopters might perceive adoption and use as potentially complicated.
- *Trialability*, reflecting the possibility of testing the technology before adopting it. Residential PV suffers from low trialability, as a PV system cannot easily be installed and uninstalled for testing on a rooftop.
- *Observability*, being the extent to which members of a social system can observe the results of an adoption. While residential PV has a high observability in terms of *awareness* (neighbours will normally notice when someone has installed a rooftop PV system), lower observability of the actual results of PV adoption (production, economy, reliability) might be a disadvantage.

A key concept in papers 3 and 4 is that of ‘peer effects’, which captures social influence between peers (e.g. neighbours, co-workers or friends) in the adoption decision process. Although Rogers did not use this particular term, much of his framework is, as should be evident from the above account, dedicated to this topic. Peer effects can be *active* (occurring through direct communication between peers) or *passive* (occurring without direct communication, for example when someone observes a new PV installation in their neighbourhood) (e.g. Rai and Robinson, 2013). Peer effects have been observed in the adoption of a variety of technologies, such as menstrual cups among Nepalese adolescents (Oster and Thornton, 2009), electric vehicles (Axsen et al., 2009), information and communication technologies (e.g. Stewart, 2007), housing renovation (Helms, 2012) and various kinds of farming equipment (Rogers, 1983). Peer effects are often highly localised (Rode and Weber, 2013), and local peer effects for residential PV systems have been quantified in a number of recent studies (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). There has, nevertheless, been a lack of qualitative research on peer effects in PV adoption, and consequently the understanding of the underlying mechanisms of peer effects in PV adoption has remained poor. This gap was addressed in paper 4.

2.2. Research design

The research was mainly based on case studies carried out using qualitative methods. Data were collected through a variety of methods, including interviews (all papers), surveys (papers 3 and 4) and comprehensive internet searches (all papers). Both primary and secondary data (academic and non-academic) were used (secondary data were relatively more important for papers 1 and 2). In this section, the case study approach(es) adopted and the methods for data collection and analysis are outlined. (For a more detailed account of the research designs of each paper, see section 3 or the appended papers.)

2.2.1. Case studies

The thesis is largely based on *case studies*, i.e. empirical in-depth inquiries in single settings (Eisenhardt, 1989; Yin, 2009). Case studies are suitable to shed light on 'how'- or 'why'-questions regarding contemporary phenomena over which the researcher has little or no control (Yin, 2009). Case studies can be based on qualitative or quantitative methods, or a combination of both, and they normally make use of a variety of evidence, including documents, artefacts, interviews, and observations (Eisenhardt, 1989; Yin, 2009). Case studies are generalisable to theoretical propositions rather than to populations, and one of their important strengths is to explain causal links in complex situations (Yin, 2009).

Case studies can be based on one or more cases, which should be selected on the basis of their expected ability to provide useful information rather than to provide a representative sample of a larger universe (Eisenhardt, 1989; Yin, 2009). If the number of candidates for cases to study exceeds about a dozen, quantitative data should be collected about the cases and pre-defined criteria should be specified to select a smaller number (Yin, 2009). This strategy was adopted for paper 3.

For papers 1-3, a clear-cut case study approach was adopted, while paper 4 employed elements of case study methodology. Paper 1 was carried out as a single-case study to identify and assess barriers and drivers within one particular setting (Sweden as a whole). Papers 2 and 3, on the other hand, used multiple-case approaches to support generalisations by means of comparison between different settings.

2.2.2. Data collection and analysis

In line with the interdisciplinary nature of the research and with case study methodology, data were collected and analysed using a variety of sources and methods (Table 1). This allowed for knowledge to be added regarding various aspects of the posed research questions. The variety also allowed for triangulation, i.e. for increasing the internal validity of the findings using evidence derived from different datasets and methods (Richards, 2007). While papers 1 and 2 were exclusively qualitative, papers 3 and 4 used a mix of qualitative and quantitative methods. Paper 4 used a narrower set of data sources than the other papers. Both primary and secondary data were used. Primary data were collected mainly from interviews and surveys. See Table 1, section 3 or the appended papers for more detailed information on the data used for each paper.

Participants (interviewees and survey respondents) were selected through *purposeful sampling,* i.e. they were selected based on their expected ability to provide useful information rather than to achieve a representative sample of a larger population. Purposeful sampling is generally adequate in qualitative research (Maxwell, 2008).

Interviews were carried out in a semi-structured manner, meaning that a set of questions (an interview guide) was prepared in advance but was not necessarily followed strictly. Thus, any unforeseen and interesting matters surging during the interview could be addressed. In total, 59 interviews were performed. In addition, numerous shorter or less structured communications were performed with various actors, mainly through telephone or email. The main function of these shorter contacts was to guide the research towards relevant data sources or topics.

The interviews were analysed differently between the papers, mostly depending on their relative importance for the respective paper. For papers 1-3, interviews were not recorded but notes were taken during the interviews. For paper 4, in which interviews were relatively more important, not only notes were taken but the interviews were also recorded and (whenever the notes were not considered detailed enough) revisited and partly transcribed. Simple coding techniques were used to analyse the interviews, through which themes were identified and put into categories. This allowed the researcher to keep track of how many interviewees had made certain statements or expressed certain considerations. Some degree of interview coding was performed for all papers, although it was done most systematically for paper 4.

Two surveys were performed to collect data for papers 3 and 4, respectively. Questionnaires (see appendices A and B) were sent by postal mail to Swedish PV adopters. The response rates were 74-80% (which is to be regarded as high) and in total 130 valid responses were obtained. The data obtained through the surveys were used mainly for descriptive statistics and to guide the further research, although some inferential statistics were also performed.

Table 1. Data systematically collected for the four papers, by type and quantity. In addition to what is shown in this table, systematic Internet searches were important for papers 1-3, leading to the use of various secondary data.

Paper	Data		
	Type	Actor/source	Quantity
1	Interviews (duration 0.5-1 h)	PV installers	9
		Electricity companies	9
		Experts	4
2	Interviews, marketing material	Companies (Japan)	5
	Websites	Companies (U.S, Germany)	70
3	Survey questionnaire (appendix A)	Adopters	65 valid responses (80% response rate)
	Interviews (duration 0.25-0.5 h)	Local actors (e.g. PV installers, electric utilities, municipal energy advisers)	16
4	Survey questionnaire (appendix B)	PV adopters	65 valid responses (74% response rate)
	Interviews (appendix C) (duration 0.25-0.75 h)	PV adopters	16

Secondary data were collected from various sources. Documents such as industry reports, academic publications, newspaper articles and the websites of firms and other organisations were used. For papers 1-3, comprehensive Internet searches were an important tool to identify and gather data. An important data source and tool was the Swedish Energy Agency's register of applications and approvals for an investment subsidy scheme that has been available to PV adopters since 2009. The names and addresses of PV adopters obtained from this register allowed for analysis of geographical differences in PV adoption rates within Sweden, and made it possible for the researcher to contact adopters for the surveys and interviews. This register was used for papers 3 and 4.

When feasible, data were collected until theoretical saturation (Glaser and Strauss, 1967) was approached, i.e. until the marginal gain in insights obtained through additional data collection was not large enough to motivate the effort of collecting more data. There were, nevertheless, restrictions regarding the extent to which theoretical saturation could be applied (see section 1.4).

2.3. Interdisciplinarity

The research behind this thesis is *interdisciplinary* by nature. Interdisciplinarity is the combination and (partial) integration of elements from two or more academic disciplines (Boden, 1999; Klein, 2010, 1990). A broad scope alone does not necessarily imply interdisciplinarity, and neither does the mere juxtaposition of different disciplines (Klein, 1990). For interdisciplinarity to be meaningful, the strengths of different disciplines should contribute to address one and the same issue and, ideally, the disciplines should enrich each other (Boden, 1999). Although interdisciplinarity is often confused with *multidisciplinarity*, the latter term refers to the juxtaposition of disciplines without any requirements on integration (Klein, 1990). Distinctions between different branches of social science are to a large extent arbitrary and historically forged (Calhoun and Rhoten, 2010), meaning that that interdisciplinary approaches are often no more intrinsically wide-scoped or integrative than research within established disciplines.

Interdisciplinary approaches are often useful to study phenomena that are complex or that do not fit into one particular discipline (Calhoun and Rhoten, 2010; Klein, 1990; Krohn, 2010), including many policy challenges facing humanity, such as climate change and sustainability transitions in the energy sector (Bhaskar et al., 2010; Miller, 2010). The present research made use of two theoretical frameworks (TIS and business models) that are in themselves pronouncedly interdisciplinary (Pateli and Giaglis, 2007; Sharif, 2006). In addition, theories originating in sociology (the diffusion of innovations framework) were used to understand the role of adopters in PV deployment. Although these three frameworks were used largely in parallel rather than integrated with each other in the four papers, this chapeau ties the findings more closely together, thus strengthening the interdisciplinarity of the research.

3. Key findings organised by papers

The four papers studied barriers and drivers to PV deployment in different geographical contexts and using different approaches. In paper 1, a sociotechnical systems approach was used to identify and assess various barriers and drivers to PV deployment in Sweden. In paper 2, business models for PV deployment that have been successful in three important PV markets (the United States, Germany and Japan) were analysed regarding their ability to overcome country-specific barriers. In paper 3, drivers that could explain the relatively high adoption rates observed in certain Swedish municipalities were identified and assessed using a multiple-case study approach. In paper 4, social influence between peers (peer effects) was studied regarding how Swedish PV adopters have increased the willingness of their peers to adopt PV. In the following, the four papers are summarised one by one.

3.1. Paper 1 – Systems perspective on barriers and drivers to PV deployment (Sweden)

3.1.1. Background

The Swedish government has an outspoken ambition to increase the share of solar energy and other renewables in the country's energy system, and subsidies for PV deployment have been available for a number of years. As previously stated, the deployment of radical energy technologies is however a complex process that may encounter several unforeseen barriers. This calls for a systematic review of the overall conditions for PV deployment within the country. Such an analysis has previously been performed by Sandén et al. (2008), who included not only deployment but also development and production in their study. This thesis provides an updated study devoted solely to the deployment phase.

3.1.2. Objective and approach

The objective of this paper was to identify and assess barriers and drivers to the deployment of residential PV systems in Sweden. Such an analysis could result in information useful to policymakers. A technological innovation systems (TIS) approach was adopted, which is a sociotechnical systems perspective developed to analyse the dynamics of technology development, production and deployment, and to identify and assess barriers and drivers throughout a technology's value chain (see section 2.1.1). In the present thesis, however, the TIS framework was applied to the deployment phase exclusively, allowing for a more robust analysis of this phase.

Methods for data collection were comprehensive Internet searches, 22 interviews with experts, installation firms and electricity companies, as well as a number of brief communications with various actors. A large amount of secondary data, mainly identified through the Internet searches, was reviewed, including legislative texts, debate articles, organisations' websites, statistics from governmental organisations, governmental reports, etc.

The Swedish national borders were set as the geographical system boundary because they coincide with the reach of several important institutions and because a purpose of the study was to inform Swedish policymakers. Timewise, the study focused on the early 2010s.

3.1.3. Results

The analysis revealed that the Swedish TIS for PV deployment was small and underdeveloped, although the market was (in relative terms) in a state of rapid growth. Commercial actors involved in PV deployment were largely restricted to small installation companies, although electric utilities[1] and electricity retailers had also shown an increasing interest in PV systems sales and trade in solar electricity. Installation firms were typically small and with a local focus. They were often not exclusively devoted to PV technology, thus lacking the benefit of specialisation. Potentially important actors such as architects or construction companies were not

[1] In this thesis, an *electric utility* is defined as an organisation that operates an electrical distribution grid. Although the legal entity that is most directly responsible for operating the grid is not allowed by Swedish law to trade in electricity or appliances such as PV systems, a grid-operating entity and an electricity-trading entity can be (and are often) gathered within the same group of companies. The group of companies can then sell PV systems though the electricity-trading entity, while it runs the grid through its grid-operating entity. In this thesis, the term *utility* may refer to such groups of entities or to pure grid-operators. For companies engaged in electricity-trading but not in grid-operation, the term *electricity retailer* will be used.

engaged in PV deployment more than marginally. PV systems were almost exclusively purchased by the adopters, meaning that third-party ownership business models that have been common in some more developed markets were practically non-existent in Sweden. This lack of alternative business models could be a barrier to some potential adopters who would prefer to adopt PV without purchasing a system.

Overall, the most important barrier to PV deployment was found to be the poor economic profitability of investing in a PV system. This was not only because of expensive PV systems and relatively low amounts of solar influx, but also because electricity prices in Sweden have generally been relatively low by international standards. Thus, the Swedish PV market had been created and upheld by subsidies. However, the subsidy schemes in place were sub-optimally designed, impaired by uncertainties and complexities.

The most important subsidy for PV deployment has been an investment subsidy scheme available for residential PV since 2009. Through this subsidy, adopters have been reimbursed for a fixed share of their expenses for purchasing a PV system. The scheme has repeatedly reached its budget cap, after which no more applications have been approved until more funding has been added through political decisions. As the PV market was very dependent on this subsidy scheme, the reaching of the cap has led to discontinuations not only in the scheme but in the whole PV market. This has created severe problems for installation firms that have suddenly and repeatedly lost their source of revenue. It has most often been unknown to the actors if and when new funding was to be added to the scheme. The interviews revealed that, as a result of these uncertainties, installation firms have often postponed decisions regarding the recruitment of new employees, purchasing of equipment or acquiring of a more appropriate office.

Furthermore, whenever the cap had been reached, additional applications were placed in a queue to be considered if and when new funding was added through political decisions. This led to waiting times for getting applications approved gradually increasing to more than a year, creating complications not only for adopters but also for firms. The delays have resulted in extra transaction costs for installers who have often had the feeling that they have been forced to 'sell the PV system twice', once when the adopter contacts them before filing an application for the subsidy and again after the application has been approved.

In parallel to the investment subsidy scheme, a tradable green certificates (TGC) scheme has been in place since 2003. Through the TGC scheme, owners of PV systems and a number of other renewable electricity technologies have been granted tradable certificates for their electricity production (one certificate per megawatt-hour). Certificates have been sellable on a 'free' market, demand being created by legal obligations on other actors to acquire certificates in proportion to their production or use of electricity.

The TGC scheme was launched as the main Swedish policy instrument to support renewable electricity, and an important feature was its alleged ‘technology neutrality’. It has been an important driver of the dissemination of renewable electricity technologies, mainly for wind power (Swedenergy, 2012). The scheme has, however, been poorly adapted for micro-generation of electricity (e.g. in residential PV systems). Trading small quantities of certificates has been complicated, and although PV owners have formally been entitled certificates corresponding to their whole production, hassle and extra costs have made it unattractive to acquire certificates for the self-consumed part of the production. Perhaps most importantly, expensive metering equipment has had to be installed by the PV owner for certificates to be granted for self-consumed electricity. The misalignment of the TGC scheme to micro-generation is illustrated by the fact that only a fraction of the Swedish PV adopters had found it worthwhile to apply for TGCs at the time of the study. For example, by the end of 2012 a mere 10% of all grid-connected PV systems in Sweden were benefiting from the scheme (Stridh et al., 2013).

As regards the institutional set-up beyond subsidies, existing institutions were found to be fairly well-aligned to residential PV deployment in the sense that no particular barriers of prohibitive magnitude could be identified. An important barrier was removed in 2010 when PV adopters were given the legal right to connect their system to the grid at no cost. Building permits for PV systems have usually been granted without prohibitive costs or hassle, and even though there has been some variation between municipalities’ building permit policies, national regulation has kept these costs and restrictions within certain limits.

There have, however, been some barriers related to tax rules. Most of the existing tax rules of relevance were designed decades ago for a regime of centralised large-scale electricity generation, and have not always been straightforwardly applicable to micro-generation. For example, there have been uncertainties regarding whether micro-producers selling their surplus electricity to an electricity retailer are to be regarded as ‘professional’ and thereby subject to extra taxation and paper work. According to the tax agency, tax rules on the EU and Swedish levels have also prohibited net metering (the practice of subtracting any electricity fed into the grid from the consumption before applying taxes), although the tax agency’s interpretation of the rules on this point has been opposed by some actors.

A large problem has been uncertainties regarding the future development of the institutional set-up. Most importantly, future taxes and subsidies have been unpredictable, both regarding their design and at what times they would be in operation. Apart from the aforementioned uncertainties regarding the investment subsidy, there were important uncertainties regarding the planned introduction of a tax reduction scheme for PV owners[2], for example regarding the compatibility of the tax reduction with existing tax rules.

The functional analysis revealed a linear chain reaction driving deployment. 'Legitimation' had been necessary for 'resource mobilisation' of the funding used for the investment subsidy scheme. This caused 'market formation' to take off, which in turn provided 'guidance of the search' for entrepreneurs to get involved in the PV installation business. The functions not mentioned in this chain reaction ('knowledge development and diffusion' and 'entrepreneurial experimentation') were excluded because little evidence was found that these functions operated on more than a basic level. Most installation had taken place in a rather traditional manner both technically and organisationally, and the experimentation of electric utilities and other commercial actors had remained a rather marginal phenomenon. The knowledge employed by actors involved in PV deployment was rather basic (add-on PV installation is in itself not a very complicated process), and the awareness of consumers necessary for their propensity to adopt PV was rather captured by the legitimation function. Because of the deployment focus, functional feedback mechanisms from deployment to production that are often analysed in TIS studies were not made visible in this case. However, the Swedish PV market was too small to significantly affect the global PV production system and such feedback mechanisms could thus be neglected.

3.2. Paper 2 – Business models for PV deployment (Germany, United States, Japan)

3.2.1. Background

In overcoming barriers to PV deployment, firms may play an important role through organisational innovation. The development and adaptation of new and existing business models have historically often been crucial in technological transitions. As PV is a radical technology in the electricity and housing sectors, business model innovation will most likely be key to coping with various barriers. Barriers, not least related to these sectors, can vary substantially between different geographical contexts, and there is thus a need to analyse how different business models can address barriers in different PV markets. Insights into how business models can

[2] After the publication of the paper, the tax reduction has been implemented in parallel to the other schemes, meaning that there are now (December 2016) three overlapping subsidy schemes.

counteract barriers to PV deployment could be useful to support deployment in Sweden and other emerging PV markets around the world. As revealed in paper 1, the TIS function 'entrepreneurial experimentation' was rather weak in Swedish PV deployment as practically all installation companies offered the same basic sales of turnkey PV systems. In other markets around the world, however, a variety of PV business models with rather different characteristics has emerged lately. Thus, paper 2 went beyond the Swedish setting to find empirical evidence on alternative business models.

3.2.2. Objective and approach

This study aimed at analysing how different business models for PV deployment can overcome barriers in different national contexts, and how different barriers and other contextual factors affect which kind of business models that will emerge and succeed in different settings. The study compared three distinctively different business models for PV deployment that have achieved success in three important PV markets, namely in Japan, Germany and the United States. In Germany, PV systems have been purchased and owned by the user as a financial investment. In the United States, third-party ownership (TPO) business models have proliferated. In Japan, the building industry has taken a leading role by integrating PV systems into prefabricated homes. An in-depth analysis was performed regarding the characteristics of each business model and the national contexts in which they thrive. How context has mattered for the success of the different business models, and implications for policymakers and firms, were then elaborated upon.

Based on theoretical sampling (Eisenhardt, 1989), the cases were selected for three key reasons. First, distinctively different business models have succeeded in the three countries, which allows for the identification of contextual factors that might explain why a certain business model thrives in a certain context. Second, the three countries together accounted for about 45% of the cumulative global installed PV capacity at the time of the study being performed (REN 21, 2014), making them important cases to learn from regarding successful PV deployment. Third, the extensive experience of PV deployment in the three countries was instrumental for data access.

Key data sources included firms' own material, such as websites, marketing material and annual reports. Also, legislative texts, standards, research reports, academic literature, trade journals etc. were used. In the case of Japan, the possibilities to use secondary data were more restricted due to the language barrier, and interviews were thus carried out with five companies in the prefabricated housing sector and with a number of experts, using an interpreter.

3.2.3. Results

Below, a case-by-case account of the different business models and their respective contexts is given. The conclusions are then accounted for.

3.2.3.1. United States

In the United States, business models based on third-party ownership (TPO) have been highly successful, accounting for 70-90% of residential installations in important sub-markets such as California, Arizona and Colorado. In these business models, the adopter is not the owner of the PV system. Instead, the system is owned by a firm providing a full-service solution including planning, installation and maintenance. Financing is obtained through an arrangement in which firms package several projects into funds that are sold to investors.

TPO models are commonly based on either a power purchase agreement (PPA) or a lease. In a PPA, adopters purchase the electricity that the PV system generates. Certain criteria are set for the price so that it is highly predictable over a period of 15-20 years. At the end of this term, the adopter can purchase the PV system, have it removed by the PPA provider or renew the agreement. In a lease, the adopter instead pays a time-based fee for using the system, and gets to use the produced electricity without additional payments. PV leasing has been common in states in which PPA has not been allowed.

The TPO models used in the United States have successfully addressed several common barriers to PV adoption. First, they have minimised consumer transaction costs. The adopter's only point of contact has typically been the firm providing the TPO model, rather than numerous actors such as installation and maintenance firms, banks, insurers and government agencies. The TPO firm has also taken care of any administrative tasks related to subsidies, permits and grid-connection. Second, risks related to the ownership have been shifted from the adopter towards the firm. Third, the adopter has not had to raise capital to finance the system.

TPO models have addressed barriers that have been particularly prevalent in the Unites States. Homeowners in the United States have had lower savings rates than homeowners in Japan or Germany, and potential adopters in the United States have thus been less likely to be able to finance a PV system upfront without a mortgage. Furthermore, access to home equity loans has been severely restricted in the wake of the financial crisis of 2008, which has left many homeowners 'underwater' (their home mortgage being larger than the value of their home), further restricting potential adopters' ability to finance a PV system purchase. People in the United States also tend to move relatively frequently, which for many potential adopters has likely increased the relative attractiveness of immediate electricity bill savings compared to a long-term investment in their home. Lastly, transaction costs in PV deployment have been higher in the United States than in Japan or Germany, which has made it more attractive for adopters to impose them on a third party.

3.2.3.2. Germany

In Germany, PV systems have mainly been financed and owned by the adopters themselves. In the business model dominating German PV deployment, the value proposition has been based on PV adoption as a low-risk financial investment fully competitive with other investment alternatives. Adopters have been guaranteed stable revenues for 20-21 years through a feed-in tariff scheme backed up by national legislation. Policymakers have regularly monitored the cost development of PV systems and adapted the feed-in tariffs to keep the IRR of PV adoption at around 7%.

Transaction costs in PV deployment have been relatively low in Germany. Institutional alignment and local learning among practitioners since the early 1990s have led to a relatively smooth deployment process, and legal-administrative processes related to PV deployment have become among the least complicated in Europe. The absence of high transaction costs has made the third-party owner somewhat redundant as a key function of a third-party owner is otherwise to absorb transaction costs. This is likely a partial explanation for German PV adopters' preference for purchasing and owning PV systems without the involvement of a third-party owner.

As German adopters have fully financed the upfront cost, the German business model has benefited from the availability of low-interest loans especially dedicated to PV. These loans have been provided through a government-owned bank since 1999. The loans have often been supplemented by equity from the customers, and the relatively high savings rates of German homeowners have thus facilitated the business model.

Just like firms in the United States, German firms have been offering a variety of services and features to reduce uncertainties and complexity. These include comprehensive insurance packages, long-term warranties for durability and performance, as well as certification of PV system components and installers through reputable organisations.

3.2.3.3. Japan

In Japan, the cross-selling of PV systems together with other products has been widespread, particularly in the construction sector. The *prefabricated homes industry* has been leading in this regard and, as early as 2011, about 60% of all new prefabricated homes came with a PV system. The prefabricated homes sector has held around 20% of the market for new homes and 10-15% of the residential PV market. The prefabrication of homes has been dominated by around ten large companies.

The value proposition has had several advantages compared to value propositions based on add-on PV systems. PV systems sold with new homes have been less expensive for the adopter than add-on systems, and roof integration has allowed for aesthetically appealing solutions. As the adopter has already established a contact with the supplier for the purpose of purchasing a home, transaction costs have been reduced for both parties. In Japan, PV adopters who have purchased their PV system together with a new home have typically been more satisfied with the adoption than have other PV adopters (Mukai et al., 2011).

The expenses for the PV system have generally been integrated into the home mortgage, reducing transaction costs and interest rates. As a mortgage needs to be issued for the home in any case, it has been easy to expand this loan to include the PV system. From the perspective of the financial institution issuing the loan, the income generated through the PV system has enhanced the adopter's creditworthiness. Building-integration has also been a benefit in this regard as a system physically integrated into the roof cannot as easily come adrift.

A key contextual factor explaining the success of this business model is the pre-existence of a highly industrialised prefabrication sector. Built upon large volumes, automation and advanced logistics systems, Japan's prefabrication industry has seemingly been the most industrialised house-building industry in the world. Industrialisation has brought about a high degree of standardisation, benefitting PV integration. The high level of industrialisation has, in turn, sprung out of a 'scrap and rebuild' culture in which almost 90% of all homes sold have been newly produced. Homes in Japan have typically depreciated very rapidly as they have increased in age.

Unlike in Western countries, prefabricated homes in Japan have been considered to be of higher quality than site-built homes, and they have typically been more expensive and equipped with more features. The cost savings achieved through industrialisation and mass-production have generally been used to add more features to the homes rather than to reduce consumer prices. Through this so called *mass customisation*, consumers have been offered a wide variety of choices between mass-produced components, including energy devices such as batteries, fuel cells, heat pumps and home energy management systems. PV systems have neatly fitted into this pattern.

Another relevant contextual factor has been the domestic PV industry, which has been dominated by large electronics companies keeping large parts of the PV value chain within their own organisation. The Japanese PV industry has played a key role in making prefabricated PV homes become common in Japan by marketing their products intensely towards the prefabrication industry rather than directly to consumers. They have also been seeking collaboration with prefabrication companies, something that, as revealed by the interviews, the prefabrication companies have often perceived as valuable and helpful. The interviews also revealed that house producers have tended to prioritise stable long-term partnerships with PV module suppliers over lower prices or higher efficiency of the modules. Although Japanese modules have been substantially more expensive than for example Chinese modules, all house producers interviewed used Japanese modules. They motivated this choice by explaining that communication with and reliability of the module producer and its products are crucial when modules are to be customised to fit the roofs.

Also, assurances of the national government that subsidies were to be present for an extended period have been important for the prefabrication industry to work with PV integration. Changing production lines is expensive, and the house-building industry has preferred certainty that PV systems were to remain attractive for their customers before making such investments.

3.2.3.4. Conclusions

In all three cases, the studied business models for PV deployment have enabled firms to overcome typical barriers faced by prospective PV adopters, such as complexity, transaction costs, risks and access to finance. Yet, the business models have been distinctively different. The analysis suggests that the differences between them have to a large extent been the result of differences in the national contexts in which they have occurred. The importance of context implies that business models for PV deployment cannot necessarily be viably transferred from one setting to another. (For example, recent attempts to implement TPO business models in Germany have not been very successful.)

The strong presence of TPO models in the United States and their absence in Germany and Japan is not likely to only be the result of differences in consumer preferences, but also of other contextual factors. TPO models have effectively addressed issues that have been particularly prevalent in the Unites States, such as low savings rates, restricted access to capital, high mobility on the housing market and high transaction costs. In Germany and Japan, on the other hand, higher savings rates, better access to low-interest loans, lower mobility on the housing market and lower transaction costs have made PV adopters more prone to purchase and finance the PV systems themselves.

TPO models for PV deployment may gradually lose their relevance for most adopters as PV markets mature. Market maturation usually entails a reduction in transaction costs and risks, which might make it more attractive for adopters to finance and own PV systems themselves. As TPO models require more middle-men capturing their share of the lifecycle economic gains of a PV system, business models based on self-ownership have the potential to become more financially beneficial for adopters. Once other barriers disappear, self-ownership could thus become the most viable option for most adopters also in markets such as the United States. A high proliferation of TPO models could perhaps even serve as an indicator for policymakers that there are barriers that should be dealt with. TPO models could, however, still prevail in mature markets to serve certain market segments, as some adopters might value the simplicity of TPO models more than the prospects of higher long-term financial gains.

3.3. Paper 3 – Local factors and information channels influencing PV deployment (Sweden)

3.3.1. Background

On the surface, the conditions for PV deployment seem to be rather homogenous throughout Sweden, as economic and institutional conditions do not differ much between different parts of the country. Yet, PV adoption rates vary between municipalities to an extent that is beyond what could be explained by local factors such as building stock characteristics, solar influx or average income. This raises the question of whether there are unknown local drivers present in these high-dissemination municipalities that have increased local adoption rates.

3.3.2. Objective and approach

This paper aimed at identifying and assessing factors that could explain high localised adoption rates of residential PV systems in Swedish municipalities. An explorative multiple-case study approach was used (Yin, 2009). Five municipalities that stood out in terms of high PV adoption rates were studied in depth. These main cases were then compared to 50 municipalities with low PV adoption rates, which were studied in less depth. Triangulation of quantitative and qualitative methods and different data sources was used to enhance the robustness of the findings.

The main cases were selected as follows. All Swedish municipalities were ranked by their per capita PV density and by their PV density in terms of number of PV systems per detached home. Those five municipalities that occurred in the top ten in *both* these rankings were selected. As comparison cases, the 50 municipalities with the lowest per capita PV adoption rates were selected (except for one municipality that was excluded because it had very few detached homes). The case selection was thus a combination of replication (cases with the same outcome on a key variable) and a 'two tail' design (cases on either extreme of a key variable) (Yin, 2009).

Data were collected by three main methods. First, a survey questionnaire (see appendix A) was sent by postal mail to all presumed PV adopters that could be identified in the five main case municipalities. The survey yielded 65 valid responses at a response rate of 80%. The aim of the survey was to assess various local information channels that might have affected the respondents' decision to adopt PV. Second, 16 interviews, as well as a number of shorter communications, were performed with local installers, electric utilities and other key actors. Third, comprehensive Internet searches were performed to identify actors and gather other relevant information about the cases.

The data necessary to estimate municipalities' adoption rates and to contact adopters were obtained from the Swedish Energy Agency. More specifically, a register of applications and approvals for the national investment subsidy scheme (this scheme has been described in section 3.1.3) was used, containing the names and addresses of adopters. Since few PV systems had been installed outside this scheme, these data were assumed to provide a good representation of the actual number of installations.

3.3.3. Results

The results pointed to local actors promoting PV as an important explanatory factor behind the relatively high adoption rates in the five main case municipalities. This finding was corroborated through triangulation, as the three main sources of data (survey, interviews and Internet searches) pointed largely to the same explanatory factors. Common to the five municipalities was the presence of local organisations promoting solar energy from an early stage, mainly electric utilities and installation firms selling PV systems and disseminating information. The survey respondents recognised that they had been influenced to a substantial extent by these activities. Overall, the respondents rated local information channels as slightly more influential than common non-local information channels such as nation-wide media, websites with a non-local focus and non-local acquaintances. The survey results indicated that the local factors had not only *raised the respondents' interest* in PV but also *influenced their final decision* to adopt, suggesting that these factors operated throughout a substantial portion of the innovation-decision process (cf. Rogers, 1983).

The relative importance of different factors varied between the studied municipalities. Regarding this variation, the survey results were largely in line with the results obtained through the interviews and Internet searches (factors that were found to be of high relative importance in a municipality using one method were also found to be of high relative importance using the other methods). For instance, in the two municipalities with the most active local utilities, the respondents regarded utilities as more important than respondents in the other three main case municipalities did. In one municipality where installations had been largely concentrated to one zip code area in which an installation company was based, peer effects and PV installers were recognised by the respondents as relatively important. In another municipality, where a local association has realised a number of larger ground-mounted PV installations, the presence of ground-mounted PV was recognised by the respondents as important in inspiring them to adopt PV.

Local electric utilities supporting PV appeared to have been a particularly important driver elevating local PV adoption rates. Local utilities promoting PV during the period studied were found in four of the five main case municipalities, while none of the local utilities in the 50 comparison municipalities were found to have engaged in PV promotion during or before the period studied. The local utilities supporting PV in the main case municipalities had started their promotion of PV *before* the PV market started taking off, indicating causation in the direction from utilities towards increased adoption rates. The importance of utilities was also recognised by the survey respondents. Seminars attended by the respondents had (as reported by the respondents) been arranged mainly by local utilities, and 54% and 24% of the respondents agreed that their final decision to adopt PV had to some or to a large extent, respectively, been due to their utility purchasing PV electricity.

The results also indicated some causality going in the other direction. During the interviews, some representatives of PV-promoting utilities acknowledged that their organisations had been influenced to some extent by customers adopting PV or contacting them for information on grid-connection of PV, thus pushing them towards developing strategies for PV. This reveals the presence of a positive feedback loop: customers influence their utilities, which in turn influence other customers to adopt. The interviews also revealed that the utilities' engagement in PV promotion had in most cases started largely as the result of one devoted staff member (usually the CEO). These persons had, for one reason or the other, adopted a positive attitude towards PV, and had had the personal drive to win their organisation over to promoting PV.

Lastly, respondents in all municipalities recognised having been influenced by PV adopters in their proximity (peer effects), both through direct communication with adopters and by observing PV systems in their neighbourhood. These findings were strengthened by the interviews with installation companies, which largely agreed that after installing a PV system at a particular place, they would often shortly thereafter get additional requests from homeowners in the same area. These homeowners had, according to the interviewees, often been inspired by the first installation. On average, the survey respondents considered local acquaintances to have been about as influential on their adoption decision as installation firms. However, local peers whom the respondents categorised as 'neighbours' were seen as having had a rather minor influence, indicating that the peer effects had been mediated through other kinds of social relations than those between people regarding each other primarily as neighbours.

3.4. Paper 4 – Peer effects in PV adoption (Sweden)

3.4.1. Background

The results of paper 3 suggested that peer effects (social influence between peers) have been a factor in reducing barriers to PV adoption in Sweden. A number of previous studies have also quantified peer effects in PV adoption in other settings, mainly Germany and the United States (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). This research has mainly been concerned with estimating the increased probability of PV adoptions occurring within a small geographical area as the result of previous adoptions in the vicinity. Little, however, has been known about the inner workings of peer effects in PV adoption. Thus, in paper 4, a closer look was taken at the role of peer effects among Swedish PV adopters.

3.4.2. Objective and approach

The study took a mixed-methods approach (combining quantitative and qualitative methods) to add knowledge of the inner workings of peer effects among Swedish PV adopters. More specifically, the research aimed at shedding light on what kinds of social relations mediate peer effects, what kind of information is transferred between the peers and what emotions are evoked leading to the adoption of a PV system.

Data were collected through a survey questionnaire (see appendix B) and interviews (see appendix C) with selected survey respondents. The survey was sent by postal mail to Swedish PV adopters. To maximise the occurrence of peer effects among the respondents, adopters living in zip code areas with high adoption rates were targeted. Just like for paper 3, data for estimating local adoption rates and addresses of adopters were obtained from the Swedish Energy Agency's register of applications and approvals for the national investment subsidy scheme. All Swedish zip code areas were ranked by their number of PV systems per capita, and the survey was sent to all 92 individuals that had had their applications for the subsidy approved in the 25 zip code areas with the highest adoption rates (except for five areas that were located in the municipalities studied in paper 3, which were excluded because the adopters on those areas had recently been sent a similar questionnaire). The survey yielded 65 valid responses at a response rate of 74% (four presumed adopters returned the questionnaire informing that they had in fact not adopted). The survey was mainly built upon five-point rating scales of both unipolar and Likert type, in which the respondents were asked to rate how they perceived that seeing PV systems or talking to PV adopters in or outside their neighbourhood had influenced their perceptions of PV technology.

Telephone interviews were performed with selected survey respondents. Those 22 respondents who reported having been in contact with at least one PV adopter in their neighbourhood prior to taking a final decision to adopt (and who had provided their telephone number) were selected, and full interviews were carried out with 16 of them. The interviews were recorded, and whenever the notes taken during the interviews were not considered detailed enough, the recordings were used to complement the notes. Key data were coded in a spreadsheet.

Considering that people tend to consistently underestimate the impact of social influence on their decision making (Nolan et al., 2008), the risk of overestimating peer effects using the chosen methodology, which relied on participants' self-estimation, was assumed to be small.

3.4.3. Results

As in paper 3, the presence of peer effects was widely recognised by the participating PV adopters. Among the survey respondents, 38% reported that contact with a peer (local or non-local) had been highly important ("4" or "5" in the rating scales) for raising their interest in PV. The corresponding figure for the final decision to adopt was 35%. Among respondents who had been in contact with an adopter in their neighbourhood before they decided to adopt (28 respondents), half agreed that the contact had been highly important for raising their interest in PV, and almost half did so regarding their final decision to adopt.

The interviews revealed that the contacts had almost exclusively occurred through pre-existing and rather close social networks, such as friends and family. Contacts with PV-using neighbours to whom the respondent had no deeper relationship had been rare and of minor importance (this was also suggested by the survey carried out for paper 3). This contrasts somewhat to what has been previously believed about peer effects in PV adoption, where the role of neighbour relations has (more or less implicitly) been assumed to be important. Furthermore, even though the sample was selected based on a presumed high occurrence of *local* peer effects, almost as many respondents reported having been highly influenced ("4" or "5" in the rating scales) by someone living *outside* as *inside* their neighbourhood.

The main function of the peer effects appears to have been a confirmation that PV works as intended and without hassle, rather than the procreation of unexpected insights or the provision of more advanced information. The confirmation was strengthened by the trustworthiness of the peers, who (apart from being known by the participants) as private homeowners were in a situation similar to that of the participants, and who (as opposed to PV installers) lacked economic incentives to recommend PV adoption. The information transferred had generally not been of a very advanced character, and had mainly related to ease of use and economic performance – that PV systems worked as intended and without hassle, and that they delivered as much electricity as expected. This information had, nevertheless, been perceived as useful by the interviewees; it had contributed to reducing a general uncertainty about PV as a new and 'unknown' technology, and had increased the participants' determination to adopt. Overall, few of the contact persons had recommended PV adoption outright – rather, they had provided more 'neutral' accounts of their experiences as adopters. Almost all interviewees had seriously contemplated PV adoption and acquired some knowledge of PV before any contact with previous adopters took place, and the contacts did thus not evoke much unexpected insight.

When it comes to the role of *passive* peer effects (influence of *seeing* PV), the results indicated that these had been of minor importance. As in the survey carried out for paper 3, seeing PV systems was regarded as a relatively important influential factor. However, a closer look at the data revealed that respondents who had seen a PV system in their neighbourhood tended to regard this as influential only if they had also been in contact with an adopter. The interviews confirmed that it was when a PV system had been seen in connection with adopter contact that it had been influential, for example when visiting a PV owner that demonstrated his or her PV system.

Contacts between the interviewees and previous adopters had come about in two principal ways: either the interviewee had approached the PV adopter with the purpose of acquiring information from him or her, or the topic had come up as they had met for another purpose. Only in one case had the interviewee experienced being approached by an adopter (other than a salesperson) who appeared to have had the purpose of talking about PV. In the previous literature, it has sometimes been assumed that seeing local PV systems tend to induce people to contact the systems' owners to get more information. However, the findings of the present study did not support that such an order of events had been common in the studied setting, as almost no contacts had come about as the result (partly or fully) of the interviewee first seeing the contact person's PV system.

4. Concluding discussion

In this section, a synthesis of the findings of the four papers will first be presented. The methodological contributions of the thesis will then be discussed. Based on the findings, some recommendations for policy will also be provided, both specific advice for reforms of Swedish policy and more general advice. Lastly, some pathways for further research will be suggested.

4.1. Synthesis of findings

The objective of this thesis was to identify and assess barriers and drivers to residential PV deployment in different geographical settings, taking the spatial dimension into account. The findings of each paper have been accounted for separately in section 3. The added value of this synthesis is that it builds a larger and more coherent picture of barriers and drivers on different spatial levels, thus contributing to an improved understanding of the geography of sustainability transitions (cf. Coenen et al., 2012; Hansen and Coenen, 2015).

While the price and performance of PV technology have been largely determined on the international level, the thesis goes into depth with barriers and drivers rooted in national and local settings. By studying altogether four national PV markets, papers 1 and 2 identify and assess barriers and drivers mainly rooted on the national level, providing various examples of how institutions, industry, culture and financial aspects have affected PV deployment. On the local level, papers 3 and 4 show how local organisations and private individuals have driven PV deployment through information provision and social influence. Together, barriers and drivers rooted on all these levels determine the conditions for PV deployment at any given location. Thus, an understanding of barriers and drivers on all levels is important.

Paper 1 took a systemic perspective to identify and assess barriers and drivers in Sweden. The analysis was facilitated by the technological innovation systems (TIS) framework, which guided the research to relevant actors, networks, institutions and processes. The analysis depicts a small, underdeveloped Swedish TIS for PV deployment, albeit in rapid growth in relative terms. Limited economic profitability in PV adoption was a crucial barrier during the period studied (also including subsidies). The results reveal that the Swedish policy environment has been uncertain and complex, creating problems for different actors. The institutional barriers in Swedish PV deployment (which have been described in more detail in section 3.1.3) could be coarsely summarised as follows: First, the fact that more than one subsidy scheme for PV deployment have been running in parallel is a complexity in itself. Second, there have been uncertainties regarding when different subsidies were to be available, and on what conditions. Third, important rules, mainly related to taxes, have been unpredictable.

Even though the institutions affecting PV deployment in Sweden have mainly been national, they have not always been fully controlled by the national government. For example, Swedish rules for taxes and building permits affecting PV deployment have partly been determined on the EU and the municipal levels, respectively. Paper 1 reveals that institutions on the EU level have restricted the ability of the Swedish government to adapt rules to PV and other micro-generation technologies, resulting in institutional rigidity that has contributed to a lock-in of the incumbent energy system (cf. Unruh, 2000).

The thesis also demonstrates that country-specific characteristics of a domestic industrial sector can be important for PV deployment. Paper 2 reveals that certain characteristics of the Japanese construction sector, such as a high degree of industrialisation and standardisation, have been important for the physical and organisational integration of PV into the construction of new buildings in Japan. Those factors are rather unique to the Japanese construction sector compared to other domestic construction sectors around the world. This is likely an important explanation of why the Japanese construction sector has been highly involved in PV deployment as compared to construction sectors in other important PV markets.

The thesis also identifies barriers and drivers that vary between countries but are less confined to administrative borders. Such factors include cultural and behavioural aspects such as savings rates, homeowner mobility (how often people move), accustomedness to TPO business models (not only for PV) and priorities regarding long-term versus immediate cost savings. As suggested by paper 2, these aspects will influence what kind of business models will be most viable within a certain context, as different business models are suited to overcome different barriers to deployment. Perhaps most importantly, this relates to the ability of potential adopters to raise capital and to their preferences regarding whether to own the PV system or consult a TPO firm. Another example is real estate prices, which have developed rather differently between countries and regions, influencing homeowners' ability to finance a PV system. If the value of a home substantially exceeds the mortgage for the same home, the homeowner can often quite easily get a home equity loan to finance a PV system. This will be the situation for most homeowners in regions where the prices of homes have increased substantially in recent years. On the other hand, there are many regions around the world in which the values of homes have decreased dramatically in the wake of the financial crisis of 2008. In these regions, homeowners will typically have less opportunity of getting a home equity loan, and many of them will be 'underwater', meaning that the value of their home is lower than their mortgage. These homeowners will often find it difficult to finance a PV system, and TPO business models might then be a viable option. As argued in paper 2, this is likely a contributing factor to the success of TPO business models in California, where housing prices declined substantially after the financial crisis.

Paper 2 illustrates that certain business models can successfully overcome complexities and uncertainties faced by prospective PV adopters on the national level. It is thus noteworthy that Sweden, with its complex and uncertain policy environment, has (as was found in paper 1) lacked alternative business models such as TPO even though these have been successful in addressing complexities and uncertainties in other countries. As argued in paper 2, a lack of alternative business models (such as TPO) could be a barrier for some categories of potential adopters, and trying to explain the absence of TPO models in Sweden is thus justified. Drawing on papers 1 and 2, this synthesis allows for some remarks in this regard. A first reason for the absence of TPO models in Sweden could be the low economic profitability of PV investments; TPO models require a middle-man taking a share of the life cycle economic gains of a PV system, and the total economic gains might simply have been too small in Sweden for TPO to be viable. Second, the small size of the Swedish PV market might have decreased the likelihood of TPO models occurring as they require a higher level of organisational sophistication. Third, the Swedish institutional uncertainties have created risks of events that would affect all installations simultaneously. This contrasts to risks of events that occur independently of one another for each installation. While TPO models do not address the former kind of risk (events affecting all installations simultaneously could ruin a TPO firm), they successfully address the latter kind by spreading the risks over a large number of installations. Fourth, the Swedish housing market has withstood the global financial crisis remarkably well from an international perspective, and the prices of homes have increased rather consistently during the last decade, which has made it easier for Swedish homeowners in general to finance PV systems themselves without the need for a TPO model.

When it comes to the local level, papers 3 and 4 point to local sources of information as being an important driver of PV deployment. Local information seminars organised by electric utilities seem to have had a substantial effect in increasing adoption rates in Swedish municipalities (paper 3), and basic information transferred between peers appears to have been important in convincing Swedish homeowners to adopt PV (paper 4). Even though information channels operating on a higher geographical level, such as websites directed towards a national or international audience and media with a national coverage, were important for the decision making of the participating adopters, the findings of paper 3 suggest that local sources of information were of equal or higher importance. A substantial function of the information appears to have related to raising the interest in PV among potential adopters, indicating a lack of basic awareness.

Even though the geographical entity studied in paper 3 was the municipality, the findings point to another geographical entity of relevance, namely the area covered by the electrical grid operated by a certain utility. Different utilities have developed different strategies and attitudes regarding PV, and the results of paper 3 strongly suggest that a local utility's supportive attitude can substantially increase local PV adoption rates. Even though these effects are surely not strictly confined to the area covered by the utility's grid, the reach of the grid is likely to be of significant importance as everyone connected to the grid is a customer of the utility and thus subject to its communication. While utilities might have different roles in different countries, previous research on local sources of market formation (Dewald and Truffer, 2012) has not acknowledged the role of utilities, which might be relevant in some (though likely not all) other countries as well.

A driver with an inherently large local component is *peer effects* (social influence between peers resulting in PV adoptions). Previous research has identified substantial localised peer effects in PV deployment using quantitative research methods (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). Little has been known, however, about the inner workings of peer effects in PV deployment. Together, papers 3 and 4 contribute to deepening the understanding of peer effects by surveying in total 130 PV adopters and interviewing 16 of them, thus introducing a qualitative perspective that has been lacking in the previous research. Paper 3 confirms that peer effects in PV adoption also exist in the Swedish setting, and the paper provides some tentative findings regarding their underlying mechanisms. In paper 4, the mechanisms behind the peer effects were investigated more deeply. The two papers used data from different sets of participants (one set for each paper) and, as some survey items were identical or very similar for the sets, they together provide a larger sample on some aspects.

Paper 4 suggests that the main function of the peer effects was a *confirmation* from a trustworthy source that PV adoption would be a sound choice. The information transferred was generally not of a very advanced character, and related mainly to ease of use and economic performance – that the technology worked as intended and without hassle, and that it delivered as much electricity as expected. This information was perceived as useful by the interviewees, and it contributed to reducing a general uncertainty regarding PV as a new and 'unknown' technology, thus reducing barriers to adoption. Paper 4 was unique not only to the Swedish context, but also globally, as peer effects in PV adoption had not previously been studied through interviews with adopters.

The results of papers 3 and 4 suggest that the main reason (at least in the studied setting) for peer effects having a large local component is that people who are family and friends tend to live close to one another, rather than people influencing one another through more superficial neighbour relations. Both papers reveal that relations with people who the adopters perceived as ‘neighbours’ were perceived to have been of minor importance – instead, the influence had taken place through closer and more established social networks. The high degree of localisation in peer effects has led to an assumption in the previous literature that neighbour relations and passive influence (through passively observing neighbours’ PV systems) have been important mediators of peer effects. However, paper 4 suggests that passive peer effects played but a minor role in the studied context. One implication of these results relates to the fruitfulness of different computational models of peer effects in PV deployment. Two different approaches to such models are based on social networks and geography, respectively (Bale et al., 2013; Rode and Weber, 2013). The results of this thesis indicate that the former approach might more accurately reflect the underlying processes at work.

Lastly, the thesis demonstrates how the local nature of PV deployment can create inefficiencies, at least in a small and early market such as the Swedish one. Paper 1 reveals that the installation of PV systems in Sweden has been dominated by small, local firms that have often not been exclusively devoted to PV technology, thus lacking the benefit of specialisation. This can be seen as a consequence of the fact that PV systems need to be installed on-site by the firm’s staff, in combination with a small market size. Several of the installers interviewed for paper 1 expressed the ambition to become more specialised, claiming that the small market size within their catchment area would not support specialisation. With limited demand for PV systems within a reasonable travelling distance, a full-time job cannot be sustained by the demand for PV installations only. This leads to poor economies of scale on the local level, and to a lack of competition as the number of installers offering their services in any given place will be limited.

4.2. Methodological contribution

The thesis makes some contributions regarding research methodology, which will be discussed below. A first contribution relates to the application of the TIS framework. In paper 1, this framework was used to study PV deployment separately from processes occurring earlier in the PV value chain. Paper 1 demonstrates that it is meaningful to apply the TIS framework to study deployment separately in order to identify and assess barriers and drivers, and that deployment taken on its own is a complex and systemic process that motivates the use of a holistic analysis tool such as the TIS framework. The thesis argues that in cases where a mature technology is to be deployed in a catching-up market that is small in relation to the international production system for the technology in question, a pure deployment focus is motivated in TIS analyses. The value of this contribution is made evident by the fact that a pure deployment focus allows the researcher to focus his or her resources on the deployment phase, thus avoiding spending valuable time studying technology development and production, and saving him or her the effort of doing an international and spatially differentiated TIS analysis. Furthermore, increasing global specialisation and division of labour, as well as an increasing availability of mature renewable energy technologies that can be deployed in new regions, can be expected to create an increasing need for deployment-focused TIS studies (see section 2.1.1.3).

The thesis also demonstrates how the TIS framework, the business models framework and Rogers' diffusion of innovations framework can be combined to study technology deployment (see section 2.1). The latter two frameworks fit within the scope of the TIS framework and are appropriate choices when zooming in on selected parts of a TIS that relate to technology deployment. The thesis argues that the latter frameworks connect well to certain phenomena described in the TIS literature, such as certain categories of actors and the functions 'entrepreneurial experimentation', 'knowledge development and diffusion', 'legitimation' and 'market formation'. Thus, the latter frameworks could well be positioned within the TIS framework – the very concept of a 'business model', as well as various core concepts within both the frameworks, could be incorporated into the TIS framework, in some cases perhaps by replacing existing terminology. This would, nevertheless, require a deeper analysis, which is beyond the scope of the present thesis.

Another methodological contribution relates more directly to the application of the business models framework. In paper 2, the viability of different business models for PV deployment in different countries was studied. Previous literature on business models had elaborated upon how business model innovation can bring new (sustainable) technologies to the market (Bocken et al., 2014; Boons and Lüdeke-

Freund, 2013; Mont et al., 2006; Reim et al., 2015; Tukker, 2004) and upon the role of the wider sociotechnical context for shaping business models (Birkin et al., 2009; Budde Christensen et al., 2012; Casper and Kettler, 2001; Linder and Cantrell, 2000; Provance et al., 2011). The methodological uniqueness of paper 2 was that it combined the business models framework with a comparative case study approach to pinpoint contextual factors in different geographical settings. This had not previously been done for PV technology and, to the best knowledge of the authors, it had not been done for the deployment of any other technology either. The approach proved useful in understanding how different business models can overcome contextual barriers (see section 3.2.3) to technology deployment and thereby create value for adopters and firms.

Also some contributions regarding methodology to study local variations in PV adoption rates were made. For paper 3, an approach based on comparative case studies was developed to identify and assess local drivers in Swedish municipalities. A combination of a replication and a 'two tail' design (Yin, 2009) was used. Five 'main cases' (municipalities with the highest adoption rates) and 50 'comparison cases' (municipalities with the lowest adoption rates) were studied. The number of comparison cases was larger because data were scarcer for this category. The comparative element of the approach was two-fold. First, the main cases were compared to one another. Second, the two categories of cases were compared to each other. The method proved useful to pinpoint local drivers that could explain why certain municipalities have stood out in terms of high PV adoption rates. To the best knowledge of the author, there has not previously been any research on local variations in technology adoption rates using an approach including the elements described above.

Furthermore, paper 3 introduced a novel approach for dealing with differences in building stock when selecting cases for comparative case studies of geographical differences in PV adoption rates. There is often a need to take building stock into consideration when studying causal factors behind PV adoption rates, as the characteristics of the built environment (e.g. the share of detached homes) may otherwise become an important confounding variable. For paper 3, all Swedish municipalities were ranked by their PV-density using two measures: the number of PV systems *per capita* and *per detached home*. Municipalities that occurred at the top or bottom of *both* these rankings were selected. The inclusion of the latter criteria served as a control mechanism, reducing the risk of local building stock characteristics confounding the selection process (see section 3.3.2).

Lastly, for paper 4, a mixed-methods approach was developed to study peer effects in PV adoption, combining qualitative and quantitative research methods through a survey and follow-up interviews with selected respondents. Thus, a qualitative perspective that had hitherto been lacking in studies of peer effects in PV adoption was introduced. As peer effects are by nature closely related to the adopters' own thoughts and emotions, survey data arguably need to be complemented with interviews – particularly in a stage where the understanding of the effects is limited – to make sure that the survey data have been interpreted correctly and to increase the chances of identifying any important matters not identified through the survey. The method proved useful to nuance the previous understanding of peer effects in PV adoption, and continued research using this or similar approaches may be fruitful in achieving a deeper understanding of peer effects in the adoption of PV or other technologies.

4.3. Implications for policymakers, firms and others

Based on the findings of this thesis, some recommendations can be derived for policymakers, firms and other actors aiming to support PV dissemination. Below, a set of general advice will first be provided. Then, a number of more specific recommendations for reforms of existing Swedish policy will follow.

A first set of advice relates to *business models* for PV deployment (paper 2). The findings regarding the relationship between business models and their surrounding context may be useful to both policymakers and firms. Even though the research on business models was not carried out in Sweden (as was the rest of the research), the findings might prove useful to overcome barriers in Sweden and other catching-up markets.

One piece of advice for policymakers is to remove any institutional barriers that might obstruct the use of certain business models, or to provide enabling legislation for business models that have proven viable in other contexts. Preferences vary between consumer groups, and a variety of business models for prospective adopters to choose from could thus increase the overall adoption rates by satisfying the preferences of a larger number of consumers. Furthermore, a substantial number of the potential adopters will, in many contexts, find it difficult to finance and own a PV system even if a purchase would be their first choice. Any institutions hindering TPO business models may thus impose a barrier to PV deployment. This does not necessarily mean that policy has failed if all business models that have proven successful in other markets are not present in the market of interest, as it might simply be the case that the market has selected against certain business models due to differences in consumer preferences or other contextual differences that are beyond the direct control of policymakers.

When it comes to firms, the findings on business models could be informative when planning to enter new markets or targeting certain consumer segments. The findings could also guide firms in how to respond to a changing context.

A second set of advice relates to *electric utilities* (organisations operating electrical grids). Paper 3 strongly suggests that local utilities can elevate PV uptake in their area by supporting PV. Policymakers could exploit this by influencing utilities to take a supportive attitude towards residential PV. Such influence could be exercised by informing utilities about PV technology and about how other organisations have worked with PV, for instance by offering utilities' staff training as to how to best support PV deployment. A web-based platform for the provision and exchange of information directed towards utilities could be implemented (perhaps as part of a larger platform for PV information directed to a broader audience). Educating utilities might both increase the chance of them choosing to support PV deployment, and make utilities perform better in providing their customers with relevant information. In cases where a government owns a utility (Swedish utilities are, for example, often owned by local governments), the government could steer the utility towards promoting PV. Utilities could also be regulated to take a more active role in PV deployment.

Another piece of advice is to arrange *information seminars* targeting private homeowners. Such seminars could be arranged by any actor (such as utilities, non-profit organisations, local governments and installation firms) interested in supporting PV deployment. Paper 3 suggests that local information seminars have been an effective strategy to convince homeowners to adopt PV in Sweden. The effectiveness of seminars might, nevertheless, depend on context-specific factors. Two key characteristics of the Swedish PV market are that it is in an early stage of development and that there is limited economic profitability in residential PV adoption. As convincingly argued by Noll et al. (2014), there are reasons to believe that information provision has the highest prospects of being effective in markets where PV is neither very profitable nor clearly unprofitable. Awareness of PV might also be lower in early markets, in which case there is a higher need for information dissemination. The generalisability this advice might thus be more or less limited to markets that are similar to Sweden in these respects.

A last piece of advice relates to *peer effects* (papers 3 and 4). Actors with a goal to increase PV uptake could seek to make use of peer effects by involving existing PV adopters in information campaigns or marketing. This might prove a cost-effective strategy for policy and businesses even if the existing adopters are economically compensated for their involvement.

Paper 4 reveals that information obtained from peers plays a partly different and complementary role compared to other information sources, such as the advice of professionals. Peers (at least in the context studied) seem to convince each other to adopt PV by giving reassurance that adoption is indeed a sound choice, rather than through the provision of more factual information (which can be found in written sources or obtained through professional advisers). Trust is not only gained through established social relations, but also through peers being in a similar situation (as private homeowners), having actual experience as adopters, and (as opposed to firms) lacking economic incentives to portray PV in an excessively positive manner. The participation of PV adopters in information campaigns or marketing could thus be effective as a complement to other means of information provision.

There are various conceivable strategies for making use of peer effects. One suggestion is to include sessions in information seminars where visitors get the opportunity to talk to adopters, for example in Q&A sessions or group discussions. Study visits could also be organised by firms or policymakers to the premises of adopters to let attendants see their PV system and talk to them. Another option would be to have local energy advisors provide citizens with contact information to local adopters. Policymakers might even want to target certain individuals to become PV adopters if these individuals could be expected to be particularly likely to create further adoptions through peer effects. If so, the findings of paper 4 suggest that socially well-connected individuals should be targeted rather than individuals who have the most visible rooftops.

4.3.1. Reforms of existing Swedish policy

A substantial portion of the research behind this thesis relates to existing Swedish institutions, and the results thus lend themselves to some Sweden-specific policy advice. This advice does not involve increased subsidisation, but rather changes in the design of existing subsidy schemes or other advice that does not require increased public spending. The advice relates to issues that were identified in the research *and* that are still present at the time of finishing the thesis (December 2016), which includes the majority of the issues identified in the research.

Paper 1 points to several uncertainties and complexities in the Swedish policy framework that could be addressed. First, the circumstance that more than one subsidy schemes for PV deployment have been running in parallel is an unnecessary complication that creates extra administration and transaction costs for adopters, installation firms and authorities, and that makes it more difficult for (potential) adopters to estimate the economic consequences of PV adoption. At the time of writing (December 2016), three subsidy schemes are running in parallel, as the proposed tax reduction was implemented after the completion of paper 1. Second, it was – and still is – unclear for how long the different subsidy schemes will run. The total budget for PV within these schemes should thus preferably be gathered within one coherent long-term strategy with high predictability and transparency.

The most important Swedish subsidy scheme for PV deployment – the investment subsidy launched in 2009 – has been flawed with uncertainties. This issue could be addressed through some relatively straightforward reforms. First, the scheme's duration and future remuneration levels should be planned and made transparent. This could be done through the setting of certain conditions to determine the future development of the scheme. For example, it could be decided that investing in a residential PV should yield a certain economic profitability, e.g. an IRR of around 5%. Factors that influence this figure (most importantly the cost development of PV systems) should then be monitored continuously so that remuneration levels can be adapted to keep the profitability at the desired level. Once the profitability reaches the desired level without the need for subsidies, the scheme has served its purpose and should be terminated. Second, measures should be taken to mitigate the long queue of applications awaiting approval. Even though the remuneration level has been reduced to 20% since paper 1 was finished while a substantial amount of long-term funding has been added, the long queue has persisted, resulting in waiting times of up to two years as of November 2016 (Svensk Solenergi, 2016). As regards the market fluctuations caused by discontinuations in the scheme, this problem appears to have been resolved. Even if new discontinuations in the scheme would occur, the current remuneration level of only 20% in combination with reduced prices of PV systems have induced an increased share of the new adopters to purchase the system *before* their application is approved, hoping to get the subsidy retroactively. This secures a more evenly distributed demand for PV systems regardless of any discontinuations in the scheme.

Paper 1 also shows that the tradable green certificates (TGC) scheme, which has been available for PV and other renewables since 2003, has been poorly adapted to residential PV and other modes of micro-production of electricity. To adapt this scheme, the selling of small quantities of certificates could be made easier. This could be achieved for example through the provision of a user-friendly web-based trading platform, or by authorities purchasing certificates at market rates from micro-producers using an automated system (the authorities could then re-sell the certificates in bulk to other actors). Another issue is the high cost for micro-producers of acquiring certificates for self-consumed electricity, as this requires the installation of additional metering equipment. This could – if the TGC scheme is to be intended for micro-producers in the future – be solved through for example relaxed requirements on metering, certificates for self-consumption being granted on the basis of a template, or by providing PV adopters with free metering equipment. However, a burning issue is whether the TGC scheme should be intended at all for micro-production. If so, the scheme should be adapted accordingly. If not, micro-production should be formally excluded from the TGC system (any subsidisation should then be carried out by other means).

The building permit system could also be reformed. To reduce complexity, rules could be standardised between municipalities. Building permits for residential PV could also be abolished if certain criteria are fulfilled (e.g. that the panels follow the inclination of the roof). Fees could be abolished, or only be due once a permit has been approved (thus reducing uncertainty and risk for prospective adopters). Information on building permits regarding fees, requirements, administration time etc. could be provided on municipalities' websites.

As regards uncertainties regarding tax rules, it was recently (after the completion of paper 1) established that residential PV adopters are under most circumstances indeed not subject to extra taxation and related administration. Any remaining uncertainties could be mitigated by adaptation of rules in a planned, transparent manner, by clear and official statements regarding the intended direction of future reform, or by clarifying official statements regarding how existing rules should be applied.

4.4. Suggestions for further research

In this section, some possible lines of research that could be addressed subsequent to this thesis will be identified. Four potential areas of research will be discussed, one following each paper.

4.4.1. Technological innovation systems (TIS)

As argued in this thesis, there will likely be an increasing need for TIS studies focusing exclusively on the deployment phase of PV (as was done in paper 1) and other technologies. Although this thesis makes some methodological contributions in how to perform such studies (see section 4.2), further methodological development is needed. For example, methods need to be developed regarding how to set system boundaries for geography and value chain based on what phenomena interact in a systemic manner and how different phenomena relate to space. A deployment focus is also likely to have implications regarding the functional dynamics of TISs. The relative importance of different functions might change in some generalisable ways and there might be differences in which functions are important on different geographical scales. New empirical research, or re-analysis of existing TIS literature with a 'new lens', might shed light on these issues.

Conceptual work could also be done regarding how the TIS framework connects to other streams of literature. As observed in this thesis (see section 2.1), the business models framework as well as Rogers' diffusion of innovations framework both fit within the scope of the TIS framework and are useful when zooming in on certain key parts of a TIS. These, and perhaps other, frameworks could be more elaborately positioned within the TIS framework in future conceptual work.

4.4.2. Business models and their context

Paper 2 served as a first step in analysing how business models for PV deployment depend on barriers and other contextual factors in different geographical settings. The findings pointed towards a number of factors that appeared to have influenced the success of different business models in the studied markets. However, more research is needed in order to gain a deeper understanding of how and to what extent these and other factors influence the viability of different business models. As an increasing number of PV markets become mature enough to host more elaborate business models, there will be more potential cases to study. Paper 2 could also be complemented through data collection from adopters (surveys, interviews) in the studied markets or in other markets. This could shed light on adopters' motives for preferring a certain business model, and on whether any particular contextual factors influenced their preferences. Furthermore, business models for the deployment of other technologies than PV could be studied in relation to their context. This could yield valuable technology-specific as well as generalisable knowledge regarding the relationship between business models and their context.

4.4.3. Local barriers and drivers

Paper 3 was and early attempt to identify causes of locally elevated adoption rates of residential PV. There are several ways to continue this line of research. First, the adopter perspective could be further explored, e.g. through interviews with adopters in municipalities with high adoption rates. This way, a deeper understanding of factors influencing the different stages of their adoption decision process could be gained. Approaches similar to that developed for paper 3 could also be used to study other settings than the Swedish one. This could reveal to what extent the findings of paper 3 are generalisable; for example, the findings might be specific for early PV markets or for some other characteristic that Sweden shares with certain other settings. Another possibility would be to use statistical regression analyses to compare municipalities or other geographical entities with each other, using PV adoption rates as the dependent variable. This could reveal correlations not visible through case study methodology.

One finding of paper 3 was that local electric utilities supporting PV appeared to have had a substantial positive effect on adoption rates. This could be further explored in different ways. For example, it could be investigated why some utilities choose to engage in PV promotion and sales. From a purely economic perspective, promoting PV might appear as a bad decision for utilities as increased PV penetration undermines their source of revenue. Furthermore, PV sales are arguably beyond their core business. Research on incumbent companies in the offshore oil and gas sector that have diversified into wind power suggests that a key reason for this diversification has been to attract the most talented staff for use in their core business (Hansen and Steen, 2015). However, there is as yet little research on the reasons for energy incumbents to engage in renewables, and on whether and under what circumstances such engagement might be economically rational for such organisations.

Furthermore, the role (current and potential) of utilities might differ between countries. For example, utilities are typically highly regulated on the national level, which might create rather different opportunities for utilities in different countries to act beyond their core tasks (and thus to support PV). This could be researched.

Lastly, more research could be done on the role of local information in increasing PV adoption rates. The findings of paper 3 indicated that information seminars have been important in the cases studied, but little is known about what defines successful information dissemination on the local level (e.g. how an information seminar should be designed in order to spur PV adoptions). As information dissemination can be a low-cost intervention, it can (if effective) be a cost-effective way to increase PV uptake. For example, it has been argued that information dissemination has the highest potential to be effective in early markets in which PV is neither very profitable nor clearly unprofitable (Noll et al., 2014), but there is currently little empirical evidence to support this.

4.4.4. Peer effects

This thesis offers an initial attempt to understand the inner workings of peer effects in PV adoption. To build a more solid understanding of the mechanisms behind these peer effects, more qualitative empirical research is needed. Using the approach developed for paper 4 or a similar methodology combining survey and interviews appears to be a fruitful way of moving this research forward. Data could be collected from adopters, non-adopters, or potential adopters in different settings.

Depending on the exact research question and on the expected occurrence of useful information among adopters, representative or purposeful sampling could be used. For example, peer effects could often be expected to be more common in areas with high adoption rates. Thus, any given sample size could yield more useful information through purposeful sampling in such areas. As large samples are costly to manage, purposeful sampling could be beneficial in situations where a representative sample is not necessary. Future research could in those cases imitate or be inspired by the sampling strategy developed for the present thesis.

Research could also be done to find out whether and how the characteristics of peer effects vary between different contexts, such as between early and more mature markets. For example, as early adopters are generally more cosmopolite than later adopters (Rogers, 1983), peer effects might be less localised in early markets (as was the case in the studied Swedish early market).

The findings of this thesis raise some doubt as to the role of passive peer effects in PV adoption. In previous literature, these have often been assumed to be an important part of the 'total' peer effects. The importance of the passive component could be assessed by investigating the impact of PV systems' visibility. If, for example, rooftop PV systems facing roads generate substantially larger increases in local adoption rates than PV systems facing backyards, this could indicate a large passive component.

Lastly, the possibilities of utilising peer effects in campaigns could be explored. Is, for example, information provision (e.g. seminars) more effective when adopters are involved? How should they be engaged to make the highest impact: should they give lectures, be available for Q&A sessions, or take part in conversation groups? (As anecdotal evidence, small conversation groups among seminar participants were described as a very important influential factor by one of the interviewees.) Would it be cost-effective to pay them to participate? Are organised study visits to PV adopters' premises a viable strategy? Such alternatives could be investigated, for example through experiments.

5. Conclusions

This thesis identifies and assesses various barriers and drivers to the deployment of residential PV systems in different geographical contexts. Using a sociotechnical systems approach, the thesis demonstrates how the *technological innovation systems* TIS framework can be amended by the *business models* and the *diffusion of innovations* frameworks to study the deployment of a mature technology (in this case PV) in a catching-up market, treating the development and production of the technology as a 'black box'. On the national level, the analysis shows that the Swedish sociotechnical system for residential PV deployment has been immature and infested by various institutional barriers. Most notably, the Swedish subsidy schemes for PV deployment have been flawed with uncertainties and complexities, and there have been important uncertainties regarding the future development of the Swedish institutional set-up. The results also demonstrate how barriers in different national contexts have affected what kinds of business models for PV deployment that have been viable. On the local level, the results demonstrate how actors such as local electric utilities and private individuals have influenced homeowners to adopt PV through information dissemination and social influence (peer effects). The findings can inform policymakers, firms and other actors as to how to better support PV deployment.

6. References

Amit, R., Zott, C., 2001. Value creation in E-business. Strateg. Manag. J. 22, 493–520. doi:10.1002/smj.187

Antràs, P., Chor, D., Fally, T., Hillberry, R., 2012. Measuring the Upstreamness of Production and Trade Flows. Am. Econ. Rev. 412.

Arvizu, D., Balaya, P., Cabeza, L.F., Hollands, K.G.T., Jäger-Waldau, A., Kondo, M., Konseibo, C., Meleshko, V., Stein, W., Tamaura, Y., Xu, H., Zilles, R., 2011. Direct Solar Energy, in: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (Eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Awerbuch, S., 2000. Investing in photovoltaics: risk, accounting and the value of new technology. Energy Policy, The viability of solar photovoltaics 28, 1023–1035. doi:10.1016/S0301-4215(00)00089-6

Axsen, J., Mountain, D.C., Jaccard, M., 2009. Combining stated and revealed choice research to simulate the neighbor effect: The case of hybrid-electric vehicles. Resour. Energy Econ. 31, 221–238. doi:10.1016/j.reseneeco.2009.02.001

Baldwin, R., Robert-Nicoud, F., 2014. Trade-in-goods and trade-in-tasks: An integrating framework. J. Int. Econ. 92, 51–62. doi:10.1016/j.jinteco.2013.10.002

Bale, C.S.E., McCullen, N.J., Foxon, T.J., Rucklidge, A.M., Gale, W.F., 2013. Harnessing social networks for promoting adoption of energy technologies in the domestic sector. Energy Policy 63, 833–844. doi:10.1016/j.enpol.2013.09.033

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B., 2015. Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. Environ. Innov. Soc. Transit. 16, 51–64. doi:10.1016/j.eist.2015.07.003

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Res. Policy 37, 407–429. doi:10.1016/j.respol.2007.12.003

Bergek, A., Jacobsson, S., Sandén, B., 2008b. Legitimation and development of positive externalities: Two key processes in the formation phase of technological innovation systems. Technol. Anal. Strateg. Manag.

Bhaskar, R., Frank, C., Høyer, K.G., Naess, P., Parker, J. (Eds.), 2010. Interdisciplinarity and Climate Change: Transforming Knowledge and Practice for Our Global Future, 1 edition. ed. Routledge, London; New York.

Date Submitted	11/6/2018	**Section**	3401	**Proponent**	Bryan Holland
Chapter	34	**Affects HVHZ**	No	**Attachments**	Yes
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **Yes** **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposed modification revises the applicability of the FBC-R related to electrical installations by providing a pointer to the NFPA 70 for compliance and requests the rest of Chapter 34 and all of Chapter 35-43 to be placed in "reserved" status.

Rationale

Having electrical installation requirements for buildings under the scope of the FBC-R in both the NEC and Chapters 34-43 of the FBC-R has caused confusion and has complicated proper enforcement. Since the rules outlined in Chapters 34-43 are direct extracts from the NEC, these rules are not needed in the FBC-R here in the state of Florida.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

This proposed modification will enhance the enforcement of the code by simply referencing the NEC for electrical installation compliance.

Impact to building and property owners relative to cost of compliance with code

This proposed modification will have little to no impact on building and property owners.

Impact to industry relative to the cost of compliance with code

This proposed modification will not result in any change of cost of compliance with the code.

Impact to small business relative to the cost of compliance with code

This proposed modification will have little to no impact on small business.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

This proposed modification has no impact on the health, safety, and welfare of the general public.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

This proposed modification improves the code usability and enhances proper enforcement of the code.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

This proposed modification does not discriminate against materials, products, methods, or systems of construction.

Does not degrade the effectiveness of the code

This proposed modification enhances the effectiveness of the code.

1st Comment Period History

E7199-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the Code includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

(See attached support file for complete proposed modification)

E3401.1 Applicability.

Electrical systems, equipment, and components for buildings under the scope of this code shall comply with the applicable provisions of NFPA 70, National Electrical Code. ~~The provisions of Chapters 34 through 43 shall establish the general scope of the electrical system and equipment requirements of this code. Chapters 34 through 43 cover those wiring methods and materials most commonly encountered in the construction of one- and two-family dwellings and structures regulated by this code. Other wiring methods, materials and subject matter covered in NFPA 70 are also allowed by this code.~~

E3401.2 Scope.

RESERVED

~~Chapters 34 through 43 shall cover the installation of electrical systems, equipment and components indoors and outdoors that are within the scope of this code, including services, power distribution systems, fixtures, appliances, devices and appurtenances. Services within the scope of this code shall be limited to 120/240-volt, 0- to 400-ampere, single-phase systems. These chapters specifically cover the equipment, fixtures, appliances, wiring methods and materials that are most commonly used in the construction or alteration of one- and two-family dwellings and accessory structures regulated by this code. The omission from these chapters of any material or method of construction provided for in the referenced standard NFPA 70 shall not be construed as prohibiting the use of such material or method of construction. Electrical systems, equipment or components not specifically covered in these chapters shall comply with the applicable provisions of NFPA 70.~~

E3401.3 Not covered.

RESERVED

~~Chapters 34 through 43 do not cover the following:~~

~~1. Installations, including associated lighting, under the exclusive control of communications utilities and electric utilities.~~

~~2. Services over 400 amperes.~~

E3401.4 Additions and alterations.

Any addition or alteration to an existing electrical system shall be made in conformity to the provisions of the Florida Building Code, Existing Buildings and NFPA 70, National Electrical Code. ~~Chapters 34 through 43. Where additions subject portions of existing systems to loads exceeding those permitted herein, such portions shall be made to comply with Chapters 34 through 43.~~

CHAPTER 34
GENERAL REQUIREMENTS

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~~This Electrical Part is a compilation of provisions extracted from the 2014 edition of the NEC. The NEC, like all NFPA codes and standards, is developed through a consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on fire and other safety issues. While the NFPA administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate or verify the accuracy of any information or the soundness of any judgments contained in its codes and standards.~~

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SECTION E3401
GENERAL

E3401.1 Applicability.

Electrical systems, equipment, and components for buildings under the scope of this code shall comply with the applicable provisions of NFPA 70, National Electrical Code. ~~The provisions of Chapters 34 through 43 shall establish the general scope of the electrical system and equipment requirements of this code. Chapters 34 through 43 cover those wiring methods and materials most commonly encountered in the construction of one- and two-family dwellings and structures regulated by this code. Other wiring methods, materials and subject matter covered in NFPA 70 are also allowed by this code~~.

E3401.2 Scope.

RESERVED

~~Chapters 34 through 43 shall cover the installation of electrical systems, equipment and components indoors and outdoors that are within the scope of this code, including services, power distribution systems, fixtures, appliances, devices and appurtenances. Services within the scope of this code shall be limited to 120/240-volt, 0- to 400- ampere, single-phase systems. These chapters specifically cover the equipment, fixtures, appliances, wiring methods and materials that are most commonly used in the construction or alteration of one- and two-family dwellings and accessory structures regulated by this code. The omission from these chapters of any material or method of construction provided for in the referenced standard NFPA 70 shall not be construed as prohibiting the use of such material or method of construction. Electrical systems, equipment or components not specifically covered in these chapters shall comply with the applicable provisions of NFPA 70.~~

E3401.3 Not covered.

RESERVED

~~Chapters 34 through 43 do not cover the following:~~

~~1. Installations, including associated lighting, under the exclusive control of communications utilities and electric utilities.~~

~~2. Services over 400 amperes.~~

E3401.4 Additions and alterations.

Any addition or alteration to an existing electrical system shall be made in conformity to the provisions of the Florida Building Code, Existing Buildings and NFPA 70, National Electrical Code. ~~Chapters 34 through 43. Where additions subject portions of existing systems to loads exceeding those permitted herein, such portions shall be made to comply with Chapters 34 through 43.~~

SECTION E3402
BUILDING STRUCTURE PROTECTION

E3402.1 Drilling and notching.

RESERVED

~~Wood-framed structural members shall not be drilled, notched or altered in any manner except as provided for in this code.~~

E3402.2 Penetrations of fire-resistance-rated assemblies.

RESERVED

~~Electrical installations in hollow spaces, vertical shafts and ventilation or air-handling ducts shall be made so that the possible spread of fire or products of combustion will not be substantially increased. Electrical penetrations into or through fire-resistance-rated walls, partitions, floors or ceilings shall be protected by approved methods to maintain the fire-resistance rating of the element penetrated. Penetrations of fire-resistance-rated walls shall be limited as specified in Section R302.4. (300.21)~~

E3402.3 Penetrations of firestops and draftstops.

RESERVED

~~Penetrations through fire blocking and draftstopping shall be protected in an approved manner to maintain the integrity of the element penetrated.~~

SECTION E3403
INSPECTION AND APPROVAL

E3403.1 Approval.

RESERVED

~~Electrical materials, components and equipment shall be approved. (110.2)~~

E3403.2 Inspection required.

RESERVED

~~New electrical work and parts of existing systems affected by new work or alterations shall be inspected by the building official to ensure compliance with the requirements of Chapters 34 through 43.~~

E3403.3 Listing and labeling.

RESERVED

~~Electrical materials, components, devices, fixtures and equipment shall be listed for the application, shall bear the label of an approved agency and shall be installed, and used, or both, in accordance with the manufacturer's installation instructions. [110.3(B)]~~

SECTION E3404
GENERAL EQUIPMENT REQUIREMENTS

E3404.1 Voltages.

RESERVED

~~Throughout Chapters 34 through 43, the voltage considered shall be that at which the circuit operates. (110.4)~~

E3404.2 Interrupting rating.

RESERVED

~~Equipment intended to interrupt current at fault levels shall have a minimum interrupting rating of 10,000 amperes. Equipment intended to interrupt current at levels other than fault levels shall have an interrupting rating at nominal circuit voltage of not less than the current that must be interrupted. (110.9)~~

E3404.3 Circuit characteristics.

RESERVED

~~The overcurrent protective devices, total impedance, equipment short-circuit current ratings and other characteristics of the circuit to be protected shall be so selected and coordinated as to permit the circuit protective devices that are used to clear a fault to do so without extensive damage to the electrical equipment of the circuit. This fault shall be assumed to be either between two or more of the circuit conductors or between any circuit conductor and the equipment grounding conductors permitted in Section E3908.8. Listed equipment applied in accordance with its list-ing shall be considered to meet the requirements of this section. (110.10)~~

E3404.4 Enclosure types.

RESERVED

~~Enclosures, other than surrounding fences or walls, of panelboards, meter sockets, enclosed switches, transfer switches, circuit breakers, pullout switches and motor controllers, rated not over 600 volts nominal and intended for such locations, shall be marked with an enclosure type number as shown in Table E3404.4.~~

~~Table E3404.4 shall be used for selecting these enclosures for use in specific locations other than hazardous (classified) locations. The enclosures are not intended to protect against conditions such as~~

~~condensation, icing, corrosion, or contamination that might occur within the enclosure or enter through the conduit or unsealed openings. (110.28)~~

TABLE E3404.4 (Table 110.28)

ENCLOSURE SELECTION

RESERVED

~~PROVIDES A DEGREE OF PROTECTION AGAINST THE FOLLOWING ENVIRONMENTAL CONDITIONS~~	~~FOR OUTDOOR USE Enclosure-type Number~~									
	~~3~~	~~3R~~	~~3S~~	~~3X~~	~~3RX~~	~~3SX~~	4	~~4X~~	~~6~~	~~6P~~
~~Incidental contact with the enclosed equipment~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~
~~Rain, snow and sleet~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~
~~Sleet~~[a]	—	—	~~X~~	—	—	~~X~~	—	—	—	—
~~Windblown dust~~	~~X~~	—	~~X~~	~~X~~	—	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~
~~Hosedown~~	—	—	—	—	—	—	~~X~~	~~X~~	~~X~~	~~X~~
~~Corrosive agents~~	—	—	—	~~X~~	~~X~~	~~X~~	—	~~X~~	—	~~X~~
~~Temporary submersion~~	—	—	—	—	—	—	—	—	~~X~~	~~X~~
~~Prolonged submersion~~	—	—	—	—	—	—	—	—	—	~~X~~

~~PROVIDES A DEGREE OF PROTECTION AGAINST THE FOLLOWING ENVIRONMENTAL CONDITIONS~~	~~FOR INDOOR USE Enclosure-type Number~~									
	~~1~~	~~2~~	4	~~4X~~	~~5~~	~~6~~	~~6P~~	~~12~~	~~12K~~	~~13~~
~~Incidental contact with the enclosed equipment~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~

~~Falling dirt~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~
~~Falling liquids and light splashing~~	—	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~
~~Circulating dust, lint, fibers and flyings~~	—	—	~~X~~	~~X~~	—	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~
~~Settling airborne dust, lint, fibers and flings~~	—	—	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~	~~X~~
~~Hosedown and splashing water~~	—	—	~~X~~	~~X~~	—	~~X~~	~~X~~	—	—	—
~~Oil and coolant seepage~~	—	—	—	—	—	—	—	~~X~~	~~X~~	~~X~~
~~Oil or coolant spraying and splashing~~	—	—	—	—	—	—	—	—	—	~~X~~
~~Corrosive agents~~	—	—	—	~~X~~	—	—	~~X~~	—	—	—
~~Temporary submersion~~	—	—	—	—	—	~~X~~	~~X~~	—	—	—
~~Prolonged submersion~~	—	—	—	—	—	—	~~X~~	—	—	—

1. ~~a.Mechanism shall be operable when ice covered.~~
2. ~~Note 1:The term raintight is typically used in conjunction with Enclosure Types 3, 3S, 3SX, 3X, 4, 4X, 6 and 6P. The term rainproof is typically used in conjunction with Enclosure Types 3R and 3RX. The term watertight is typically used in conjunction with Enclosure Types 4, 4X, 6 and 6P. The term driptight is typically used in conjunction with Enclosure Types 2, 5, 12, 12K and 13. The term dusttight is typically used in conjunction with Enclosure Types 3, 3S, 3SX, 3X, 5, 12, 12K and 13.~~
3. ~~Note 2:Ingress protection (IP) ratings are found in ANSI/NEMA 60529, *Degrees of Protection Provided by Enclosures*. IP ratings are not a substitute for enclosure type ratings.~~

E3404.5 Protection of equipment.

RESERVED

~~Equipment not identified for outdoor use and equipment identified only for indoor use, such as "dry locations," "indoor use only" "damp locations," or enclosure Type 1, 2, 5, 12, 12K and/or 13, shall be protected against damage from the weather during construction. (110.11)~~

E3404.6 Unused openings.

RESERVED

~~Unused openings, other than those intended for the operation of equipment, those intended for mounting purposes, and those permitted as part of the design for listed equipment, shall be closed to afford protection substantially equivalent to the wall of the equipment. Where metallic plugs or plates are used with nonmetallic enclosures they shall be recessed at least $^{1}/_{4}$ inch (6.4 mm) from the outer surface of the enclosure. [110.12(A)]~~

E3404.7 Integrity of electrical equipment.

RESERVED

~~Internal parts of electrical equipment, including busbars, wiring terminals, insulators and other surfaces, shall not be damaged or contaminated by foreign materials such as paint, plaster, cleaners or abrasives, and corrosive residues. There shall not be any damaged parts that might adversely affect safe operation or mechanical strength of the equipment such as parts that are broken; bent; cut; deteriorated by corrosion, chemical action, or overheating. Foreign debris shall be removed from equipment. [110.12(B)]~~

E3404.8 Mounting.

RESERVED

~~Electrical equipment shall be firmly secured to the surface on which it is mounted. Wooden plugs driven into masonry, concrete, plaster, or similar materials shall not be used. [110.13(A)]~~

E3404.9 Energized parts guarded against accidental contact.

RESERVED

~~Approved enclosures shall guard energized parts that are operating at 50 volts or more against accidental contact. [110.27(A)]~~

E3404.10 Prevent physical damage.

RESERVED

~~In locations where electrical equipment is likely to be exposed to physical damage, enclosures or guards shall be so arranged and of such strength as to prevent such damage. [110.27(B)]~~

E3404.11 Equipment identification.

RESERVED

~~The manufacturer's name, trademark or other descriptive marking by which the organization responsible for the product can be identified shall be placed on all electric equipment. Other markings shall be provided that indicate voltage, current, wattage or other ratings as specified elsewhere in~~

~~Chapters 34 through 43. The marking shall have the durability to withstand the environment involved. [110.21(A)]~~

E3404.12 Field-applied hazard markings.

RESERVED

~~Where caution, warning, or danger signs or labels are required by this code, the labels shall meet the following requirements:~~

~~4. 1.The marking shall adequately warn of the hazard using effective words, colors, or symbols or combinations of such.~~

~~5. 2.Labels shall be permanently affixed to the equipment or wiring method.~~

~~6. 3.Labels shall not be hand written except for portions of labels or markings that are variable, or that could be subject to changes. Labels shall be legible.~~

~~7. 4.Labels shall be of sufficient durability to withstand the environment involved. [110.21(B)]~~

E3404.13 Identification of disconnecting means.

RESERVED

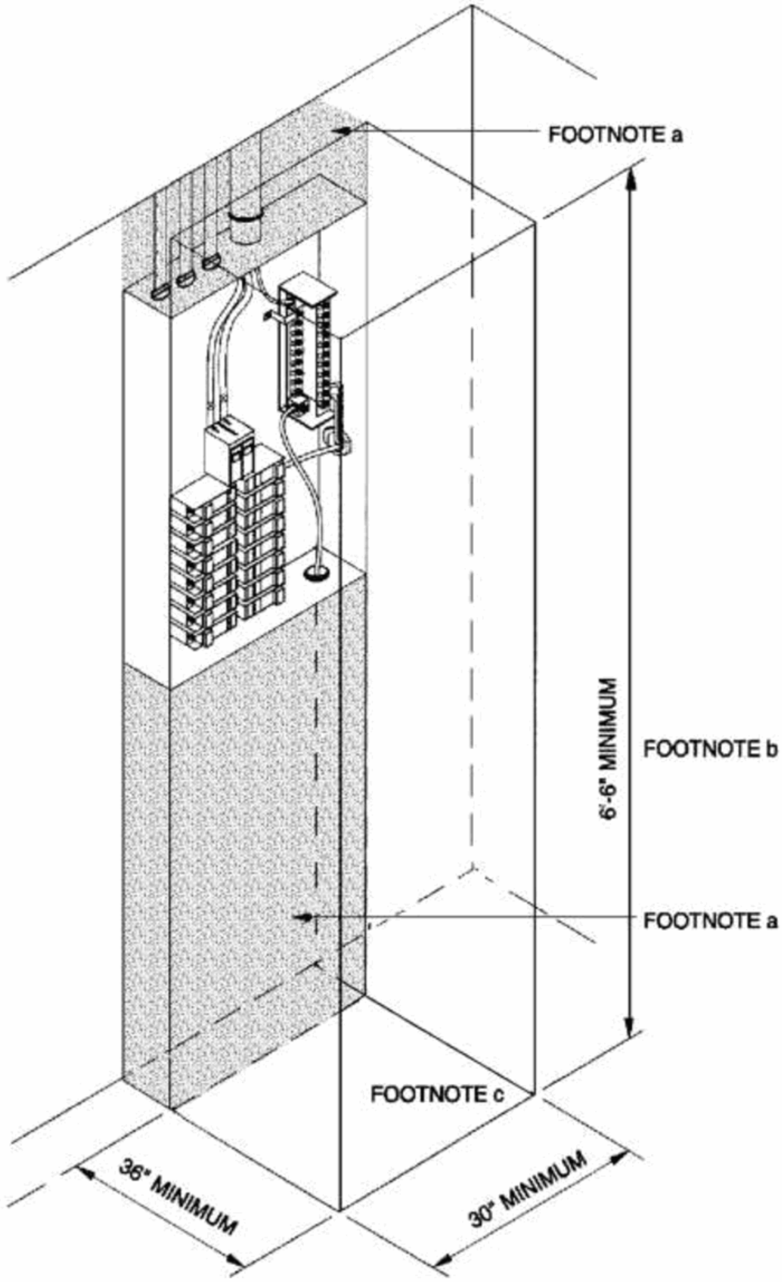
~~Each disconnecting means shall be legibly marked to indicate its purpose, except where located and arranged so that the purpose is evident. The marking shall have the durability to withstand the environment involved. [110.22(A)]~~

SECTION E3405
EQUIPMENT LOCATION AND CLEARANCES

E3405.1 Working space and clearances.

RESERVED

~~Access and working space shall be provided and maintained around all electrical equipment to permit ready and safe operation and maintenance of such equipment in accordance with this section and Figure E3405.1. (110.26)~~



~~For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.~~

~~8. a.Equipment, piping and ducts foreign to the electrical installation shall not be placed in the shaded areas extending from the floor to a height of 6 feet above the panelboard enclosure, or to the structural ceiling, whichever is lower.~~

9. b.The working space shall be clear and unobstructed from the floor to a height of 6.5 feet or the height of the equipment, whichever is greater.
10. c.The working space shall not be designated for storage.
11. d.Panelboards, service equipment and similar enclosures shall not be located in bathrooms, toilet rooms, clothes closets or over the steps of a stairway.
12. e.Such work spaces shall be provided with artificial lighting where located indoors and shall not be controlled by automatic means only.

FIGURE E3405.1[a, b, c, d, e]

WORKING SPACE AND CLEARANCES

E3405.2 Working clearances for energized equipment and panelboards.

RESERVED

Except as otherwise specified in Chapters 34 through 43, the dimension of the working space in the direction of access to panelboards and live parts of other equipment likely to require examination, adjustment, servicing or maintenance while energized shall be not less than 36 inches (914 mm) in depth. Distances shall be measured from the energized parts where such parts are exposed or from the enclosure front or opening where such parts are enclosed. In addition to the 36- inch dimension (914 mm), the work space shall not be less than 30 inches (762 mm) wide in front of the electrical equipment and not less than the width of such equipment. The work space shall be clear and shall extend from the floor or platform to a height of 6.5 feet (1981 mm) or the height of the equipment, whichever is greater. In all cases, the work space shall allow at least a 90-degree (1.57 rad) opening of equipment doors or hinged panels. Equipment associated with the electrical installation located above or below the electrical equipment shall be permitted to extend not more than 6 inches (152 mm) beyond the front of the electrical equipment. [110.26(A) (1), (2), (3)]

Exceptions:

13. 1.In existing dwelling units, service equipment and panelboards that are not rated in excess of 200 amperes shall be permitted in spaces where the height of the working space is less than 6.5 feet (1981 mm). [110.26(A)(3) Exception No. 1]
14. 2.Meters that are installed in meter sockets shall be permitted to extend beyond the other equipment. Meter sockets shall not be exempt from the requirements of this section. [110.26(A)(3) Exception No. 2]

E3405.3 Indoor dedicated panelboard space.

RESERVED

~~The indoor space equal to the width and depth of the panelboard and extending from the floor to a height of 6 feet (1829 mm) above the panelboard, or to the structural ceiling, whichever is lower, shall be dedicated to the electrical installation. Piping, ducts, leak protection apparatus and other equipment foreign to the electrical installation shall not be installed in such dedicated space. The area above the dedicated space shall be permitted to contain foreign systems, provided that protection is installed to avoid damage to the electrical equipment from condensation, leaks and breaks in such foreign systems (see Figure E3405.1).~~

~~**Exception:** Suspended ceilings with removable panels shall be permitted within the 6-foot (1829 mm) dedicated space.~~

E3405.4 Outdoor dedicated panelboard space.

<u>RESERVED</u>

~~The outdoor space equal to the width and depth of the panelboard, and extending from grade to a height of 6 feet (1.8 m) above the panelboard, shall be dedicated to the electrical installation. Piping and other equipment foreign to the electrical installation shall not be located in this zone.~~

E3405.5 Location of working spaces and equipment.

<u>RESERVED</u>

~~Required working space shall not be designated for storage. Panelboards and overcurrent protection devices shall not be located in clothes closets, in bathrooms, or over the steps of a stairway. [110.26(B), 240.24(D), (E), (F)]~~

E3405.6 Access and entrance to working space.

<u>RESERVED</u>

~~Access shall be provided to the required working space. [110.26(C)(1)]~~

E3405.7 Illumination.

<u>RESERVED</u>

~~Artificial illumination shall be provided for all working spaces for service equipment and panelboards installed indoors and shall not be controlled by automatic means only. Additional lighting outlets shall not be required where the work space is illuminated by an adjacent light source or as permitted by Exception 1 of Section E3903.2 for switched receptacles. [110.26(D)]~~

SECTION E3406
ELECTRICAL CONDUCTORS AND CONNECTIONS

E3406.1 General.

RESERVED

~~This section provides general requirements for conductors, connections and splices. These requirements do not apply to conductors that form an integral part of equipment, such as motors, appliances and similar equipment, or to conductors specifically provided for elsewhere in Chapters 34 through 43. (310.1)~~

E3406.2 Conductor material.

RESERVED

~~Conductors used to conduct current shall be of copper except as otherwise provided in Chapters 34 through 43. Where the conductor material is not specified, the material and the sizes given in these chapters shall apply to copper conductors. Where other materials are used, the conductor sizes shall be changed accordingly. (110.5)~~

E3406.3 Minimum size of conductors.

RESERVED

~~The minimum size of conductors for feeders and branch circuits shall be 14 AWG copper and 12 AWG aluminum. The minimum size of service conductors shall be as specified in Chapter 36. The minimum size of Class 2 remote control, signaling and power-limited circuits conductors shall be as specified in Chapter 43. [310.106(A)]~~

E3406.4 Stranded conductors.

RESERVED

~~Where installed in raceways, conductors 8 AWG and larger shall be stranded. A solid 8 AWG conductor shall be permitted to be installed in a raceway only to meet the requirements of Sections E3610.2 and E4204. [310.106(C)]~~

E3406.5 Individual conductor insulation.

RESERVED

~~Except where otherwise permitted in Sections E3605.1 and E3908.9, and E4303, current-carrying conductors shall be insulated. Insulated conductors shall have insulation types identified as RHH, RHW, RHW-2, THHN, THHW, THW, THW-2, THWN, THWN-2, TW, UF, USE, USE-2, XHHW or XHHW-2. Insulation types shall be approved for the application. [310.106(C), 310.104]~~

E3406.6 Conductors in parallel.

RESERVED

~~Circuit conductors that are connected in parallel shall be limited to sizes 1/0 AWG and larger. Conductors in parallel shall: be of the same length; consist of the same conductor material; be the same circular mil area and have the same insulation type. Conductors in parallel shall be terminated in the same manner. Where run in separate raceways or cables, the raceway or cables shall have the same physical characteristics. Where conductors are in separate raceways or cables, the same number of conductors shall be used in each raceway or cable. [310.10(H)]~~

E3406.7 Conductors of the same circuit.

RESERVED

~~All conductors of the same circuit and, where used, the grounded conductor and all equipment grounding conductors and bonding conductors shall be contained within the same raceway, cable or cord. [300.3(B)]~~

E3406.8 Aluminum and copper connections.

RESERVED

~~Terminals and splicing connectors shall be identified for the material of the conductors joined. Conductors of dissimilar metals shall not be joined in a terminal or splicing connector where physical contact occurs between dissimilar conductors such as copper and aluminum, copper and copper-clad aluminum, or aluminum and copper-clad aluminum, except where the device is listed for the purpose and conditions of application. Materials such as inhibitors and compounds shall be suitable for the application and shall be of a type that will not adversely affect the conductors, installation or equipment. (110.14)~~

E3406.9 Fine stranded conductors.

RESERVED

~~Connectors and terminals for conductors that are more finely stranded than Class B and Class C stranding as shown in Table E3406.9, shall be identified for the specific conductor class or classes. (110.14)~~

~~**TABLE E3406.9 (Chapter 9, Table 10)**~~

~~**CONDUCTOR STRANDING**~~[a]

~~**CONDUCTOR SIZE**~~		~~**NUMBER OF STRANDS**~~		
		~~**Copper**~~		~~**Aluminum**~~
~~**AWG or kcmil**~~	~~**mm²**~~	~~**Class B**~~	~~**Class C**~~	~~**Class B**~~

24-30	0.20-0.05	a	—	—
22	0.32	7	—	—
20	0.52	10	—	—
18	0.82	16	—	—
16	1.3	26	—	—
14-2	2.1-33.6	7	19	7[b]
1-4/0	42.4-107	19	37	19
250-500	127-253	37	61	37
600-1000	304-508	61	91	61
1250-1500	635-759	91	127	91
1750-2000	886-1016	127	271	127

15. a.Number of strands vary

16. b.Aluminum 14 AWG (2.1 mm^2) is not available.

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E3406.10 Terminals.

RESERVED

Connection of conductors to terminal parts shall be made without damaging the conductors and shall be made by means of pressure connectors, including setscrew type, by means of splices to flexible leads, or for conductor sizes of 10 AWG and smaller, by means of wire binding screws or studs and nuts having upturned lugs or the equivalent. Terminals for more than one conductor and terminals for connecting aluminum conductors shall be identified for the application. [110.14(A)]

E3406.11 Splices.

RESERVED

~~Conductors shall be spliced or joined with splicing devices listed for the purpose. Splices and joints and the free ends of conductors shall be covered with an insulation equivalent to that of the conductors or with an insulating device listed for the purpose. Wire connectors or splicing means installed on conductors for direct burial shall be listed for such use. [110.14(B)]~~

E3406.11.1 Continuity.

RESERVED

~~Conductors in raceways shall be continuous between outlets, boxes, and devices and shall be without splices or taps in the raceway.~~

~~**Exception:** Splices shall be permitted within surface-mounted raceways that have a removable cover. [300.13(A)]~~

E3406.11.2 Device connections.

RESERVED

~~The continuity of a grounded conductor in multiwire branch circuits shall not be dependent on connection to devices such as receptacles and lampholders. The arrangement of grounding connections shall be such that the disconnection or the removal of a receptacle, luminaire or other device fed from the box does not interfere with or interrupt the grounding continuity. [300.13(B)]~~

E3406.11.3 Length of conductor for splice or termination.

RESERVED

~~Where conductors are to be spliced, terminated or connected to fixtures or devices, a minimum length of 6 inches (152 mm) of free conductor shall be provided at each outlet, junction or switch point. The required length shall be measured from the point in the box where the conductor emerges from its raceway or cable sheath. Where the opening to an outlet, junction or switch point is less than 8 inches (200 mm) in any dimension, each conductor shall be long enough to extend at least 3 inches (75 mm) outside of such opening. (300.14)~~

E3406.12 Grounded conductor continuity.

RESERVED

~~The continuity of a grounded conductor shall not depend on connection to a metallic enclosure, raceway or cable armor. [200.2(B)]~~

E3406.13 Connection of grounding and bonding equipment.

RESERVED

~~The connection of equipment grounding conductors, grounding electrode conductors and bonding jumpers shall be in accordance with Sections E3406.13.1 and E3406.13.2.~~

E3406.13.1 Permitted methods.

RESERVED

~~Equipment grounding conductors, grounding electrode conductors, and bonding jumpers shall be connected by one or more of the following means:~~

~~18. 1.Listed pressure connectors.~~

~~19. 2.Terminal bars.~~

~~20. 3.Pressure connectors listed as grounding and bonding equipment.~~

~~21. 4.Exothermic welding process.~~

~~22. 5.Machine screw-type fasteners that engage not less than two threads or are secured with a nut.~~

~~23. 6.Thread-forming machine screws that engage not less than two threads in the enclosure.~~

~~24. 7.Connections that are part of a listed assembly.~~

~~25. 8.Other listed means. [250.8 (A)]~~

E3406.13.2 Methods not permitted.

RESERVED

~~Connection devices or fittings that depend solely on solder shall not be used. [250.8 (B)]~~

SECTION E3407
CONDUCTOR AND TERMINAL IDENTIFICATION

E3407.1 Grounded conductors.

RESERVED

~~Insulated grounded conductors of sizes 6 AWG or smaller shall be identified by a continuous white or gray outer finish or by three continuous white or gray stripes on other than green insulation along the entire length of the conductors. Conductors of sizes 4 AWG or larger shall be identified either by a continuous white or gray outer finish or by three continuous white or gray stripes on other than green insulation along its entire length or at the time of installation by a distinctive white or gray marking at its terminations. This marking shall encircle the conductor or insulation. [200.6(A) & (B)]~~

E3407.2 Equipment grounding conductors.

RESERVED

~~Equipment grounding conductors of sizes 6 AWG and smaller shall be identified by a continuous green color or a continuous green color with one or more yellow stripes on the insulation or covering, except where bare. Conductors with insulation or individual covering that is green, green with one or more yellow stripes, or otherwise identified as permitted by this section shall not be used for ungrounded or grounded circuit conductors. (250.119)~~

~~Equipment grounding conductors 4 AWG and larger AWG that are not identified as required for conductors of sizes 6 AWG and smaller shall, at the time of installation, be permanently identified as an equipment grounding conductor at each end and at every point where the conductor is accessible, except where such conductors are bare.~~

~~The required identification for conductors 4 AWG and larger shall encircle the conductor and shall be accomplished by one of the following:~~

~~26. 1.Stripping the insulation or covering from the entire exposed length.~~

~~27. 2.Coloring the exposed insulation or covering green at the termination.~~

~~28. 3.Marking the exposed insulation or covering with green tape or green adhesive labels at the termination. [250.119(A)]~~

~~**Exceptions:**~~

~~29. 1.Conductors 4 AWG and larger shall not be required to be identified in conduit bodies that do not contain splices or unused hubs. [250.119(A)(1) Exception]~~

~~30. 2.Power-limited, Class 2 or Class 3 circuit cables containing only circuits operating at less than 50 volts shall be permitted to use a conductor with green insulation for other than equipment grounding purposes. [250.119 Exception No. 1]~~

E3407.3 Ungrounded conductors.

RESERVED

~~Insulation on the ungrounded conductors shall be a continuous color other than white, gray and green. [310.110(C)]~~

~~**Exception:** An insulated conductor that is part of a cable or flexible cord assembly and that has a white or gray finish or a finish marking with three continuous white or gray stripes shall be permitted to be used as an ungrounded conductor where it is permanently reidentified to indicate its use as an ungrounded conductor by marking tape, painting, or other effective means at all terminations and at each location where the conductor is visible and accessible. Identification shall encircle the insulation and shall be a color other than white, gray, and green. [200.7(C)(1)]~~

~~Where used for single-pole, 3-way or 4-way switch loops, the reidentified conductor with white or gray insulation or three continuous white or gray stripes shall be used only for the supply to the switch, not as a return conductor from the switch to the outlet. [200.7(C)(2)]~~

E3407.4 Identification of terminals.

RESERVED

~~Terminals for attachment to conductors shall be identified in accordance with Sections E3407.4.1 and E3407.4.2.~~

E3407.4.1 Device terminals.

RESERVED

~~All devices excluding panelboards, provided with terminals for the attachment of conductors and intended for connection to more than one side of the circuit shall have terminals properly marked for identification, except where the terminal intended to be connected to the grounded conductor is clearly evident. [200.10(A)]~~

~~**Exception:** Terminal identification shall not be required for devices that have a normal current rating of over 30 amperes, other than polarized attachment caps and polarized receptacles for attachment caps as required in Section E3407.4.2. [200.10(A) Exception]~~

E3407.4.2 Receptacles, plugs and connectors.

RESERVED

~~Receptacles, polarized attachment plugs and cord connectors for plugs and polarized plugs shall have the terminal intended for connection to the grounded (white) conductor identified. Identification shall be by a metal or metal coating substantially white in color or by the word "white" or the letter "W" located adjacent to the identified terminal. Where the terminal is not visible, the conductor entrance hole for the connection shall be colored white or marked with the word "white" or the letter "W." [200.10(B)]~~

CHAPTER35
ELECTRICAL DEFINITIONS

RESERVED

~~**SECTION**E3501~~
~~GENERAL~~

~~E3501.1Scope.~~

~~This chapter contains definitions that shall apply only to the electrical requirements of Chapters 34 through 43. Unless otherwise expressly stated, the following terms shall, for the purpose of this code,~~

have the meanings indicated in this chapter. Words used in the present tense include the future; the singular number includes the plural and the plural the singular. Where terms are not defined in this section and are defined in Section R202 of this code, such terms shall have the meanings ascribed to them in that section. Where terms are not defined in these sections, they shall have their ordinarily accepted meanings or such as the context implies.

ACCESSIBLE. (As applied to equipment.) Admitting close approach; not guarded by locked doors, elevation or other effective means.

ACCESSIBLE. (As applied to wiring methods.) Capable of being removed or exposed without damaging the building structure or finish, or not permanently closed in by the structure or finish of the building.

ACCESSIBLE, READILY. Capable of being reached quickly for operation, renewal or inspections, without requiring those to whom ready access is requisite to take actions such as to use tools, to climb over or remove obstacles or to resort to portable ladders, etc.

AMPACITY. The maximum current in amperes that a conductor can carry continuously under the conditions of use without exceeding its temperature rating.

APPLIANCE. Utilization equipment, normally built in standardized sizes or types, that is installed or connected as a unit to perform one or more functions such as clothes washing, air conditioning, food mixing, deep frying, etc.

APPROVED. Acceptable to the authority having jurisdiction.

ARC-FAULT CIRCUIT INTERRUPTER. A device intended to provide protection from the effects of arc-faults by recognizing characteristics unique to arcing and by functioning to de-energize the circuit when an arc-fault is detected.

ATTACHMENT PLUG (PLUG CAP) (PLUG). A device that, by insertion into a receptacle, establishes connection between the conductors of the attached flexible cord and the conductors connected permanently to the receptacle.

AUTOMATIC. Performing a function without the necessity of human intervention.

BATHROOM. An area, including a basin, with one or more of the following: a toilet, a urinal, a tub, a shower, a bidet, or similar plumbing fixture.

BONDED (BONDING). Connected to establish electrical continuity and conductivity.

BONDING CONDUCTOR OR JUMPER. A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.

BONDING JUMPER (EQUIPMENT). The connection between two or more portions of the equipment grounding conductor.

~~**BONDING JUMPER, MAIN.** The connection between the grounded circuit conductor and the equipment grounding conductor at the service.~~

~~**BONDING JUMPER, SUPPLY-SIDE.** A conductor installed on the supply side of a service or within a service equipment enclosure(s) that ensures the required electrical conductivity between metal parts required to be electrically connected.~~

~~**BRANCH CIRCUIT.** The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s).~~

~~**BRANCH CIRCUIT, APPLIANCE.** A branch circuit that supplies energy to one or more outlets to which appliances are to be connected, and that has no permanently connected luminaires that are not a part of an appliance.~~

~~**BRANCH CIRCUIT, GENERAL PURPOSE.** A branch circuit that supplies two or more receptacle outlets or outlets for lighting and appliances.~~

~~**BRANCH CIRCUIT, INDIVIDUAL.** A branch circuit that supplies only one utilization equipment.~~

~~**BRANCH CIRCUIT, MULTIWIRE.** A branch circuit consisting of two or more ungrounded conductors having voltage difference between them, and a grounded conductor having equal voltage difference between it and each ungrounded conductor of the circuit, and that is connected to the neutral or grounded conductor of the system.~~

~~**CABINET.** An enclosure designed either for surface or flush mounting and provided with a frame, mat or trim in which a swinging door or doors are or may be hung.~~

~~**CIRCUIT BREAKER.** A device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating.~~

~~**CLOTHES CLOSET.** A nonhabitable room or space intended primarily for storage of garments and apparel.~~

~~**CONCEALED.** Rendered inaccessible by the structure or finish of the building.~~

~~**CONDUCTOR.**~~

~~**Bare.** A conductor having no covering or electrical insulation whatsoever.~~

~~**Covered.** A conductor encased within material of composition or thickness that is not recognized by this code as electrical insulation.~~

~~**Insulated.** A conductor encased within material of composition and thickness that is recognized by this code as electrical insulation.~~

~~**CONDUIT BODY.** A separate portion of a conduit or tubing system that provides access through a removable cover(s) to the interior of the system at a junction of two or more sections of the system or at a terminal point of the system. Boxes such as FS and FD or larger cast or sheet metal boxes are not classified as conduit bodies.~~

~~**CONNECTOR, PRESSURE (SOLDERLESS).** A device that establishes a connection between two or more conductors or between one or more conductors and a terminal by means of mechanical pressure and without the use of solder.~~

~~**CONTINUOUS LOAD.** A load where the maximum current is expected to continue for 3 hours or more.~~

~~**COOKING UNIT, COUNTER-MOUNTED.** A cooking appliance designed for mounting in or on a counter and consisting of one or more heating elements, internal wiring and built-in or separately mountable controls.~~

~~**COPPER-CLAD ALUMINUM CONDUCTORS.** Conductors drawn from a copper-clad aluminum rod with the copper metallurgically bonded to an aluminum core. The copper forms a minimum of 10 percent of the cross-sectional area of a solid conductor or each strand of a stranded conductor.~~

~~**CUTOUT BOX.** An enclosure designed for surface mounting and having swinging doors or covers secured directly to and telescoping with the walls of the box proper (see "Cabinet").~~

~~**DEAD FRONT.** Without live parts exposed to a person on the operating side of the equipment.~~

~~**DEMAND FACTOR.** The ratio of the maximum demand of a system, or part of a system, to the total connected load of a system or the part of the system under consideration.~~

~~**DEVICE.** A unit of an electrical system that carries or controls electrical energy as it principal function.~~

~~**DISCONNECTING MEANS.** A device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply.~~

~~**DWELLING.**~~

~~**Dwelling unit.** A single unit, providing complete and independent living facilities for one or more persons, including permanent provisions for living, sleeping, cooking and sanitation.~~

~~**One-family dwelling.** A building consisting solely of one dwelling unit.~~

~~**Two-family dwelling.** A building consisting solely of two dwelling units.~~

~~**EFFECTIVE GROUND-FAULT CURRENT PATH.** An intentionally constructed, low-impedance electrically conductive path designed and intended to carry current under ground-fault conditions from the point of a ground fault on a wiring system to the electrical supply source and that facilitates the operation of the overcurrent protective device or ground-fault detectors.~~

~~**ENCLOSED.** Surrounded by a case, housing, fence or walls that will prevent persons from accidentally contacting energized parts.~~

~~**ENCLOSURE.** The case or housing of apparatus, or the fence or walls surrounding an installation, to prevent personnel from accidentally contacting energized parts or to protect the equipment from physical damage.~~

~~**ENERGIZED.** Electrically connected to, or is, a source of voltage.~~

~~**EQUIPMENT.** A general term including material, fittings, devices, appliances, luminaires, apparatus, machinery and the like used as a part of, or in connection with, an electrical installation.~~

~~**EXPOSED.** (As applied to live parts.) Capable of being inadvertently touched or approached nearer than a safe distance by a person.~~

~~**EXPOSED.** (As applied to wiring methods.) On or attached to the surface or behind panels designed to allow access.~~

~~**EXTERNALLY OPERABLE.** Capable of being operated without exposing the operator to contact with live parts.~~

~~**FEEDER.** All circuit conductors between the service equipment, or the source of a separately derived system, or other power supply source and the final branch-circuit overcurrent device.~~

~~**FITTING.** An accessory such as a locknut, bushing or other part of a wiring system that is intended primarily to perform a mechanical rather than an electrical function.~~

~~**GROUND.** The earth.~~

~~**GROUNDED (GROUNDING).** Connected (connecting) to ground or to a conductive body that extends the ground connection.~~

~~**GROUNDED, EFFECTIVELY.** Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazards to connected equipment or to persons.~~

~~**GROUNDED CONDUCTOR.** A system or circuit conductor that is intentionally grounded.~~

~~**GROUNDING CONDUCTOR, EQUIPMENT (EGC).** The conductive path(s) that provides a ground-fault current path and connects normally noncurrent-carrying metal parts of equipment together and, to the system grounded conductor, the grounding electrode conductor or both.~~

~~**GROUNDING ELECTRODE.** A conducting object through which a direct connection to earth is established.~~

~~**GROUNDING ELECTRODE CONDUCTOR.** A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system.~~

GROUND-FAULT CIRCUIT-INTERRUPTER. A device intended for the protection of personnel that functions to deenergize a circuit or portion thereof within an established period of time when a current to ground exceeds the value for a Class A device.

GROUND-FAULT CURRENT PATH. An electrically conductive path from the point of a ground fault on a wiring system through normally non-current carrying conductors, equipment, or the earth to the electrical supply source.

Examples of ground-fault current paths are any combination of equipment grounding conductors, metallic raceways, metallic cable sheaths, electrical equipment, and any other electrically conductive material such as metal, water, and gas piping; steel framing members; stucco mesh; metal ducting; reinforcing steel; shields of communications cables; and the earth itself.

GUARDED. Covered, shielded, fenced, enclosed or otherwise protected by means of suitable covers, casings, barriers, rails, screens, mats or platforms to remove the likelihood of approach or contact by persons or objects to a point of danger.

IDENTIFIED. (As applied to equipment.) Recognizable as suitable for the specific purpose, function, use, environment, application, etc., where described in a particular code requirement.

INTERRUPTING RATING. The highest current at rated voltage that a device is identified to interrupt under standard test conditions.

INTERSYSTEM BONDING TERMINATION. A device that provides a means for connecting intersystem bonding conductors for communications systems to the grounding electrode system.

ISOLATED. (As applied to location.) Not readily accessible to persons unless special means for access are used.

KITCHEN. An area with a sink and permanent provisions for food preparation and cooking.

LABELED. Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization acceptable to the authority having jurisdiction and concerned with product evaluation that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

LIGHTING OUTLET. An outlet intended for the direct connection of a lampholder or luminaire.

LIGHTING TRACK (Track Lighting). A manufactured assembly designed to support and energize luminaires that are capable of being readily repositioned on the track. Its length can be altered by the addition or subtraction of sections of track.

LISTED. Equipment, materials or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation

~~of services, and whose listing states either that the equipment, material or services meets identified standards or has been tested and found suitable for a specified purpose.~~

~~**LIVE PARTS.** Energized conductive components.~~

~~**LOCATION, DAMP.** Location protected from weather and not subject to saturation with water or other liquids but subject to moderate degrees of moisture.~~

~~**LOCATION, DRY.** A location not normally subject to dampness or wetness. A location classified as dry may be temporarily subject to dampness or wetness, as in the case of a building under construction.~~

~~**LOCATION, WET.** Installations underground or in concrete slabs or masonry in direct contact with the earth and locations subject to saturation with water or other liquids, such as vehicle washing areas, and locations exposed to weather.~~

~~**LUMINAIRE.** A complete lighting unit consisting of a light source such as a lamp or lamps together with the parts designed to position the light source and connect it to the power supply. A luminaire can include parts to protect the light source or the ballast or to distribute the light. A lampholder itself is not a luminaire.~~

~~**MULTIOUTLET ASSEMBLY.** A type of surface, or flush, or freestanding raceway; designed to hold conductors and receptacles, assembled in the field or at the factory.~~

~~**NEUTRAL CONDUCTOR.** The conductor connected to the neutral point of a system that is intended to carry current under normal conditions.~~

~~**NEUTRAL POINT.** The common point on a wye-connection in a polyphase system or midpoint on a single-phase, 3-wire system, or midpoint of a single-phase portion of a 3-phase delta system, or a midpoint of a 3-wire, direct-current system.~~

~~**OUTLET.** A point on the wiring system at which current is taken to supply utilization equipment.~~

~~**OVERCURRENT.** Any current in excess of the rated current of equipment or the ampacity of a conductor. Such current might result from overload, short circuit or ground fault.~~

~~**OVERLOAD.** Operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload.~~

~~**PANELBOARD.** A single panel or group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices, and equipped with or without switches for the control of light, heat or power circuits, designed to be placed in a cabinet or cutout box placed in or against a wall, partition or other support and accessible only from the front.~~

~~**PLENUM.** A compartment or chamber to which one or more air ducts are connected and that forms part of the air distribution system.~~

~~**POWER OUTLET.** An enclosed assembly that may include receptacles, circuit breakers, fuseholders, fused switches, buses and watt-hour meter mounting means, intended to supply and control power to mobile homes, recreational vehicles or boats, or to serve as a means for distributing power required to operate mobile or temporarily installed equipment.~~

~~**PREMISES WIRING (SYSTEM).** Interior and exterior wiring, including power, lighting, control and signal circuit wiring together with all of their associated hardware, fittings and wiring devices, both permanently and temporarily installed. This includes wiring from the service point or power source to the outlets and wiring from and including the power source to the outlets where there is no service point. Such wiring does not include wiring internal to appliances, luminaires, motors, controllers, and similar equipment.~~

~~**QUALIFIED PERSON.** One who has the skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved.~~

~~**RACEWAY.** An enclosed channel of metallic or nonmetallic materials designed expressly for holding wires, cables, or busbars, with additional functions as permitted in this code.~~

~~**RAINPROOF.** Constructed, protected or treated so as to prevent rain from interfering with the successful operation of the apparatus under specified test conditions.~~

~~**RAIN TIGHT.** Constructed or protected so that exposure to a beating rain will not result in the entrance of water under specified test conditions.~~

~~**RECEPTACLE.** A receptacle is a contact device installed at the outlet for the connection of an attachment plug. A single receptacle is a single contact device with no other contact device on the same yoke. A multiple receptacle is two or more contact devices on the same yoke.~~

~~**RECEPTACLE OUTLET.** An outlet where one or more receptacles are installed.~~

~~**SERVICE.** The conductors and equipment for delivering energy from the serving utility to the wiring system of the premises served.~~

~~**SERVICE CABLE.** Service conductors made up in the form of a cable.~~

~~**SERVICE CONDUCTORS.** The conductors from the service point to the service disconnecting means.~~

~~**SERVICE CONDUCTORS, OVERHEAD.** The overhead conductors between the service point and the first point of connection to the service-entrance conductors at the building or other structure.~~

~~**SERVICE CONDUCTORS, UNDERGROUND.** The underground conductors between the service point and the first point of connection to the service-entrance conductors in a terminal box, meter, or other enclosure, inside or outside of the building wall.~~

~~**SERVICE DROP.** The overhead service conductors between the utility electric supply system and the service point.~~

~~**SERVICE-ENTRANCE CONDUCTORS, OVERHEAD SYSTEM.** The service conductors between the terminals of the service equipment and a point usually outside of the building, clear of building walls, where joined by tap or splice to the service drop or overhead service conductors.~~

~~**SERVICE-ENTRANCE CONDUCTORS, UNDERGROUND SYSTEM.** The service conductors between the terminals of the service equipment and the point of connection to the service lateral or underground service conductors.~~

~~**SERVICE EQUIPMENT.** The necessary equipment, usually consisting of a circuit breaker(s) or switch(es) and fuse(s), and their accessories, connected to the load end of the service conductors to a building or other structure, or an otherwise designated area, and intended to constitute the main control and cutoff of the supply.~~

~~**SERVICE LATERAL.** The underground service conductors between the electric utility supply system and the service point.~~

~~**SERVICE POINT.** The point of connection between the facilities of the serving utility and the premises wiring.~~

~~**STRUCTURE.** That which is built or constructed.~~

~~**SWITCHES.**~~

~~**General-use switch.** A switch intended for use in general distribution and branch circuits. It is rated in amperes and is capable of interrupting its rated current at its rated voltage.~~

~~**General-use snap switch.** A form of general-use switch constructed so that it can be installed in device boxes or on box covers or otherwise used in conjunction with wiring systems recognized by this code.~~

~~**Isolating switch.** A switch intended for isolating an electric circuit from the source of power. It has no interrupting rating and is intended to be operated only after the circuit has been opened by some other means.~~

~~**Motor-circuit switch.** A switch, rated in horsepower that is capable of interrupting the maximum operating overload current of a motor of the same horsepower rating as the switch at the rated voltage.~~

~~**UNGROUNDED.** Not connected to ground or to a conductive body that extends the ground connection.~~

~~**UTILIZATION EQUIPMENT.** Equipment that utilizes electric energy for electronic, electromechanical, chemical, heating, lighting or similar purposes.~~

~~**VENTILATED.** Provided with a means to permit circulation of air sufficient to remove an excess of heat, fumes or vapors.~~

~~**VOLTAGE (OF A CIRCUIT).** The greatest root-meansquare (rms) (effective) difference of potential between any two conductors of the circuit concerned.~~

~~**VOLTAGE, NOMINAL.** A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (e.g., 120/240). The actual voltage at which a circuit operates can vary from the nominal within a range that permits satisfactory operation of equipment.~~

~~**VOLTAGE TO GROUND.** For grounded circuits, the voltage between the given conductor and that point or conductor of the circuit that is grounded. For ungrounded circuits, the greatest voltage between the given conductor and any other conductor of the circuit.~~

~~**WATERTIGHT.** Constructed so that moisture will not enter the enclosure under specified test conditions.~~

~~**WEATHERPROOF.** Constructed or protected so that exposure to the weather will not interfere with successful operation.~~

CHAPTER 36
SERVICES

RESERVED

~~**SECTION**E3601~~
~~GENERAL SERVICES~~

~~E3601.1Scope.~~

~~This chapter covers service conductors and equipment for the control and protection of services and their installation requirements. (230.1)~~

~~E3601.2Number of services.~~

~~One- and two-family dwellings shall be supplied by only one service. (230.2)~~

~~E3601.3One building or other structure not to be supplied through another.~~

~~Service conductors supplying a building or other structure shall not pass through the interior of another building or other structure.~~

~~E3601.4Other conductors in raceway or cable.~~

~~Conductors other than service conductors shall not be installed in the same service raceway or service cable. (230.7)~~

~~**Exceptions:**~~

1. ~~1.Grounding electrode conductors and equipment bonding jumpers or conductors.~~
2. ~~2.Load management control conductors having overcurrent protection.~~

~~E3601.5Raceway seal.~~

~~Where a service raceway enters from an underground distribution system, it shall be sealed in accordance with Section E3803.6. (230.8)~~

~~E3601.6Service disconnect required.~~

~~Means shall be provided to disconnect all conductors in a building or other structure from the service entrance conductors. (230.70)~~

~~E3601.6.1Marking of service equipment and disconnects.~~

~~Service disconnects shall be permanently marked as a service disconnect. [230.70(B)]~~

~~E3601.6.2Service disconnect location.~~

~~The service disconnecting means shall be installed at a readily accessible location either outside of a building or inside nearest the point of entrance of the service conductors. Service disconnecting means shall not be installed in bathrooms. Each occupant shall have access to the disconnect serving the dwelling unit in which they reside. [230.70(A)(1), 230.72(C)]~~

~~E3601.7Maximum number of disconnects.~~

~~The service disconnecting means shall consist of not more than six switches or six circuit breakers mounted in a single enclosure or in a group of separate enclosures. [230.71(A)]~~

~~**SECTION**E3602~~
~~SERVICE SIZE AND RATING~~

~~E3602.1Ampacity of ungrounded conductors.~~

~~Ungrounded service conductors shall have an ampacity of not less than the load served. For one-family dwellings, the ampacity of the ungrounded conductors shall be not less than 100 amperes, 3-wire. For all other installations, the ampacity of the ungrounded conductors shall be not less than 60 amperes. [230.42(B), 230.79(C) & (D)]~~

~~E3602.2Service load.~~

~~The minimum load for ungrounded service conductors and service devices that serve 100 percent of the dwelling unit load shall be computed in accordance with Table E3602.2. Ungrounded service conductors and service devices that serve less than 100 percent of the dwelling unit load shall be computed as required for feeders in accordance with Chapter 37. [220.82(A)]~~

~~TABLE E3602.2~~

~~MINIMUM SERVICE LOAD CALCULATION~~

~~LOADS AND PROCEDURE~~

~~3 volt-amperes per square foot of floor area for general lighting and general use receptacle outlets.~~

~~Plus~~

~~1,500 volt-amperes multiplied by total number of 20-ampere-rated small appliance and laundry circuits.~~

~~Plus~~

~~The nameplate volt-ampere rating of all fastened-in-place, permanently connected or dedicated circuit-supplied appliances such as ranges, ovens, cooking units, clothes dryers not connected to the laundry branch circuit and water heaters.~~

~~Apply the following demand factors to the above subtotal:~~

~~The minimum subtotal for the loads above shall be 100 percent of the first 10,000 volt-amperes of the sum of the above loads plus 40 percent of any portion of the sum that is in excess of 10,000 voltamperes.~~

~~Plus the largest of the following:~~

~~One-hundred percent of the nameplate rating(s) of the air-conditioning and cooling equipment.~~

~~One hundred percent of the nameplate rating(s) of the heat pump where a heat pump is used without any supplemental electric heating.~~

~~One-hundred percent of the nameplate rating of the electric thermal storage and other heating systems where the usual load is expected to be continuous at the full nameplate value. Systems qualifying under this selection shall not be figured under any other category in this table.~~

~~One-hundred percent of nameplate rating of the heat pump compressor and sixty-five percent of the supplemental electric heating load for central electric space-heating systems. If the heat pump compressor is prevented from operating at the same time as the supplementary heat, the compressor load does not need to be added to the supplementary heat load for the total central electric spaceheating load.~~

~~Sixty-five percent of nameplate rating(s) of electric space-heating units if less than four separately controlled units.~~

~~Forty percent of nameplate rating(s) of electric space-heating units of four or more separately controlled units.~~

~~The minimum total load in amperes shall be the volt-ampere sum calculated above divided by 240 volts.~~

~~E3602.2.1Services under 100 amperes.~~

~~Services that are not required to be 100 amperes shall be sized in accordance with Chapter 37. [230.42(A), (B), and (C)]~~

~~E3602.3Rating of service disconnect.~~

~~The combined rating of all individual service disconnects serving a single dwelling unit shall be not less than the load determined from Table E3602.2 and shall be not less than as specified in Section E3602.1. (230.79 & 230.80)~~

~~E3602.4Voltage rating.~~

~~Systems shall be three-wire, 120/240-volt, single-phase with a grounded neutral. [220.82(A)]~~

~~**SECTION**E3603~~
~~SERVICE, FEEDER AND GROUNDING~~
~~ELECTRODE CONDUCTOR SIZING~~

~~E3603.1Grounded and ungrounded service conductor size.~~

~~Service and feeder conductors supplied by a single-phase, 120/240-volt system shall be sized in accordance with Sections E3603.1.1 through E3603.1.4 and Table 3705.1.~~

~~E3603.1.1Ungrounded service conductors.~~

~~For a service rated at 100 through 400 amperes, the service conductors supplying the entire load associated with a one-family dwelling, or the service conductors supplying the entire load associated with an individual dwelling unit in a twofamily dwelling, shall have an ampacity of not less than 83 percent of the service rating.~~

~~E3603.1.2Ungrounded feeder conductors.~~

~~For a feeder rated at 100 through 400 amperes, the feeder conductors supplying the entire load associated with a one-family dwelling, or the feeder conductors supplying the entire load associated with an individual dwelling unit in a two-family dwelling, shall have an ampacity of not less than 83 percent of the feeder rating.~~

~~E3603.1.3Feeder size relative to service size.~~

~~A feeder for an individual dwelling unit shall not be required to have an ampacity greater than that specified in Sections E3603.1.1 and E3603.1.2.~~

~~E3603.1.4Grounded conductors.~~

~~The grounded conductor ampacity shall be not less than the maximum unbalance of the load and the size of the grounded conductor shall be not smaller than the required minimum grounding electrode conductor size specified in Table E3603.4. [310.15(B)(7)]~~

~~E3603.2Ungrounded service conductors for accessory buildings and structures.~~

~~Ungrounded conductors for other than dwelling units shall have an ampacity of not less than 60 amperes and shall be sized as required for feeders in Chapter 37. [230.79(D)]~~

~~**Exceptions:**~~

3. ~~1.For limited loads of a single branch circuit, the service conductors shall have an ampacity of not less than 15 amperes. [230.79(A)]~~
4. ~~2.For loads consisting of not more than two two-wire branch circuits, the service conductors shall have an ampacity of not less than 30 amperes. [230.79(C)]~~

~~E3603.3Overload protection.~~

~~Each ungrounded service conductor shall have overload protection. (230.90)~~

~~E3603.3.1Ungrounded conductor.~~

~~Overload protection shall be provided by an overcurrent device installed in series with each ungrounded service conductor. The overcurrent device shall have a rating or setting not higher than the allowable service or feeder rating specified in Section E3603.1. A set of fuses shall be considered to be all of the fuses required to protect all of the ungrounded conductors of a circuit. Single-pole circuit breakers, grouped in accordance with Section E3601.7, shall be considered as one protective device. [230.90(A)]~~

~~**Exception:** Two to six circuit breakers or sets of fuses shall be permitted as the overcurrent device to provide the overload protection. The sum of the ratings of the circuit breakers or fuses shall be permitted to exceed the ampacity of the service conductors, provided that the calculated load does not exceed the ampacity of the service conductors. [230.90(A) Exception No. 3]~~

~~E3603.3.2Not in grounded conductor.~~

~~Overcurrent devices shall not be connected in series with a grounded service conductor except where a circuit breaker is used that simultaneously opens all conductors of the circuit. [230.90(B)]~~

~~E3603.3.3Location.~~

~~The service overcurrent device shall be an integral part of the service disconnecting means or shall be located immediately adjacent thereto. (230.91)~~

~~E3603.4Grounding electrode conductor size.~~

~~The grounding electrode conductors shall be sized based on the size of the service entrance conductors as required in Table E3603.4. (250.66)~~

~~TABLE E3603.4~~

~~GROUNDING ELECTRODE CONDUCTOR SIZE[a, b, c, d, e, f]~~

~~**SIZE OF LARGEST UNGROUNDED SERVICE-ENTRANCE CONDUCTOR OR EQUIVALENT AREA FOR PARALLEL CONDUCTORS (AWG/kcmil)**~~		~~**SIZE OF GROUNDING ELECTRODE CONDUCTOR(AWG/kcmil)**~~	
~~**Copper**~~	~~**Aluminum or copper-clad aluminum**~~	~~**Copper**~~	~~**Aluminum or copper-clad aluminum**~~
~~2 or smaller~~	~~1/0 or smaller~~	~~8~~	~~6~~
~~1 or 1/0~~	~~2/0 or 3/0~~	~~6~~	4
~~2/0 or 3/0~~	~~4/0 or 250~~	4	~~2~~
~~Over 3/0 through 350~~	~~Over 250 through 500~~	~~2~~	~~1/0~~
~~Over 350 through 600~~	~~Over 500 through 900~~	~~1/0~~	~~3/0~~

~~5. a.If multiple sets of service-entrance conductors connect directly to a service drop, set of overhead service conductors, set of underground service conductors, or service lateral, the equivalent size of the largest serviceentrance conductor shall be determined by the largest sum of the areas of the corresponding conductors of each set.~~

~~6. b.Where there are no service-entrance conductors, the grounding electrode conductor size shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served.~~

~~7. c.Where protected by a ferrous metal raceway, grounding electrode conductors shall be electrically bonded to the ferrous metal raceway at both ends. [250.64(E)(1)]~~

8. d.An 8 AWG grounding electrode conductor shall be protected with rigid metal conduit, intermediate metal conduit, rigid polyvinyl chloride (Type PVC) nonmetallic conduit, rigid thermosetting resin (Type RTRC) nonmetallic conduit, electrical metallic tubing or cable armor. [250.64(B)]

9. e.Where not protected, 6 AWG grounding electrode conductor shall closely follow a structural surface for physical protection. The supports shall be spaced not more than 24 inches on center and shall be within 12 inches of any enclosure or termination. [250.64(B)]

10. f.Where the sole grounding electrode system is a ground rod or pipe as covered in Section E3608.3, the grounding electrode conductor shall not be required to be larger than 6 AWG copper or 4 AWG aluminum. Where the sole grounding electrode system is the footing steel as covered in Section E3608.1.2, the grounding electrode conductor shall not be required to be larger than 4 AWG copper conductor. [250.66(A) and (B)]

E3603.5Temperature limitations.

Except where the equipment is marked otherwise, conductor ampacities used in determining equipment termination provisions shall be based on Table E3705.1. [110.14(C)(1)]

SECTIONE3604
OVERHEAD SERVICE AND SERVICE-
ENTRANCE CONDUCTOR INSTALLATION

E3604.1Clearances on buildings.

Open conductors and multiconductor cables without an overall outer jacket shall have a clearance of not less than 3 feet (914 mm) from the sides of doors, porches, decks, stairs, ladders, fire escapes and balconies, and from the sides and bottom of windows that open. See Figure E3604.1. [230.9(A)]

For SI: 1 foot = 304.8 mm.

FIGURE E3604.1

CLEARANCES FROM BUILDING OPENINGS

E3604.2Vertical clearances.

Overhead service conductors shall not have ready access and shall comply with Sections E3604.2.1 and E3604.2.2. (230.24)

E3604.2.1Above roofs.

~~Conductors shall have a vertical clearance of not less than 8 feet (2438 mm) above the roof surface. The vertical clearance above the roof level shall be maintained for a distance of not less than 3 feet (914 mm) in all directions from the edge of the roof. See Figure E3604.2.1. [230.24(A)]~~

~~**Exceptions:**~~

11. ~~1.Conductors above a roof surface subject to pedestrian traffic shall have a vertical clearance from the roof surface in accordance with Section E3604.2.2. [230.24(A) Exception No. 1]~~
12. ~~2.Where the roof has a slope of 4 inches (102 mm) in 12 inches (305 mm), or greater, the minimum clearance shall be 3 feet (914 mm). [230.24(A) Exception No. 2]~~
13. ~~3.The minimum clearance above only the overhanging portion of the roof shall not be less than 18 inches (457 mm) where not more than 6 feet (1829 mm) of overhead service conductor length passes over 4 feet (1219 mm) or less of roof surface measured horizontally and such conductors are terminated at a through-the-roof raceway or approved support. [230.24(A) Exception No. 3]~~
14. ~~4.The requirement for maintaining the vertical clearance for a distance of 3 feet (914 mm) from the edge of the roof shall not apply to the final conductor span where the service drop is attached to the side of a building. [230.24(A) Exception No. 4]~~
15. ~~5.Where the voltage between conductors does not exceed 300 and the roof area is guarded or isolated, a reduction in clearance to 3 feet (914 mm) shall be permitted. [230.24(A) Exception No. 5]~~

~~For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.~~

~~FIGURE E3604.2.1~~

~~CLEARANCES FROM ROOFS~~

~~E3604.2.2Vertical clearance from grade.~~

~~Overhead service conductors shall have the following minimum clearances from final grade:~~

16. ~~1.For conductors supported on and cabled together with a grounded bare messenger wire, the minimum vertical clearance shall be 10 feet (3048 mm) at the electric service entrance to buildings, at the lowest point of the drip loop of the building electric entrance, and above areas or sidewalks accessed by pedestrians only. Such clearance shall be measured from final grade or other accessible surfaces.~~
17. ~~2.Twelve feet (3658 mm) – over residential property and driveways.~~

~~18. 3.Eighteen feet (5486 mm) – over public streets, alleys, roads or parking areas subject to truck traffic. [(230.24(B)(1), (2), and (4)]~~

~~E3604.3Point of attachment.~~

~~The point of attachment of the overhead service conductors to a building or other structure shall provide the minimum clearances as specified in Sections E3604.1 through E3604.2.2. The point of attachment shall be not less than 10 feet (3048 mm) above finished grade. (230.26)~~

~~E3604.4Means of attachment.~~

~~Multiconductor cables used for overhead service conductors shall be attached to buildings or other structures by fittings approved for the purpose. (230.27)~~

~~E3604.5Service masts as supports.~~

~~A service mast used for the support of service-drop or overhead service conductors shall comply with Sections E3604.5.1 and E3604.5.2. Only power service drop or overhead service conductors shall be attached to a service mast.~~

~~E3604.5.1Strength.~~

~~The service mast shall be of adequate strength or shall be supported by braces or guys to safely withstand the strain imposed by the service-drop or overhead service conductors. Hubs intended for use with a conduit that serves as a service mast shall be identified for use with service-entrance equipment.~~

~~E3604.5.2Attachment.~~

~~Service-drop or overhead service conductors shall not be attached to a service mast at a point between a coupling and a weatherhead or the end of the conduit, where the coupling is located above the last point of securement of the building or other structure or is located above the building or other structure. [230.28(A) & (B)]~~

~~E3604.6Supports over buildings.~~

~~Service conductors passing over a roof shall be securely supported. Where practicable, such supports shall be independent of the building. (230.29)~~

~~**SECTION**E3605~~
~~SERVICE-ENTRANCE CONDUCTORS~~

~~E3605.1Insulation of service-entrance conductors.~~

~~Service-entrance conductors entering or on the exterior of buildings or other structures shall be insulated in accordance with Section E3406.5. (230.41)~~

~~**Exceptions:**~~

~~19. 1.A copper grounded conductor shall not be required to be insulated where it is:~~

~~1. 1.1.In a raceway or part of a service cable assembly,~~

~~2. 1.2.Directly buried in soil of suitable condition, or~~

~~3. 1.3.Part of a cable assembly listed for direct burial without regard to soil conditions.~~

~~20. 2.An aluminum or copper-clad aluminum grounded conductor shall not be required to be insulated where part of a cable or where identified for direct burial or utilization in underground raceways. (230.41 Exception)~~

~~E3605.2Wiring methods for services.~~

~~Service-entrance wiring methods shall be installed in accordance with the applicable requirements in Chapter 38. (230.43)~~

~~E3605.3Spliced conductors.~~

~~Service-entrance conductors shall be permitted to be spliced or tapped. Splices shall be made in enclosures or, if directly buried, with listed underground splice kits. Conductor splices shall be made in accordance with Chapters 34, 37, 38 and 39. (230.33, 230.46)~~

~~E3605.4Protection of underground service entrance conductors.~~

~~Underground service-entrance conductors shall be protected against physical damage in accordance with Chapter 38. (230.32)~~

~~E3605.5Protection of all other service cables.~~

~~Aboveground service-entrance cables, where subject to physical damage, shall be protected by one or more of the following: rigid metal conduit, intermediate metal conduit, Schedule 80 PVC conduit, electrical metallic tubing or other approved means. [230.50(1)]~~

~~E3605.6Locations exposed to direct sunlight.~~

~~Insulated conductors and cables used where exposed to direct rays of the sun shall comply with one of the following:~~

~~21. 1.The conductors and cables shall be listed, or listed and marked, as being sunlight resistant.~~

~~22. 2.The conductors and cables are covered with insulating material, such as tape or sleeving, that is listed, or listed and marked, as being sunlight resistant. [310.10(D)]~~

~~E3605.7Mounting supports.~~

~~Service-entrance cables shall be supported by straps or other approved means within 12 inches (305 mm) of every service head, gooseneck or connection to a raceway or enclosure and at intervals not exceeding 30 inches (762 mm). [230.51(A)]~~

~~E3605.8Raceways to drain.~~

~~Where exposed to the weather, raceways enclosing service-entrance conductors shall be suitable for use in wet locations and arranged to drain. Where embedded in masonry, raceways shall be arranged to drain. (230.53)~~

~~E3605.9Overhead service locations.~~

~~Connections at service heads shall be in accordance with Sections E3605.9.1 through E3605.9.7. (230.54)~~

~~E3605.9.1Rain-tight service head.~~

~~Service raceways shall be equipped with a service head at the point of connection to service-drop or overhead conductors. The service head shall be listed for use in wet locations. [230.54(A)]~~

~~E3605.9.2Service cable, service head or gooseneck.~~

~~Service-entrance cable shall be equipped with a service head or shall be formed into a gooseneck in an approved manner. The service head shall be listed for use in wet locations. [230.54(B)]~~

~~E3605.9.3Service-head location.~~

~~Service heads, and goosenecks in service-entrance cables, shall be located above the point of attachment of the service drop or overhead service conductors to the building or other structure. [230.54(C)]~~

~~**Exception:** Where it is impracticable to locate the service head or gooseneck above the point of attachment, the service head or gooseneck location shall be not more than 24 inches (610 mm) from the point of attachment. [230.54(C) Exception]~~

~~E3605.9.4Separately bushed openings.~~

~~Service heads shall have conductors of different potential brought out through separately bushed openings. [230.54(E)]~~

~~E3605.9.5Drip loops.~~

~~Drip loops shall be formed on individual conductors. To prevent the entrance of moisture, service-entrance conductors shall be connected to the service-drop or overhead conductors either below the level of the service head or below the level of the termination of the service-entrance cable sheath. [230.54(F)]~~

~~E3605.9.6Conductor arrangement.~~

~~Service-entrance and overhead service conductors shall be arranged so that water will not enter service raceways or equipment. [230.54(G)]~~

~~E3605.9.7Secured.~~

~~Service-entrance cables shall be held securely in place. [230.54(D)]~~

~~**SECTION**E3606~~
~~SERVICE EQUIPMENT—GENERAL~~

~~E3606.1Service equipment enclosures.~~

~~Energized parts of service equipment shall be enclosed. (230.62)~~

~~E3606.2Working space.~~

~~The working space in the vicinity of service equipment shall be not less than that specified in Chapter 34. (110.26)~~

~~E3606.3Available short-circuit current.~~

~~Service equipment shall be suitable for the maximum fault current available at its supply terminals, but not less than 10,000 amperes. (110.9)~~

~~E3606.4Marking.~~

~~Service equipment shall be marked to identify it as being suitable for use as service equipment. Service equipment shall be listed. Individual meter socket enclosures shall not be considered as service equipment. (230.66)~~

~~**SECTION**E3607~~
~~SYSTEM GROUNDING~~

~~E3607.1System service ground.~~

~~The premises wiring system shall be grounded at the service with a grounding electrode conductor connected to a grounding electrode system as required by this code. Grounding electrode conductors shall be sized in accordance with Table E3603.4. [250.20(B)(1) and 250.24(A)]~~

~~E3607.2Location of grounding electrode conductor connection.~~

~~The grounding electrode conductor shall be connected to the grounded service conductor at any accessible point from the load end of the overhead service conductors, service drop, underground service conductors, or service lateral to and including the terminal or bus to which the grounded service conductor is connected at the service disconnecting means. A grounding connection shall not be made to any grounded circuit conductor on the load side of the service disconnecting means, except as provided in Section E3607.3.2. [250.24(A)(1) and (A)(5)]~~

~~E3607.3Buildings or structures supplied by feeder(s) or branch circuit(s).~~

~~Buildings or structures supplied by feeder(s) or branch circuit(s) shall have a grounding electrode or grounding electrode system installed in accordance with Section E3608. The grounding electrode conductor(s) shall be connected in a manner specified in Section E3607.3.1 or, for existing premises wiring systems only, Section E3607.3.2. Where there is no existing grounding electrode, the grounding electrode(s) required in Section E3608 shall be installed. [250.32(A)]~~

~~**Exception:** A grounding electrode shall not be required where only one branch circuit, including a multiwire branch circuit, supplies the building or structure and the branch circuit includes an equipment grounding conductor for grounding the noncurrent-carrying parts of all equipment. For the purposes of this section, a multiwire branch circuit shall be considered as a single branch circuit. [250.32(A) Exception]~~

~~E3607.3.1Equipment grounding conductor.~~

~~An equipment grounding conductor as described in Section E3908 shall be run with the supply conductors and connected to the building or structure disconnecting means and to the grounding electrode(s). The equipment grounding conductor shall be used for grounding or bonding of equipment, structures or frames required to be grounded or bonded. The equipment grounding conductor shall be sized in accordance with Section E3908.12. Any installed grounded conductor shall not be connected to the equipment grounding conductor or to the grounding electrode(s). [250.32(B) and Table 250.122]~~

~~E3607.3.2Grounded conductor, existing premises.~~

~~For installations made in compliance with previous editions of this code that permitted such connection and where an equipment grounding conductor is not run with the supply conductors to the building or structure, there are no continuous metallic paths bonded to the grounding system in both buildings or structures involved, and ground-fault protection of equipment has not been installed on the supply side of the feeder(s), the grounded conductor run with the supply to the buildings or structure shall be connected to the building or structure disconnecting means and to the grounding electrode(s) and shall be used for grounding or bonding of equipment, structures, or frames required to be grounded or bonded. Where used for grounding in accordance with this provision, the grounded conductor shall be not smaller than the larger of:~~

~~23. 1.That required by Section E3704.3.~~

~~24. 2.That required by Section E3908.12. [250.32(B)(1) Exception]~~

~~E3607.4Grounding electrode conductor.~~

~~A grounding electrode conductor shall be used to connect the equipment grounding conductors, the service equipment enclosures, and the grounded service conductor to the grounding electrode(s). This conductor shall be sized in accordance with Table E3603.4. [250.24(D)]~~

E3607.5Main bonding jumper.

An unspliced main bonding jumper shall be used to connect the equipment grounding conductor(s) and the service-disconnect enclosure to the grounded conductor of the system within the enclosure for each service disconnect. [250.24(B)]

E3607.6Common grounding electrode.

Where an ac system is connected to a grounding electrode in or at a building or structure, the same electrode shall be used to ground conductor enclosures and equipment in or on that building or structure. Where separate services, feeders or branch circuits supply a building and are required to be connected to a grounding electrode(s), the same grounding electrode(s) shall be used. Two or more grounding electrodes that are effectively bonded together shall be considered as a single grounding electrode system. (250.58)

SECTIONE3608
GROUNDING ELECTRODE SYSTEM

E3608.1Grounding electrode system.

All electrodes specified in Sections E3608.1.1, E3608.1.2, E3608.1.3, E3608.1.4 E3608.1.5 and E3608.1.6 that are present at each building or structure served shall be bonded together to form the grounding electrode system. Where none of these electrodes are present, one or more of the electrodes specified in Sections E3608.1.3, E3608.1.4, E3608.1.5 and E3608.1.6 shall be installed and used. (250.50)

Exception: Concrete-encased electrodes of existing buildings or structures shall not be required to be part of the grounding electrode system where the steel reinforcing bars or rods are not accessible for use without disturbing the concrete. (250.50 Exception)

E3608.1.1Metal underground water pipe.

A metal underground water pipe that is in direct contact with the earth for 10 feet (3048 mm) or more, including any well casing effectively bonded to the pipe and that is electrically continuous, or made electrically continuous by bonding around insulating joints or insulating pipe to the points of connection of the grounding electrode conductor and the bonding conductors, shall be considered as a grounding electrode (see Section E3608.1). [250.52(A)(1)]

E3608.1.1.1Interior metal water piping.

Interior metal water piping located more than 5 feet (1524 mm) from the entrance to the building shall not be used as a conductor to interconnect electrodes that are part of the grounding electrode system. [250.68(C)(1)]

E3608.1.1.2 Installation.

Continuity of the grounding path or the bonding connection to interior piping shall not rely on water meters, filtering devices and similar equipment. A metal underground water pipe shall be supplemented by an additional electrode of a type specified in Sections E3608.1.2 through E3608.1.6. The supplemental electrode shall be bonded to the grounding electrode conductor, the grounded service-entrance conductor, a nonflexible grounded service raceway, any grounded service enclosure or to the equipment grounding conductor provided in accordance with Section E3607.3.1. Where the supplemental electrode is a rod, pipe or plate electrode in accordance with Section E3608.1.4 or E3608.1.5, it shall comply with Section E3608.4.

Where the supplemental electrode is a rod, pipe or plate electrode in accordance with Section E3608.1.4 or E3608.1.5, that portion of the bonding jumper that is the sole connection to the supplemental grounding electrode shall not be required to be larger than 6 AWG copper or 4 AWG aluminum wire. [250.53(D) and (E)]

E3608.1.2Concrete-encased electrode.

A concrete-encased electrode consisting of at least 20 feet (6096 mm) of either of the following shall be considered as a grounding electrode:

25. 1.One or more bare or zinc galvanized or other electrically conductive coated steel reinforcing bars or rods not less than $^{1}/_{2}$ inch (13 mm) in diameter, installed in one continuous 20-foot (6096 mm) length, or if in multiple pieces connected together by the usual steel tie wires, exothermic welding, welding, or other effective means to create a 20-foot (6096 mm) or greater length.
26. 2.A bare copper conductor not smaller than 4 AWG.

Metallic components shall be encased by at least 2 inches (51 mm) of concrete and shall be located horizontally within that portion of a concrete foundation or footing that is in direct contact with the earth or within vertical foundations or structural components or members that are in direct contact with the earth.

Where multiple concrete-encased electrodes are present at a building or structure, only one shall be required to be bonded into the grounding electrode system. [250.52(A)(3)]

E3608.1.3Ground rings.

A ground ring encircling the building or structure, in direct contact with the earth at a depth below the earth's surface of not less than 30 inches (762 mm), consisting of at least 20 feet (6096 mm) of bare copper conductor not smaller than 2 AWG shall be considered as a grounding electrode. [250.52(A)(4)]

E3608.1.4Rod and pipe electrodes.

Rod and pipe electrodes not less than 8 feet (2438 mm) in length and consisting of the following materials shall be considered as a grounding electrode:

27. 1.Grounding electrodes of pipe or conduit shall not be smaller than trade size $^3/_4$ (metric designator 21) and, where of iron or steel, shall have the outer surface galvanized or otherwise metal-coated for corrosion protection.

28. 2.Rod-type grounding electrodes of stainless steel and copper or zinc-coated steel shall be at least $^5/_8$ inch (15.9 mm) in diameter unless listed. [250.52(A)(5)]

E3608.1.4.1 Installation.

The rod and pipe electrodes shall be installed such that at least 8 feet (2438 mm) of length is in contact with the soil. They shall be driven to a depth of not less than 8 feet (2438 mm) except that, where rock bottom is encountered, electrodes shall be driven at an oblique angle not to exceed 45 degrees (0.79 rad) from the vertical or shall be buried in a trench that is at least 30 inches (762 mm) deep. The upper end of the electrodes shall be flush with or below ground level except where the aboveground end and the grounding electrode conductor attachment are protected against physical damage. (250.53(G)]

E3608.1.5Plate electrodes.

A plate electrode that exposes not less than 2 square feet (0.186 m^2) of surface to exterior soil shall be considered as a grounding electrode. Electrodes of bare or conductively coated iron or steel plates shall be at least $^1/_4$ inch (6.4 mm) in thickness. Solid, uncoated electrodes of nonferrous metal shall be at least 0.06 inch (1.5 mm) in thickness. Plate electrodes shall be installed not less than 30 inches (762 mm) below the surface of the earth. [250.52(A)(7)]

E3608.1.6Other electrodes.

In addition to the grounding electrodes specified in Sections E3608.1.1 through E3608.1.5, other listed grounding electrodes shall be permitted. [250.52(A)(6)]

E3608.2Bonding jumper.

The bonding jumper(s) used to connect the grounding electrodes together to form the grounding electrode system shall be installed in accordance with Sections E3610.2, and E3610.3, shall be sized in accordance with Section E3603.4, and shall be connected in the manner specified in Section E3611.1. [250.53(C)]

E3608.3Rod, pipe and plate electrode requirements.

Where practicable, rod, pipe and plate electrodes shall be embedded below permanent moisture level. Such electrodes shall be free from nonconductive coatings such as paint or enamel. Where more than one such electrode is used, each electrode of one grounding system shall be not less than 6 feet (1829 mm) from any other electrode of another grounding system. Two or more grounding electrodes that are effectively bonded together shall be considered as a single grounding electrode system. That portion of a bonding jumper that is the sole connection to a rod, pipe or plate electrode shall not be required to be larger than 6 AWG copper or 4 AWG aluminum wire. [250.53(A)(1), 250.53(B), 250.53(C)]

~~E3608.4Supplemental electrode required.~~

~~A single rod, pipe, or plate electrode shall be supplemented by an additional electrode of a type specified in Sections E3608.1.2 through E3608.1.6. The supplemental electrode shall be bonded to one of the following:~~

29. ~~1.A rod, pipe, or plate electrode.~~
30. ~~2.A grounding electrode conductor.~~
31. ~~3.A grounded service-entrance conductor.~~
32. ~~4.A nonflexible grounded service raceway.~~
33. ~~5.A grounded service enclosure.~~

~~Where multiple rod, pipe, or plate electrodes are installed to meet the requirements of this section, they shall not be less than 6 feet (1829 mm) apart. [250.53(A)(2) and (A)(3)]~~

~~**Exception:** Where a single rod, pipe, or plate grounding electrode has a resistance to earth of 25 ohms or less, the supplemental electrode shall not be required. [250.53(A)(2) Exception]~~

~~E3608.5Aluminum electrodes.~~

~~Aluminum electrodes shall not be permitted. [250.52(B)(2)]~~

~~E3608.6Metal underground gas piping system.~~

~~A metal underground gas piping system shall not be used as a grounding electrode. [250.52(B)(1)]~~

~~**SECTION**E3609~~
~~BONDING~~

~~E3609.1General.~~

~~Bonding shall be provided where necessary to ensure electrical continuity and the capacity to conduct safely any fault current likely to be imposed. (250.90)~~

~~E3609.2Bonding of equipment for services.~~

~~The noncurrent-carrying metal parts of the following equipment shall be effectively bonded together:~~

34. ~~1.Raceways or service cable armor or sheath that enclose, contain, or support service conductors.~~
35. ~~2.Service enclosures containing service conductors, including meter fittings, and boxes, interposed in the service raceway or armor. [250.92(A)]~~

~~E3609.3Bonding for other systems.~~

~~An intersystem bonding termination for connecting intersystem bonding conductors required for other systems shall be provided external to enclosures at the service equipment or metering equipment enclosure and at the disconnecting means for any additional buildings or structures. The intersystem bonding termination shall comply with all of the following:~~

~~36. 1.It shall be accessible for connection and inspection.~~

~~37. 2.It shall consist of a set of terminals with the capacity for connection of not less than three intersystem bonding conductors.~~

~~38. 3.It shall not interfere with opening of the enclosure for a service, building or structure disconnecting means, or metering equipment.~~

~~39. 4.Where located at the service equipment, it shall be securely mounted and electrically connected to an enclosure for the service equipment, to the meter enclosure, or to an exposed nonflexible metallic service raceway, or shall be mounted at one of these enclosures and connected to the enclosure or to the grounding electrode conductor with a 6 AWG or larger copper conductor.~~

~~40. 5.Where located at the disconnecting means for a building or structure, it shall be securely mounted and electrically connected to the metallic enclosure for the building or structure disconnecting means, or shall be mounted at the disconnecting means and connected to the metallic enclosure or to the grounding electrode conductor with a 6 AWG or larger copper conductor.~~

~~41. 6.It shall be listed as grounding and bonding equipment. (250.94)~~

~~E3609.4Method of bonding at the service.~~

~~Bonding jumpers meeting the requirements of this chapter shall be used around impaired connections, such as reducing washers or oversized, concentric, or eccentric knockouts. Standard locknuts or bushings shall not be the only means for the bonding required by this section but shall be permitted to be installed to make mechanical connections of raceways. Electrical continuity at service equipment, service raceways and service conductor enclosures shall be ensured by one or more of the methods specified in Sections E3609.4.1 through E3609.4.4.~~

~~E3609.4.1Grounded service conductor.~~

~~Equipment shall be bonded to the grounded service conductor in a manner provided in this code.~~

~~E3609.4.2Threaded connections.~~

~~Equipment shall be bonded by connections using threaded couplings or threaded hubs on enclosures. Such connections shall be made wrench tight.~~

~~E3609.4.3Threadless couplings and connectors.~~

~~Equipment shall be bonded by threadless couplings and connectors for metal raceways and metal-clad cables. Such couplings and connectors shall be made wrench tight. Standard locknuts or bushings shall not be used for the bonding required by this section.~~

~~E3609.4.4Other devices.~~

~~Equipment shall be bonded by other listed devices, such as bonding-type locknuts, bushings and bushings with bonding jumpers. [250.92(B)]~~

~~E3609.5Sizing supply-side bonding jumper and main bonding jumper.~~

~~The bonding jumper shall not be smaller than the sizes shown in Table E3603.4 for grounding electrode conductors. Where the service-entrance conductors are paralleled in two or more raceways or cables, and an individual supply-side bonding jumper is used for bonding these raceways or cables, the supply-side bonding jumper for each raceway or cable shall be selected from Table E3603.4 based on the size of the ungrounded supply conductors in each raceway or cable. A single supply side bonding jumper installed for bonding two or more raceways or cables shall be sized in accordance with Table E3603.4 based on the largest set of parallel ungrounded supply conductors. [250.102(C)]~~

~~E3609.6Metal water piping bonding.~~

~~The metal water piping system shall be bonded to the service equipment enclosure, the grounded conductor at the service, the grounding electrode conductor where of sufficient size, or to the one or more grounding electrodes used. The bonding jumper shall be sized in accordance with Table E3603.4. The points of attachment of the bonding jumper(s) shall be accessible. [250.104(A) and 250.104(A)(1)]~~

~~E3609.7Bonding other metal piping.~~

~~Where installed in or attached to a building or structure, metal piping systems, including gas piping, capable of becoming energized shall be bonded to the service equipment enclosure, the grounded conductor at the service, the grounding electrode conductor where of sufficient size, or to the one or more grounding electrodes used. The bonding conductor(s) or jumper(s) shall be sized in accordance with Table E3908.12 using the rating of the circuit capable of energizing the piping. The equipment grounding conductor for the circuit that is capable of energizing the piping shall be permitted to serve as the bonding means. The points of attachment of the bonding jumper(s) shall be accessible. [250.104(B)]~~

~~**SECTION**E3610~~
~~GROUNDING ELECTRODE CONDUCTORS~~

~~E3610.1Continuous.~~

~~The grounding electrode conductor shall be installed in one continuous length without splices or joints and shall run to any convenient grounding electrode available in the grounding electrode system where the other electrode(s), if any, are connected by bonding jumpers in accordance with Section E3608.2, or to one or more grounding electrode(s) individually. The grounding electrode conductor shall be sized for~~

the largest grounding electrode conductor required among all of the electrodes connected to it. [250.64(C)]

Exception: Splicing of the grounding electrode conductor by irreversible compression-type connectors listed as grounding and bonding equipment or by the exothermic welding process shall not be prohibited. [250.64(C)(1)]

E3610.2Securing and protection against physical damage.

Where exposed, a grounding electrode conductor or its enclosure shall be securely fastened to the surface on which it is carried. Grounding electrode conductors shall be permitted to be installed on or through framing members. A 4 AWG or larger conductor shall be protected where exposed to physical damage. A 6 AWG grounding conductor that is free from exposure to physical damage shall be permitted to be run along the surface of the building construction without metal covering or protection where it is and securely fastened to the construction; otherwise, it shall be in rigid metal conduit, intermediate metal conduit, rigid polyvinyl chloride (PVC), nonmetallic conduit, reinforced thermosetting resin (RTRC) nonmetallic conduit, electrical metallic tubing or cable armor. Grounding electrode conductors smaller than 6 AWG shall be in rigid metal conduit, intermediate metal conduit, rigid polyvinyl chloride (PVC) nonmetallic conduit, reinforced thermoseting resin (RTRC) nonmetallic conduit, electrical metallic tubing or cable armor. Grounding electrode conductors and grounding electrode bonding jumpers shall not be required to comply with Section E3803. [250.64(B)]

Bare aluminum or copper-clad aluminum grounding electrode conductors shall not be used where in direct contact with masonry or the earth or where subject to corrosive conditions. Where used outside, aluminum or copper-clad aluminum grounding electrode conductors shall not be installed within 18 inches (457 mm) of the earth. [250.64(A)]

E3610.3Raceways and enclosures for grounding electrode conductors.

Ferrous metal raceways and enclosures for grounding electrode conductors shall be electrically continuous from the point of attachment to cabinets or equipment to the grounding electrode, and shall be securely fastened to the ground clamp or fitting. Nonferrous metal raceways and enclosures shall not be required to be electrically continuous. Ferrous metal raceways and enclosures shall be bonded at each end of the raceway or enclosure to the grounding electrode or to the grounding electrode conductor. Bonding methods in compliance with Section E3609.4 for installations at service equipment locations and with E3609.4.2 through E3609.4.4 for other than service equipment locations shall apply at each end and to all intervening ferrous raceways, boxes, and enclosures between the cabinets or equipment and the grounding electrode. The bonding jumper for a grounding electrode conductor raceway shall be the same size or larger than the required enclosed grounding electrode conductor.

Where a raceway is used as protection for a grounding conductor, the installation shall comply with the requirements of Chapter 38. [250.64(E)(4)]

E3610.4Prohibited use.

An equipment grounding conductor shall not be used as a grounding electrode conductor. (250.121)

Exception: A wire-type equipment grounding conductor shall be permitted to serve as both an equipment grounding conductor and a grounding electrode conductor where installed in accordance with the applicable requirements for both the equipment grounding conductor and the grounding electrode conductor in Chapters 36 and 39. Where used as a grounding electrode conductor, the wiretype equipment grounding conductor shall be installed and arranged in a manner that will prevent objectionable current. [250.121 Exception, 250.6(A)]

SECTIONE3611
GROUNDING ELECTRODE CONDUCTOR
CONNECTION TO THE GROUNDING ELECTRODES

E3611.1Methods of grounding conductor connection to electrodes.

The grounding or bonding conductor shall be connected to the grounding electrode by exothermic welding, listed lugs, listed pressure connectors, listed clamps or other listed means. Connections depending on solder shall not be used. Ground clamps shall be listed for the materials of the grounding electrode and the grounding electrode conductor and, where used on pipe, rod or other buried electrodes, shall also be listed for direct soil burial or concrete encasement. Not more than one conductor shall be connected to the grounding electrode by a single clamp or fitting unless the clamp or fitting is listed for multiple conductors. One of the methods indicated in the following items shall be used:

42. 1.A pipe fitting, pipe plug or other approved device screwed into a pipe or pipe fitting.
43. 2.A listed bolted clamp of cast bronze or brass, or plain or malleable iron.
44. 3.For indoor communications purposes only, a listed sheet metal strap-type ground clamp having a rigid metal base that seats on the electrode and having a strap of such material and dimensions that it is not likely to stretch during or after installation.
45. 4.Other equally substantial approved means. (250.70)

E3611.2Accessibility.

All mechanical elements used to terminate a grounding electrode conductor or bonding jumper to the grounding electrodes that are not buried or concrete encased shall be accessible. [250.68(A) and 250.68(A) Exception]

E3611.3Effective grounding path.

The connection of the grounding electrode conductor or bonding jumper shall be made in a manner that will ensure a permanent and effective grounding path. Where necessary to ensure effective grounding for a metal piping system used as a grounding electrode, effective bonding shall be provided around insulated joints and sections and around any equipment that is likely to be disconnected for repairs or

~~replacement. Bonding jumpers shall be of sufficient length to permit removal of such equipment while retaining the integrity of the grounding path. [250.68(B)]~~

~~E3611.4Interior metal water piping.~~

~~Where grounding electrode conductors and bonding jumpers are connected to interior metal water piping as a means to extend the grounding electrode conductor connection to an electrode(s), such piping shall be located not more than 5 feet (1524 mm) from the point of entry into the building.~~

~~Where interior metal water piping is used as a conductor to interconnect electrodes that are part of the grounding electrode system, such piping shall be located not more than 5 feet (1524 mm) from the point of entry into the building. [250.68(C)(1)]~~

~~E3611.5Protection of ground clamps and fittings.~~

~~Ground clamps or other fittings shall be approved for applications without protection or shall be protected from physical damage by installing them where they are not likely to be damaged or by enclosing them in metal, wood or equivalent protective coverings. (250.10)~~

~~E3611.6Clean surfaces.~~

~~Nonconductive coatings (such as paint, enamel and lacquer) on equipment to be grounded shall be removed from threads and other contact surfaces to ensure good electrical continuity or shall be connected by fittings that make such removal unnecessary. (250.12)~~

CHAPTER37
BRANCH CIRCUIT AND FEEDER REQUIREMENTS

RESERVED

~~SECTIONE3701~~
~~GENERAL~~

~~E3701.1Scope.~~

~~This chapter covers branch circuits and feeders and specifies the minimum required branch circuits, the allowable loads and the required overcurrent protection for branch circuits and feeders that serve less than 100 percent of the total dwelling unit load. Feeder circuits that serve 100 percent of the dwelling unit load shall be sized in accordance with the procedures in Chapter 36. [310.15(B)(7)(2)]~~

~~E3701.2Branch-circuit and feeder ampacity.~~

~~Branch-circuit and feeder conductors shall have ampacities not less than the maximum load to be served. Where a branch circuit or a feeder supplies continuous loads or any combination of continuous and noncontinuous loads, the minimum branch-circuit or feeder conductor size, before the application of any adjustment or correction factors, shall have an allowable ampacity equal to or greater than the noncontinuous load plus 125 percent of the continuous load. [210.19(A)(1)(a) and 215.2(A)(1)(a)]~~

~~Exception: The grounded conductors of feeders that are not connected to an overcurrent device shall be permitted to be sized at 100 percent of the continuous and noncontinuous load. [215.1(A)(1) Exception No. 2]~~

~~E3701.3Selection of ampacity.~~

~~Where more than one calculated or tabulated ampacity could apply for a given circuit length, the lowest value shall be used. [310.15(A)(2)]~~

~~Exception: Where two different ampacities apply to adjacent portions of a circuit, the higher ampacity shall be permitted to be used beyond the point of transition, a distance equal to 10 feet (3048 mm) or 10 percent of the circuit length figured at the higher ampacity, whichever is less. [310.15(A)(2) Exception]~~

~~E3701.4Branch circuits with more than one receptacle.~~

~~Conductors of branch circuits supplying more than one receptacle for cord-and-plug-connected portable loads shall have ampacities of not less than the rating of the branch circuit. [210.19(A)(2)]~~

~~E3701.5Multiwire branch circuits.~~

~~All conductors for multiwire branch circuits shall originate from the same panelboard or similar distribution equipment. Except where all ungrounded conductors are opened simultaneously by the branch-circuit overcurrent device, multiwire branch circuits shall supply only line-to-neutral loads or only one appliance. [210.4(A) and 210.4(C)]~~

~~E3701.5.1Disconnecting means.~~

~~Each multiwire branch circuit shall be provided with a means that will simultaneously disconnect all ungrounded conductors at the point where the branch circuit originates. [210.4(B)]~~

~~E3701.5.2Grouping.~~

~~The ungrounded and grounded circuit conductors of each multiwire branch circuit shall be grouped by cable ties or similar means in at least one location within the panelboard or other point of origination. [210.4(D)]~~

~~Exception: Grouping shall not be required where the circuit conductors enter from a cable or raceway unique to the circuit, thereby making the grouping obvious, or where the conductors are identified at their terminations with numbered wire markers corresponding to their appropriate circuit number. [210.4(D) Exception].~~

~~SECTIONE3702~~
~~BRANCH CIRCUIT RATINGS~~

~~E3702.1Branch-circuit voltage limitations.~~

~~The voltage ratings of branch circuits that supply luminaires or receptacles for cord-and-plug-connected loads of up to 1,400 volt-amperes or of less than 1/4 horsepower (0.186 kW) shall be limited to a maximum rating of 120 volts, nominal, between conductors.~~

~~Branch circuits that supply cord-and-plug-connected or permanently connected utilization equipment and appliances rated at over 1,440 volt-amperes or 1/4 horsepower (0.186 kW) and greater shall be rated at 120 volts or 240 volts, nominal. [210.6(A), (B), and (C)]~~

~~E3702.2Branch-circuit ampere rating.~~

~~Branch circuits shall be rated in accordance with the maximum allowable ampere rating or setting of the overcurrent protection device. The rating for other than individual branch circuits shall be 15, 20, 30, 40 and 50 amperes. Where conductors of higher ampacity are used, the ampere rating or setting of the specified over-current device shall determine the circuit rating. (210.3)~~

~~E3702.3Fifteen- and 20-ampere branch circuits.~~

~~A 15- or 20-ampere branch circuit shall be permitted to supply lighting units, or other utilization equipment, or a combination of both. The rating of any one cord-and-plug-connected utilization equipment not fastened in place shall not exceed 80 percent of the branch-circuit ampere rating. The total rating of utilization equipment fastened in place, other than luminaires, shall not exceed 50 percent of the branch-circuit ampere rating where lighting units, cord-and-plug-connected utilization equipment not fastened in place, or both, are also supplied. [210.23(A)(1) and (2)]~~

~~E3702.4Thirty-ampere branch circuits.~~

~~A 30-ampere branch circuit shall be permitted to supply fixed utilization equipment. A rating of any one cord-and-plug-connected utilization equipment shall not exceed 80 percent of the branchcircuit ampere rating. [210.23(B)]~~

~~E3702.5Branch circuits serving multiple loads or outlets.~~

~~General-purpose branch circuits shall supply lighting outlets, appliances, equipment or receptacle outlets, and combinations of such. Multioutlet branch circuits serving lighting or receptacles shall be limited to a maximum branch-circuit rating of 20 amperes. [210.23(A), (B), and (C)]~~

~~E3702.6Branch circuits serving a single motor.~~

~~Branch-circuit conductors supplying a single motor shall have an ampacity not less than 125 percent of the motor full-load current rating. [430.22(A)]~~

~~E3702.7Branch circuits serving motor-operated and combination loads.~~

~~For circuits supplying loads consisting of motor-operated utilization equipment that is fastened in place and that has a motor larger than 1/8 horsepower (0.093 kW) in combination with other loads, the total~~

~~calculated load shall be based on 125 percent of the largest motor load plus the sum of the other loads. [220.18(A)]~~

~~E3702.8Branch-circuit inductive and LED lighting loads.~~

~~For circuits supplying luminaires having ballasts or LED drivers, the calculated load shall be based on the total ampere ratings of such units and not on the total watts of the lamps. [220.18(B)]~~

~~E3702.9Branch-circuit load for ranges and cooking appliances.~~

~~It shall be permissible to calculate the branch-circuit load for one range in accordance with Table E3704.2(2). The branch-circuit load for one wall-mounted oven or one counter-mounted cooking unit shall be the nameplate rating of the appliance. The branch-circuit load for a counter-mounted cooking unit and not more than two wall-mounted ovens all supplied from a single branch circuit and located in the same room shall be calculated by adding the nameplate ratings of the individual appliances and treating the total as equivalent to one range. (220.55 Note 4)~~

~~E3702.9.1Minimum branch circuit for ranges.~~

~~Ranges with a rating of 8.75 kVA or more shall be supplied by a branch circuit having a minimum rating of 40 amperes. [210.19(A)(3)]~~

~~E3702.10Branch circuits serving heating loads.~~

~~Electric space-heating and water-heating appliances shall be considered to be continuous loads. Branch circuits supplying two or more outlets for fixed electric space-heating equipment shall be rated 15, 20, 25 or 30 amperes. [424.3(A)]~~

~~E3702.11Branch circuits for air-conditioning and heat pump equipment.~~

~~The ampacity of the conductors supplying multimotor and combination load equipment shall be not less than the minimum circuit ampacity marked on the equipment. The branch-circuit overcurrent device rating shall be the size and type marked on the appliance. [440.4(B), 440.35, 440.62(A)]~~

~~E3702.12Branch circuits serving room air conditioners.~~

~~A room air conditioner shall be considered as a single motor unit in determining its branch-circuit requirements where all the following conditions are met:~~

~~1.It is cord- and attachment plug-connected.~~

~~2.The rating is not more than 40 amperes and 250 volts; single phase.~~

~~3.Total rated-load current is shown on the room air-conditioner nameplate rather than individual motor currents.~~

4.The rating of the branch-circuit short-circuit and ground-fault protective device does not exceed the ampacity of the branch-circuit conductors, or the rating of the branch-circuit conductors, or the rating of the receptacle, whichever is less. [440.62(A)]

E3702.12.1Where no other loads are supplied.

The total marked rating of a cord- and attachment plug-connected room air conditioner shall not exceed 80 percent of the rating of a branch circuit where no other appliances are also supplied. [440.62(B)]

E3702.12.2Where lighting units or other appliances are also supplied.

The total marked rating of a cord- and attachment plug-connected room air conditioner shall not exceed 50 percent of the rating of a branch circuit where lighting or other appliances are also supplied. Where the circuitry is interlocked to prevent simultaneous operation of the room air conditioner and energization of other outlets on the same branch circuit, a cord- and attachment-plug-connected room air conditioner shall not exceed 80 percent of the branch-circuit rating. [440.62(C)]

E3702.13Electric vehicle branch circuit.

Outlets installed for the purpose of charging electric vehicles shall be supplied by a separate branch circuit. Such circuit shall not supply other outlets. (210.17)

E3702.14Branch-circuit requirement—summary.

The requirements for circuits having two or more outlets, or receptacles, other than the receptacle circuits of Sections E3703.2, E3703.3 and E3703.4, are summarized in Table E3702.14. Branch circuits in dwelling units shall supply only loads within that dwelling unit or loads associated only with that dwelling unit. Branch circuits installed for the purpose of lighting, central alarm, signal, communications or other purposes for public or common areas of a two-family dwelling shall not be supplied from equipment that supplies an individual dwelling unit. (210.24 and 210.25)

TABLE E3702.14 (Table 210.24)

BRANCH-CIRCUIT REQUIREMENTS-SUMMARYa, b

	CIRCUIT RATING		
	15 amp	20 amp	30 amp
Conductors: Minimum size (AWG) circuit conductors	14	12	10
Maximum overcurrent- protection-device rating Ampere rating	15	20	30

~~Outlet devices: Lampholders permitted Receptacle rating (amperes)~~	~~Any type 15 maximum~~	~~Any type 15 or 20~~	~~N/A 30~~
~~Maximum load (amperes)~~	~~15~~	~~20~~	~~30~~

~~a.These gages are for copper conductors.~~

~~b.N/A means not allowed.~~

~~SECTIONE3703~~
~~REQUIRED BRANCH CIRCUITS~~

~~E3703.1Branch circuits for heating.~~

~~Central heating equipment other than fixed electric space-heating shall be supplied by an individual branch circuit. Permanently connected air-conditioning equipment, and auxiliary equipment directly associated with the central heating equipment such as pumps, motorized valves, humidifiers and electrostatic air cleaners, shall not be prohibited from connecting to the same branch circuit as the central heating equipment. (422.12 and 422.12 Exceptions No. 1 and No. 2)~~

~~E3703.2Kitchen and dining area receptacles.~~

~~A minimum of two 20-ampere-rated branch circuits shall be provided to serve all wall and floor receptacle outlets located in the kitchen, pantry, breakfast area, dining area or similar area of a dwelling. The kitchen countertop receptacles shall be served by a minimum of two 20-ampere-rated branch circuits, either or both of which shall also be permitted to supply other receptacle outlets in the same kitchen, pantry, breakfast and dining area including receptacle outlets for refrigeration appliances. [210.11(C)(1) and 210.52(B)(1) and (B)(2)]~~

~~Exception: The receptacle outlet for refrigeration appliances shall be permitted to be supplied from an individual branch circuit rated 15 amperes or greater. [210.52(B)(1) Exception No. 2]~~

~~E3703.3Laundry circuit.~~

~~A minimum of one 20-ampere-rated branch circuit shall be provided for receptacles located in the laundry area and shall serve only receptacle outlets located in the laundry area. [210.11(C)(2)]~~

~~E3703.4Bathroom branch circuits.~~

~~A minimum of one 20-ampere branch circuit shall be provided to supply bathroom receptacle outlet(s). Such circuits shall have no other outlets. [210.11(C)(3)]~~

~~Exception: Where the 20-ampere circuit supplies a single bathroom, outlets for other equipment within the same bathroom shall be permitted to be supplied in accordance with Section E3702. [210.11(C)(3) Exception)~~

E3703.5Number of branch circuits.

The minimum number of branch circuits shall be determined from the total calculated load and the size or rating of the circuits used. The number of circuits shall be sufficient to supply the load served. In no case shall the load on any circuit exceed the maximum specified by Section E3702. [210.11(A)]

E3703.6Branch-circuit load proportioning.

Where the branch-circuit load is calculated on a volt-amperes-per-square-foot (m2) basis, the wiring system, up to and including the branch-circuit panelboard(s), shall have the capacity to serve not less than the calculated load. This load shall be evenly proportioned among multioutlet branch circuits within the panelboard(s). Branch-circuit overcurrent devices and circuits shall only be required to be installed to serve the connected load. [210.11(B)]

SECTIONE3704
FEEDER REQUIREMENTS

E3704.1Conductor size.

Feeder conductors that do not serve 100 percent of the dwelling unit load and branch-circuit conductors shall be of a size sufficient to carry the load as determined by this chapter. Feeder conductors shall not be required to be larger than the service-entrance conductors that supply the dwelling unit. The load for feeder conductors that serve as the main power feeder to a dwelling unit shall be determined as specified in Chapter 36 for services. [310.15(B)(7)(2) and (3)]

E3704.2Feeder loads.

The minimum load in volt-amperes shall be calculated in accordance with the load calculation procedure prescribed in Table E3704.2(1). The associated table demand factors shall be applied to the actual load to determine the minimum load for feeders. (220.40)

TABLE E3704.2(1) (Table 220.12, 220.14, Table 220.42, 220.50, 220.51, 220.52, 220.53, 220.54, 220.55, and 220.60)

FEEDER LOAD CALCULATION

LOAD CALCULATION PROCEDURE	APPLIED DEMAND FACTOR
Lighting and receptacles: A unit load of not less than 3 VA per square foot of total floor area shall constitute the lighting and 120-volt, 15- and 20-ampere general use receptacle load. 1,500 VA shall be added for each 20-ampere branch circuit serving receptacles in the kitchen, dining room, pantry, breakfast area and laundry area.	100 percent of first 3,000 VA or less and 35 percent of that in excess of 3,000 VA.

~~Plus~~

~~Appliances and motors: The nameplate rating load of all fastened-in- place appliances other than dryers, ranges, air-conditioning and space-heating equipment.~~	~~100 percent of load for three or less appliances. 75 percent of load for four or more appliances.~~

~~Plus~~

~~Fixed motors: Full load current of motors plus 25 percent of the full load current of the largest motor.~~

~~Plus~~

~~Electric clothes dryer: The dryer load shall be 5,000 VA for each dryer circuit or the nameplate rating load of each dryer, whichever is greater.~~

~~Plus~~

~~Cooking appliances: The nameplate rating of ranges, wall-mounted ovens, counter-mounted cooking units and other cooking appliances rated in excess of 1.75 kVA shall be summed.~~	~~Demand factors shall be as allowed by Table E3704.2(2).~~

~~Plus the largest of either the heating or cooling load~~

~~Largest of the following two selections:~~

~~1.100 percent of the nameplate rating(s) of the air conditioning and cooling, including heat pump compressors.~~

~~2.100 percent of the fixed electric space heating.~~

~~For SI: 1 square foot = 0.0929 m2.~~

~~TABLE E3704.2(2) (220.55 and Table 220.55)~~

~~DEMAND LOADS FOR ELECTRIC RANGES, WALL-MOUNTED OVENS, COUNTER-MOUNTED COOKING UNITS AND OTHER COOKING APPLIANCES OVER 13/4 kVA RATINGa, b~~

~~NUMBER OF APPLIANCES~~	~~MAXIMUM DEMANDb, c~~	~~DEMAND FACTORS (percent)d~~	
	~~Column A maximum 12~~	~~Column B less than 31/2~~	~~Column C 31/2 to 83/4~~

	~~kVA rating~~	~~kVA rating~~	~~kVA rating~~
~~1~~	~~8kVA~~	~~80~~	~~80~~
~~2~~	~~11kVA~~	~~75~~	~~65~~

~~a.Column A shall be used in all cases except as provided for in Footnote d.~~

~~b.For ranges all having the same rating and individually rated more than 12 kVA but not more than 27 kVA, the maximum demand in Column A shall be increased 5 percent for each additional kVA of rating or major fraction thereof by which the rating of individual ranges exceeds 12 kVA.~~

~~c.For ranges of unequal ratings and individually rated more than 8.75 kVA, but none exceeding 27 kVA, an average value of rating shall be computed by adding together the ratings of all ranges to obtain the total connected load (using 12 kVA for any ranges rated less than 12 kVA) and dividing by the total number of ranges; and then the maximum demand in Column A shall be increased 5 percent for each kVA or major fraction thereof by which this average value exceeds 12 kVA.~~

~~d.Over 1.75 kVA through 8.75 kVA. As an alternative to the method provided in Column A, the nameplate ratings of all ranges rated more than 1.75 kVA but not more than 8.75 kVA shall be added and the sum shall be multiplied by the demand factor specified in Column B or C for the given number of appliances.~~

~~E3704.3Feeder neutral load.~~

~~The feeder neutral load shall be the maximum unbalance of the load determined in accordance with this chapter. The maximum unbalanced load shall be the maximum net calculated load between the neutral and any one ungrounded conductor. For a feeder or service supplying electric ranges, wall-mounted ovens, counter-mounted cooking units and electric dryers, the maximum unbalanced load shall be considered as 70 percent of the load on the ungrounded conductors. [220.61(A) and (B)]~~

~~E3704.4Lighting and general use receptacle load.~~

~~A unit load of not less than 3 volt-amperes shall constitute the minimum lighting and general use receptacle load for each square foot of floor area (33 VA for each square meter of floor area). The floor area for each floor shall be calculated from the outside dimensions of the building. The calculated floor area shall not include open porches, garages, or unused or unfinished spaces not adaptable for future use. [220.12, Table 220.12, and 220.14(J)]~~

~~E3704.5Ampacity and calculated loads.~~

~~The calculated load of a feeder shall be not less than the sum of the loads on the branch circuits supplied, as determined by Section E3704, after any applicable demand factors permitted by Section E3704 have been applied. (220.40)~~

E3704.6Equipment grounding conductor.

Where a feeder supplies branch circuits in which equipment grounding conductors are required, the feeder shall include or provide an equipment grounding conductor that is one or more or a combination of the types specified in Section E3908.8, to which the equipment grounding conductors of the branch circuits shall be connected. Where the feeder supplies a separate building or structure, the requirements of Section E3607.3.1 shall apply. (215.6)

SECTIONE3705
CONDUCTOR SIZING
AND OVERCURRENT PROTECTION

E3705.1General.

Ampacities for conductors shall be determined based in accordance with Table E3705.1 and Sections E3705.2 and E3705.3. [310.15(A)]

TABLE E3705.1

ALLOWABLE AMPACITIES

CONDUCTOR SIZE	CONDUCTOR TEMPERATURE RATING						CONDUCTOR SIZE
	60°C	75°C	90°C	60°C	75°C	90°C	
AWG kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, USE, XHHW	Types RHW-2, THHN, THHW, THW-2, THWN-2, XHHW, XHHW-2, USE-2	Types TW, UF	Types RHW, THHW, THW, THWN, USE, XHHW	Types RHW-2, THHN, THHW, THW-2, THWN-2, XHHW, XHHW-2, USE-2	AWG kcmil
	Copper			Aluminum or copper-clad aluminum			
14a	15	20	25	—	—	—	—
12a	20	25	30	15	20	25	12a
10a	30	35	40	25	30	35	10a
8	40	50	55	35	40	45	8

~~6~~	~~55~~	~~65~~	~~75~~	~~40~~	~~50~~	~~55~~	~~6~~
~~4~~	~~70~~	~~85~~	~~95~~	~~55~~	~~65~~	~~75~~	~~4~~
~~3~~	~~85~~	~~100~~	~~115~~	~~65~~	~~75~~	~~85~~	~~3~~
~~2~~	~~95~~	~~115~~	~~130~~	~~75~~	~~90~~	~~100~~	~~2~~
~~1~~	~~110~~	~~130~~	~~145~~	~~85~~	~~100~~	~~115~~	~~1~~
~~1/0~~	~~125~~	~~150~~	~~170~~	~~100~~	~~120~~	~~135~~	~~1/0~~
~~2/0~~	~~145~~	~~175~~	~~195~~	~~115~~	~~135~~	~~150~~	~~2/0~~
~~3/0~~	~~165~~	~~200~~	~~225~~	~~130~~	~~155~~	~~175~~	~~3/0~~
~~4/0~~	~~195~~	~~230~~	~~260~~	~~150~~	~~180~~	~~205~~	~~4/0~~
~~250~~	~~215~~	~~255~~	~~290~~	~~170~~	~~205~~	~~230~~	~~250~~
~~300~~	~~240~~	~~285~~	~~320~~	~~195~~	~~230~~	~~260~~	~~300~~
~~350~~	~~260~~	~~310~~	~~350~~	~~210~~	~~250~~	~~280~~	~~350~~
~~400~~	~~280~~	~~335~~	~~380~~	~~225~~	~~270~~	~~305~~	~~400~~
~~500~~	~~320~~	~~380~~	~~430~~	~~260~~	~~310~~	~~350~~	~~500~~
~~600~~	~~350~~	~~420~~	~~475~~	~~285~~	~~340~~	~~385~~	~~600~~
~~700~~	~~385~~	~~460~~	~~520~~	~~315~~	~~375~~	~~425~~	~~700~~
~~750~~	~~400~~	~~475~~	~~535~~	~~320~~	~~385~~	~~435~~	~~750~~
~~800~~	~~410~~	~~490~~	~~555~~	~~330~~	~~395~~	~~445~~	~~800~~
~~900~~	~~435~~	~~520~~	~~585~~	~~355~~	~~425~~	~~480~~	~~900~~

~~For SI: °C = [(°F) - 32]/1.8.~~

~~a.See Table E3705.5.3 for conductor overcurrent protection limitations.~~

E3705.2Correction factor for ambient temperatures.

For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities specified in Table E3705.1 by the appropriate correction factor shown in Table E3705.2. [310.15(B)(2)]

TABLE E3705.2 [Table 310.15(B)(2)(a)]

AMBIENT TEMPERATURE CORRECTION FACTORS

For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities specified in the ampacity tables by the appropriate correction factor shown below.

Ambient Temperature (°C)	Temperature Rating of Conductor			Ambient Temperature (°F)
	60°C	75°C	90°C	
10 or less	1.29	1.20	1.15	50 or less
11-15	1.22	1.15	1.12	51-59
16-20	1.15	1.11	1.08	60-68
21-25	1.08	1.05	1.04	69-77
26-30	1.00	1.00	1.00	78-86
31-35	0.91	0.94	0.96	87-95
36-40	0.82	0.88	0.91	96-104
41-45	0.71	0.82	0.87	105-113
46-50	0.58	0.75	0.82	114-122
51-55	0.41	0.67	0.76	123-131
56-60	—	0.58	0.71	132-140
61-65	—	0.47	0.65	141-149

~~66-70~~	—	~~0.33~~	~~0.58~~	~~150-158~~
~~71-75~~	—	—	~~0.50~~	~~159-167~~
~~76-80~~	—	—	~~0.41~~	~~168-176~~
~~81-85~~	—	—	~~0.29~~	~~177-185~~

~~For SI: 1 °C = [(°F) - 32]/1.8.~~

~~E3705.3Adjustment factor for conductor proximity.~~

~~Where the number of current-carrying conductors in a raceway or cable exceeds three, or where single conductors or multiconductor cables are stacked or bundled for distances greater than 24 inches (610 mm) without maintaining spacing and are not installed in raceways, the allowable ampacity of each conductor shall be reduced as shown in Table E3705.3. [310.15(B)(3)]~~

~~Exceptions:~~

~~1.Adjustment factors shall not apply to conductors in nipples having a length not exceeding 24 inches (610 mm). [310.15(B)(3)(2)]~~

~~2.Adjustment factors shall not apply to underground conductors entering or leaving an outdoor trench if those conductors have physical protection in the form of rigid metal conduit, intermediate metal conduit, or rigid nonmetallic conduit having a length not exceeding 10 feet (3048 mm) and the number of conductors does not exceed four. [310.15(B)(3)(3)]~~

~~3.Adjustment factors shall not apply to type AC cable or to type MC cable without an overall outer jacket meeting all of the following conditions:~~

~~3.1.Each cable has not more than three current-carrying conductors.~~

~~3.2.The conductors are 12 AWG copper.~~

~~3.3.Not more than 20 current-carrying conductors are bundled, stacked or supported on bridle rings. [310.15(B)(3)(4)]~~

~~4.An adjustment factor of 60 percent shall be applied to Type AC cable and Type MC cable where all of the following conditions apply:~~

~~4.1.The cables do not have an overall outer jacket.~~

~~4.2.The number of current-carrying conductors exceeds 20.~~

~~4.3.The cables are stacked or bundled longer than 24 inches (607 mm) without spacing being maintained. [310.15(B)(3)(5)]~~

~~TABLE E3705.3 [Table 310.15(B)(3)(a)]~~

~~CONDUCTOR PROXIMITY ADJUSTMENT FACTORS~~

~~NUMBER OF CURRENT-CARRYING CONDUCTORS IN CABLE OR RACEWAY~~	~~PERCENT OF VALUES IN TABLE E3705.1~~
~~4-6~~	~~80~~
~~7-9~~	~~70~~
~~10-20~~	~~50~~
~~21-30~~	~~45~~
~~31-40~~	~~40~~
~~41 and above~~	~~35~~

~~E3705.4Temperature limitations.~~

~~The temperature rating associated with the ampacity of a conductor shall be so selected and coordinated to not exceed the lowest temperature rating of any connected termination, conductor or device. Conductors with temperature ratings higher than specified for terminations shall be permitted to be used for ampacity adjustment, correction, or both. Except where the equipment is marked otherwise, conductor ampacities used in determining equipment termination provisions shall be based on Table E3705.1. [110.14(C)]~~

~~E3705.4.1Conductors rated 60°C.~~

~~Except where the equipment is marked otherwise, termination provisions of equipment for circuits rated 100 amperes or less, or marked for 14 AWG through 1 AWG conductors, shall be used only for one of the following:~~

~~1.Conductors rated 60°C (140°F);~~

~~2.Conductors with higher temperature ratings, provided that the ampacity of such conductors is determined based on the 60°C (140°F) ampacity of the conductor size used;~~

~~3.Conductors with higher temperature ratings where the equipment is listed and identified for use with such conductors; or~~

~~4.For motors marked with design letters B, C, or D conductors having an insulation rating of 75°C (167°F) or higher shall be permitted to be used provided that the ampacity of such conductors does not exceed the 75°C (167°F) ampacity. [110.14(C)(1)(a)]~~

~~E3705.4.2Conductors rated 75°C.~~

~~Termination provisions of equipment for circuits rated over 100 amperes, or marked for conductors larger than 1 AWG, shall be used only for:~~

~~1.Conductors rated 75°C (167°F).~~

~~2.Conductors with higher temperature ratings provided that the ampacity of such conductors does not exceed the 75°C (167°F) ampacity of the conductor size used, or provided that the equipment is listed and identified for use with such conductors. [110.14(C)(1)(b)]~~

~~E3705.4.3Separately installed pressure connectors.~~

~~Separately installed pressure connectors shall be used with conductors at the ampacities not exceeding the ampacity at the listed and identified temperature rating of the connector. [110.14(C)(2)]~~

~~E3705.4.4Conductors of Type NM cable.~~

~~Conductors in NM cable assemblies shall be rated at 90°C (194°F). Types NM, NMC, and NMS cable identified by the markings NM-B, NMC-B, and NMS-B meet this requirement. The allowable ampacity of Types NM, NMC, and NMS cable shall not exceed that of 60°C (140°F) rated conductors and shall comply with Section E3705.1 and Table E3705.5.3. The 90°C (194°F) rating shall be permitted to be used for ampacity adjustment and calculations provided that the final corrected or adjusted ampacity does not exceed that for a 60°C (140°F) rated conductor. Where more than two NM cables containing two or more current-carrying conductors are installed, without maintaining spacing between the cables, through the same opening in wood framing that is to be sealed with thermal insulation, caulk or sealing foam, the allowable ampacity of each conductor shall be adjusted in accordance with Table E3705.3. Where more than two NM cables containing two or more current-carrying conductors are installed in contact with thermal insulation without maintaining spacing between cables, the allowable ampacity of each conductor shall be adjusted in accordance with Table E3705.3. (334.80 and 334.112)~~

~~E3705.4.5Conductors of Type SE cable.~~

~~Where used as a branch circuit or feeder wiring method within the interior of a building and installed in thermal insulation, the ampacity of the conductors in Type SE cable assemblies shall be in accordance with the 60°C (140°F) conductor temperature rating. The maximum conductor temperature rating shall be permitted to be used for ampacity adjustment and correction purposes, provided that the final derated ampacity does not exceed that for a 60°C (140°F) rated conductor. [338.10(B)(4)(a)]~~

~~E3705.5Overcurrent protection required.~~

All ungrounded branch-circuit and feeder conductors shall be protected against overcurrent by an overcurrent device installed at the point where the conductors receive their supply. Overcurrent devices shall not be connected in series with a grounded conductor. Overcurrent protection and allowable loads for branch circuits and for feeders that do not serve as the main power feeder to the dwelling unit load shall be in accordance with this chapter.

Branch-circuit conductors and equipment shall be protected by overcurrent protective devices having a rating or setting not exceeding the allowable ampacity specified in Table E3705.1 and Sections E3705.2, E3705.3 and E3705.4 except where otherwise permitted or required in Sections E3705.5.1 through E3705.5.3. [240.4, 240.21, and 310.15(B)(7)(2)]

E3705.5.1Cords.

Cords shall be protected in accordance with Section E3909.2. [240.5(B)]

E3705.5.2Overcurrent devices of the next higher rating.

The next higher standard overcurrent device rating, above the ampacity of the conductors being protected, shall be permitted to be used, provided that all of the following conditions are met:

1.The conductors being protected are not part of a branch circuit supplying more than one receptacle for cord- and plug-connected portable loads.

2.The ampacity of conductors does not correspond with the standard ampere rating of a fuse or a circuit breaker without overload trip adjustments above its rating (but that shall be permitted to have other trip or rating adjustments).

3.The next higher standard device rating does not exceed 400 amperes. [240.4(B)]

E3705.5.3Small conductors.

Except as specifically permitted by Section E3705.5.4, the rating of overcurrent protection devices shall not exceed the ratings shown in Table E3705.5.3 for the conductors specified therein. [240.4(D)]

TABLE E3705.5.3 [240.4(D)]

OVERCURRENT PROTECTION RATING

COPPER		ALUMINUM OR COPPER-CLAD ALUMINUM	
Size (AWG)	Maximum overcurrent-protection-device ratinga(amps)	Size (AWG)	Maximum overcurrent-protection-device ratinga(amps)
14	15	12	15

12	20	10	25
10	30	8	30

a.The maximum overcurrent-protection-device rating shall not exceed the conductor allowable ampacity determined by the application of the correction and adjustment factors in accordance with Sections E3705.2 and E3705.3.

E3705.5.4Air-conditioning and heat pump equipment.

Air-conditioning and heat pump equipment circuit conductors shall be permitted to be protected against overcurrent in accordance with Section E3702.11. [240.4(G)]

E3705.6Fuses and fixed trip circuit breakers.

The standard ampere ratings for fuses and inverse time circuit breakers shall be considered 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350 and 400 amperes. (240.6)

E3705.7Location of overcurrent devices in or on premises.

Overcurrent devices shall:

1.Be readily accessible. [240.24(A)]

2.Not be located where they will be exposed to physical damage. [240.24(C)]

3.Not be located where they will be in the vicinity of easily ignitible material such as in clothes closets. [240.24(D)]

4.Not be located in bathrooms. [240.24(E)]

5.Not be located over steps of a stairway.

6.Be installed so that the center of the grip of the operating handle of the switch or circuit breaker, when in its highest position, is not more than 6 feet 7 inches (2007 mm) above the floor or working platform. [240.24(A)]

Exceptions:

1.This section shall not apply to supplementary overcurrent protection that is integral to utilization equipment. [240.24(A)(2)]

2.Overcurrent devices installed adjacent to the utilization equipment that they supply shall be permitted to be accessible by portable means. [240.24(A)(4)]

E3705.8Ready access for occupants.

Each occupant shall have ready access to all overcurrent devices protecting the conductors supplying that occupancy. [240.24(B)]

E3705.9Enclosures for overcurrent devices.

Overcurrent devices shall be enclosed in cabinets, cutout boxes, or equipment assemblies. The operating handle of a circuit breaker shall be permitted to be accessible without opening a door or cover. [240.30(A) and (B)]

SECTIONE3706
PANELBOARDS

E3706.1Panelboard rating.

All panelboards shall have a rating not less than that of the minimum service or feeder capacity required for the calculated load. (408.30)

E3706.2Panelboard circuit identification.

All circuits and circuit modifications shall be legibly identified as to their clear, evident, and specific purpose or use. The identification shall include an approved degree of detail that allows each circuit to be distinguished from all others. Spare positions that contain unused overcurrent devices or switches shall be described accordingly. The identification shall be included in a circuit directory located on the face of the panelboard enclosure or inside the panel door. Circuits shall not be described in a manner that depends on transient conditions of occupancy. [408.4(A)]

E3706.3Panelboard overcurrent protection.

In addition to the requirement of Section E3706.1, a panelboard shall be protected by an overcurrent protective device having a rating not greater than that of the panelboard. Such overcurrent protective device shall be located within or at any point on the supply side of the panelboard. (408.36)

E3706.4Grounded conductor terminations.

Each grounded conductor shall terminate within the panelboard on an individual terminal that is not also used for another conductor, except that grounded conductors of circuits with parallel conductors shall be permitted to terminate on a single terminal where the terminal is identified for connection of more than one conductor. (408.41 and 408.41 Exception)

E3706.5Back-fed devices.

Plug-in-type overcurrent protection devices or plug-in-type main lug assemblies that are back-fed and used to terminate field-installed ungrounded supply conductors shall be secured in place by an additional fastener that requires other than a pull to release the device from the mounting means on the panel. [408.36(D)].

CHAPTER 38
WIRING METHODS

RESERVED

~~SECTIONE3801~~
~~GENERAL REQUIREMENTS~~

~~E3801.1Scope.~~

~~This chapter covers the wiring methods for services, feeders and branch circuits for electrical power and distribution. (300.1)~~

~~E3801.2Allowable wiring methods.~~

~~The allowable wiring methods for electrical installations shall be those listed in Table E3801.2. Single conductors shall be used only where part of one of the recognized wiring methods listed in Table E3801.2. As used in this code, abbreviations of the wiring-method types shall be as indicated in Table E3801.2. [110.8, 300.3(A)]~~

~~TABLE E3801.2~~

~~ALLOWABLE WIRING METHODS~~

~~ALLOWABLE WIRING METHOD~~	~~DESIGNATED ABBREVIATION~~
~~Armored cable~~	~~AC~~
~~Electrical metallic tubing~~	~~EMT~~
~~Electrical nonmetallic tubing~~	~~ENT~~
~~Flexible metal conduit~~	~~FMC~~
~~Intermediate metal conduit~~	~~IMC~~
~~Liquidtight flexible conduit~~	~~LFC~~
~~Metal-clad cable~~	~~MC~~
~~Nonmetallic sheathed cable~~	~~NM~~
~~Rigid polyvinyl chloride conduit (Type PVC)~~	~~RNC~~

~~Rigid metallic conduit~~	~~RMC~~
~~Service entrance cable~~	~~SE~~
~~Surface raceways~~	~~SR~~
~~Underground feeder cable~~	~~UF~~
~~Underground service cable~~	~~USE~~

~~E3801.3Circuit conductors.~~

~~All conductors of a circuit, including equipment grounding conductors and bonding conductors, shall be contained in the same raceway, trench, cable or cord. [300.3(B)]~~

~~E3801.4Wiring method applications.~~

~~Wiring methods shall be applied in accordance with Table E3801.4. (Chapter 3 and 300.2)~~

~~TABLE E3801.4 (Chapter 3 and 300.2)~~

~~ALLOWABLE APPLICATIONS FOR WIRING METHODSa, b, c, d, e, f, g, h, i, j, k~~

~~ALLOWABLE APPLICATIONS (application allowed where marked with an "A")~~	~~AC~~	~~EMT~~	~~ENT~~	~~FMC~~	~~IMC RMC RNC~~	~~LFCa, g~~	~~MC~~	~~NM~~	~~SR~~	~~SE~~	~~UF~~	~~USE~~
~~Services~~	—	~~A~~	~~Ah~~	~~Ai~~	~~A~~	~~Ai~~	~~A~~	—	—	~~A~~	—	~~A~~
~~Feeders~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	—	~~Ab~~	~~A~~	~~Ab~~
~~Branch circuits~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~Ac~~	~~A~~	—
~~Inside a building~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	—
~~Wet locations exposed to sunlight~~	—	~~A~~	~~Ah~~	—	~~A~~	~~A~~	~~A~~	—	—	~~A~~	~~Ae~~	~~Ae~~
~~Damp locations~~	—	~~A~~	~~A~~	~~Ad~~	~~A~~	~~A~~	~~A~~	—	—	~~A~~	~~A~~	~~A~~
~~Embedded in noncinder concrete in dry location~~	—	~~A~~	~~A~~	—	~~A~~	~~Aj~~	—	—	—	—	—	—

~~In noncinder concrete in contact with grade~~	—	~~Af~~	~~A~~	—	~~Af~~	~~Aj~~	—	—	—	—	—	—
~~Embedded in plaster not exposed to dampness~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	—	—	~~A~~	~~A~~	—
~~Embedded in masonry~~	—	~~A~~	~~A~~	—	~~Af~~	~~A~~	~~A~~	—	—	—	—	—
~~In masonry voids and cells exposed to dampness or below grade line~~	—	~~Af~~	~~A~~	~~Ad~~	~~Af~~	~~A~~	~~A~~	—	—	~~A~~	~~A~~	—
~~Fished in masonry voids~~	~~A~~	—	—	~~A~~	—	~~A~~	~~A~~	~~A~~	—	~~A~~	~~A~~	—
~~In masonry voids and cells not exposed to dampness~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	—	~~A~~	~~A~~	—
~~Run exposed~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	—
~~Run exposed and subject to physical damage~~	—	—	—	—	~~Ag~~	—	—	—	—	—	—	—
~~For direct burial~~	—	~~Af~~	—	—	~~Af~~	~~A~~	~~Af~~	—	—	—	~~A~~	~~A~~

~~For SI: 1 foot = 304.8 mm.~~

~~a.Liquid-tight flexible nonmetallic conduit without integral reinforcement within the conduit wall shall not exceed 6 feet in length.~~

~~b.Type USE cable shall not be used inside buildings.~~

~~c.The grounded conductor shall be insulated.~~

~~d.Conductors shall be a type approved for wet locations and the installation shall prevent water from entering other raceways.~~

~~e.Shall be listed as “Sunlight Resistant.”~~

~~f.Metal raceways shall be protected from corrosion and approved for the application. Aluminum RMC requires approved supplementary corrosion protection.~~

~~g.RNC shall be Schedule 80.~~

~~h.Shall be listed as “Sunlight Resistant” where exposed to the direct rays of the sun.~~

i.Conduit shall not exceed 6 feet in length.

j.Liquid-tight flexible nonmetallic conduit is permitted to be encased in concrete where listed for direct burial and only straight connectors listed for use with LFNC are used.

k.In wet locations under any of the following conditions:

1.The metallic covering is impervious to moisture.

2.A lead sheath or moisture-impervious jacket is provided under the metal covering.

3.The insulated conductors under the metallic covering are listed for use in wet locations and a corrosion-resistant jacket is provided over the metallic sheath.

SECTIONE3802
ABOVE-GROUND INSTALLATION REQUIREMENTS

E3802.1Installation and support requirements.

Wiring methods shall be installed and supported in accordance with Table E3802.1. (Chapter 3 and 300.11)

TABLE E3802.1 (Chapter 3)

GENERAL INSTALLATION AND SUPPORT REQUIREMENTS FOR WIRING METHODSa, b, c, d, e, f, g, h, i, j, k

INSTALLATION REQUIREMENTS (Requirement applicable only to wiring methods marked "A")	AC MC	EMT IMC RMC	ENT	FMC LFC	NM UF	RNC	SE	SRa	USE
Where run parallel with the framing member or furring strip, the wiring shall be not less than 11/4 inches from the edge of a furring strip or a framing member such as a joist, rafter or stud or shall be physically protected.	A	—	A	A	A	—	A	—	—
Bored holes in framing members for wiring shall be located not less than 11/4 inches from the edge of the framing member or shall be protected with a minimum 0.0625-inch steel plate or sleeve, a listed steel plate or other physical protection.	Ak	—	Ak	Ak	Ak	—	Ak	—	—
Where installed in grooves, to be covered by wallboard, siding, paneling, carpeting, or similar finish, wiring methods shall be protected by	A	—	A	A	A	—	A	A	A

~~0.0625-inchthick steel plate, sleeve, or equivalent, a listed steel plate or by not less than 11/4-inch free space for the full length of the groove in which the cable or raceway is installed.~~									
~~Securely fastened bushings or grommets shall be provided to protect wiring run through openings in metal framing members.~~	~~—~~	~~—~~	~~Aj~~	~~—~~	~~Aj~~	~~—~~	~~Aj~~	~~—~~	~~—~~
~~The maximum number of 90-degree bends shall not exceed four between junction boxes.~~	~~—~~	~~A~~	~~A~~	~~A~~	~~—~~	~~A~~	~~—~~	~~—~~	~~—~~
~~Bushings shall be provided where entering a box, fitting or enclosure unless the box or fitting is designed to afford equivalent protection.~~	~~A~~	~~A~~	~~A~~	~~A~~	~~—~~	~~A~~	~~—~~	~~A~~	~~—~~
~~Ends of raceways shall be reamed to remove rough edges.~~	~~—~~	~~A~~	~~A~~	~~A~~	~~—~~	~~A~~	~~—~~	~~A~~	~~—~~
~~Maximum allowable on center support spacing for the wiring method in feet.~~	~~4.5b, c~~	~~10l~~	~~3b~~	~~4.5b~~	~~4.5i~~	~~3d, l~~	~~2.5e~~	~~—~~	~~2.5~~
~~Maximum support distance in inches from box or other terminations.~~	~~12b, f~~	~~36~~	~~36~~	~~12b, g~~	~~12h, i~~	~~36~~	~~12~~	~~—~~	~~—~~

~~For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 degree = 0.0175 rad.~~

~~a.Installed in accordance with listing requirements.~~

~~b.Supports not required in accessible ceiling spaces between light fixtures where lengths do not exceed 6 feet.~~

~~c.Six feet for MC cable.~~

~~d.Five feet for trade sizes greater than 1 inch.~~

~~e.Two and one-half feet where used for service or outdoor feeder and 4.5 feet where used for branch circuit or indoor feeder.~~

~~f.Twenty-four inches for Type AC cable and thirty-six inches for interlocking Type MC cable where flexibility is necessary.~~

~~g.Where flexibility after installation is necessary, lengths of flexible metal conduit and liquidtight flexible metal conduit measured from the last point where the raceway is securely fastened shall not exceed: 36~~

~~inches for trade sizes 1/2 through 11/4, 48 inches for trade sizes 11/2 through 2 and 5 feet for trade sizes 21/2 and larger.~~

~~h.Within 8 inches of boxes without cable clamps.~~

~~i.Flat cables shall not be stapled on edge.~~

~~j.Bushings and grommets shall remain in place and shall be listed for the purpose of cable protection.~~

~~k.See Sections R502.8 and R802.7 for additional limitations on the location of bored holes in horizontal framing members.~~

~~E3802.2Cables in accessible attics.~~

~~Cables in attics or roof spaces provided with access shall be installed as specified in Sections E3802.2.1 and E3802.2.2. (320.3 and 334.23)~~

~~E3802.2.1Across structural members.~~

~~Where run across the top of floor joists, or run within 7 feet (2134 mm) of floor or floor joists across the face of rafters or studding, in attics and roof spaces that are provided with access, the cable shall be protected by substantial guard strips that are at least as high as the cable. Where such spaces are not provided with access by permanent stairs or ladders, protection shall only be required within 6 feet (1829 mm) of the nearest edge of the attic entrance. [330.23(A) and 334.23]~~

~~E3802.2.2Cable installed through or parallel to framing members.~~

~~Where cables are installed through or parallel to the sides of rafters, studs or floor joists, guard strips and running boards shall not be required, and the installation shall comply with Table E3802.1. [330.23(B) and 334.23]~~

~~E3802.3Exposed cable.~~

~~In exposed work, except as provided for in Sections E3802.2 and E3802.4, cable assemblies shall be installed as specified in Sections E3802.3.1 and E3802.3.2. (330.15 and 334.15)~~

~~E3802.3.1 Surface installation.~~

~~Cables shall closely follow the surface of the building finish or running boards. [334.15(A)]~~

~~E3802.3.2Protection from physical damage.~~

~~Where subject to physical damage, cables shall be protected by rigid metal conduit, intermediate metal conduit, electrical metallic tubing, Schedule 80 PVC rigid nonmetallic conduit, or other approved means. Where passing through a floor, the cable shall be enclosed in rigid metal conduit, intermediate metal conduit, electrical metallic tubing, Schedule 80 PVC rigid nonmetallic conduit or other approved means extending not less than 6 inches (152 mm) above the floor. [334.15(B)]~~

E3802.3.3Locations exposed to direct sunlight.

Insulated conductors and cables used where exposed to direct rays of the sun shall be listed or listed and marked, as being “sunlight resistant,” or shall be covered with insulating material, such as tape or sleeving, that is listed or listed and marked as being “sunlight resistant.” [310.10(D)]

E3802.4In unfinished basements and crawl spaces.

Where type NM or SE cable is run at angles with joists in unfinished basements and crawl spaces, cable assemblies containing two or more conductors of sizes 6 AWG and larger and assemblies containing three or more conductors of sizes 8 AWG and larger shall not require additional protection where attached directly to the bottom of the joists. Smaller cables shall be run either through bored holes in joists or on running boards. Type NM or SE cable installed on the wall of an unfinished basement shall be permitted to be installed in a listed conduit or tubing or shall be protected in accordance with Table E3802.1. Conduit or tubing shall be provided with a suitable insulating bushing or adapter at the point where the cable enters the raceway. The sheath of the Type NM or SE cable shall extend through the conduit or tubing and into the outlet or device box not less than 1/4 inch (6.4 mm). The cable shall be secured within 12 inches (305 mm) of the point where the cable enters the conduit or tubing. Metal conduit, tubing, and metal outlet boxes shall be connected to an equipment grounding conductor complying with Section E3908.13. [334.15(C)]

E3802.5Bends.

Bends shall be made so as not to damage the wiring method or reduce the internal diameter of raceways.

For types NM and SE cable, bends shall be so made, and other handling shall be such that the cable will not be damaged and the radius of the curve of the inner edge of any bend shall be not less than five times the diameter of the cable. (334.24 and 338.24)

E3802.6Raceways exposed to different temperatures.

Where portions of a raceway or sleeve are known to be subjected to different temperatures and where condensation is known to be a problem, as in cold storage areas of buildings or where passing from the interior to the exterior of a building, the raceway or sleeve shall be filled with an approved material to prevent the circulation of warm air to a colder section of the raceway or sleeve. [300.7(A)]

E3802.7Raceways in wet locations above grade.

Where raceways are installed in wet locations above grade, the interior of such raceways shall be considered to be a wet location. Insulated conductors and cables installed in raceways in wet locations above grade shall be listed for use in wet locations. (300.9)

SECTIONE3803
UNDERGROUND INSTALLATION REQUIREMENTS

~~E3803.1Minimum cover requirements.~~

~~Direct buried cable or raceways shall be installed in accordance with the minimum cover requirements of Table E3803.1. [300.5(A)]~~

~~TABLE E3803.1 (Table 300.5)~~

~~MINIMUM COVER REQUIREMENTS, BURIAL IN INCHESa, b, c, d, e~~

	~~TYPE OF WIRING METHOD OR CIRCUIT~~				
~~LOCATION OF WIRING METHOD OR CIRCUIT~~	~~1 Direct burial cables or conductors~~	~~2 Rigid metal conduit or intermediate metal conduit~~	~~3 Nonmetallic raceways listed for direct burial without concrete encasement or other approved raceways~~	~~4 Residential branch circuits rated 120 volts or less with GFCI protection and maximum overcurrent protection of 20 amperes~~	~~5 Circuits for control of irrigation and landscape lighting limited to not more than 30 volts and installed with type UF or in other identified cable or raceway~~
~~All locations not specified below~~	~~24~~	~~6~~	~~18~~	~~12~~	~~6~~
~~In trench below 2-inch-thick concrete or equivalent~~	~~18~~	~~6~~	~~12~~	~~6~~	~~6~~
~~Under a building~~	~~0 (In raceway only or Type MC identified for direct burial)~~	~~0~~	~~0~~	~~0 (In raceway only or Type MC identified for direct burial)~~	~~0 (In raceway only or Type MC identified for direct burial)~~
~~Under minimum of 4-inch-thick concrete exterior slab with no vehicular traffic~~	~~18~~	~~4~~	~~4~~	~~6 (Direct burial) 4 (In raceway)~~	~~6 (Direct burial) 4 (In raceway)~~

~~and the slab extending not less than 6 inches beyond the underground installation~~					
~~Under streets, highways, roads, alleys, driveways and parking lots~~	~~24~~	~~24~~	~~24~~	~~24~~	~~24~~
~~One- and two-family dwelling driveways and outdoor parking areas, and used only for dwelling-related purposes~~	~~18~~	~~18~~	~~18~~	~~12~~	~~18~~
~~In solid rock where covered by minimum of 2 inches concrete extending down to rock~~	~~2 (In raceway only)~~	~~2~~	~~2~~	~~2 (In raceway only)~~	~~2 (In raceway only)~~

~~For SI: 1 inch = 25.4 mm.~~

~~a.Raceways approved for burial only where encased concrete shall require concrete envelope not less than 2 inches thick.~~

~~b.Lesser depths shall be permitted where cables and conductors rise for terminations or splices or where access is otherwise required.~~

~~c.Where one of the wiring method types listed in columns 1 to 3 is combined with one of the circuit types in columns 4 and 5, the shallower depth of burial shall be permitted.~~

~~d.Where solid rock prevents compliance with the cover depths specified in this table, the wiring shall be installed in metal or nonmetallic raceway permitted for direct burial. The raceways shall be covered by a minimum of 2 inches of concrete extending down to the rock.~~

~~e.Cover is defined as the shortest distance in inches (millimeters) measured between a point on the top surface of any direct-buried conductor, cable, conduit or other raceway and the top surface of finished grade, concrete, or similar cover.~~

~~E3803.2Warning ribbon.~~

~~Underground service conductors that are not encased in concrete and that are buried 18 inches (457 mm) or more below grade shall have their location identified by a warning ribbon that is placed in the trench not less than 12 inches (305 mm) above the underground installation. [300.5(D)(3)]~~

~~E3803.3Protection from damage.~~

~~Direct buried conductors and cables emerging from the ground shall be protected by enclosures or raceways extending from the minimum cover distance below grade required by Section E3803.1 to a point at least 8 feet (2438 mm) above finished grade. In no case shall the protection be required to exceed 18 inches (457 mm) below finished grade. Conductors entering a building shall be protected to the point of entrance. Where the enclosure or raceway is subject to physical damage, the conductors shall be installed in rigid metal conduit, intermediate metal conduit, Schedule 80 rigid nonmetallic conduit or the equivalent. [300.5(D)(1)]~~

~~E3803.4Splices and taps.~~

~~Direct buried conductors or cables shall be permitted to be spliced or tapped without the use of splice boxes. The splices or taps shall be made by approved methods with materials listed for the application. [300.5(E)]~~

~~E3803.5Backfill.~~

~~Backfill containing large rock, paving materials, cinders, large or sharply angular substances, or corrosive material shall not be placed in an excavation where such materials cause damage to raceways, cables or other substructures or prevent adequate compaction of fill or contribute to corrosion of raceways, cables or other substructures. Where necessary to prevent physical damage to the raceway or cable, protection shall be provided in the form of granular or selected material, suitable boards, suitable sleeves or other approved means. [300.5(F)]~~

~~E3803.6Raceway seals.~~

~~Conduits or raceways shall be sealed or plugged at either or both ends where moisture will enter and contact live parts. [300.5(G)]~~

~~E3803.7Bushing.~~

~~A bushing, or terminal fitting, with an integral bushed opening shall be installed on the end of a conduit or other raceway that terminates underground where the conductors or cables emerge as a direct burial wiring method. A seal incorporating the physical protection characteristics of a bushing shall be considered equivalent to a bushing. [300.5(H)]~~

~~E3803.8Single conductors.~~

~~All conductors of the same circuit and, where present, the grounded conductor and all equipment grounding conductors shall be installed in the same raceway or shall be installed in close proximity in the same trench. [300.5(I)]~~

~~Exception: Conductors shall be permitted to be installed in parallel in raceways, multiconductor cables, and direct-buried single conductor cables. Each raceway or multiconductor cable shall contain all conductors of the same circuit, including equipment grounding conductors. Each direct-buried single conductor cable shall be located in close proximity in the trench to the other single conductor cables in the same parallel set of conductors in the circuit, including equipment grounding conductors. [300.5(I) Exception No.1]~~

~~E3803.9 Earth movement.~~

~~Where direct buried conductors, raceways or cables are subject to movement by settlement or frost, direct buried conductors, raceways or cables shall be arranged to prevent damage to the enclosed conductors or to equipment connected to the raceways. [300.5(J)]~~

~~E3803.10Wet locations.~~

~~The interior of enclosures or raceways installed underground shall be considered to be a wet location. Insulated conductors and cables installed in such enclosures or raceways in underground installations shall be listed for use in wet locations. Connections or splices in an underground installation shall be approved for wet locations. [300.5(B)]~~

~~E3803.11Under buildings.~~

~~Underground cable and conductors installed under a building shall be in a raceway. [300.5(C)]~~

~~Exception: Type MC Cable shall be permitted under a building without installation in a raceway where the cable is listed and identified for direct burial or concrete encasement and one or more of the following applies:~~

~~1.The metallic covering is impervious to moisture.~~

~~2.A moisture-impervious jacket is provided under the metal covering.~~

~~3.The insulated conductors under the metallic covering are listed for use in wet locations, and a corrosion-resistant jacket is provided over the metallic sheath. [300.5(C) Exception No.2]~~

CHAPTER 39
POWER AND LIGHTING DISTRIBUTION

RESERVED

SECTIONE3901
RECEPTACLE OUTLETS

E3901.1 General.

Outlets for receptacles rated at 125 volts, 15- and 20-amperes shall be provided in accordance with Sections E3901.2 through E3901.11. Receptacle outlets required by this section shall be in addition to any receptacle that is:

1.Part of a luminaire or appliance;

2.Located within cabinets or cupboards;

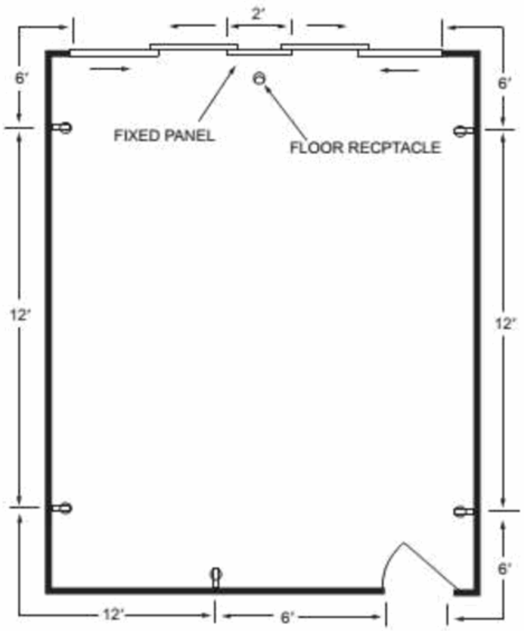
3.Controlled by a wall switch in accordance with Section E3903.2, Exception 1; or

4.Located over 5.5 feet (1676 mm) above the floor.

Permanently installed electric baseboard heaters equipped with factory-installed receptacle outlets, or outlets provided as a separate assembly by the baseboard manufacturer shall be permitted as the required outlet or outlets for the wall space utilized by such permanently installed heaters. Such receptacle outlets shall not be connected to the heater circuits. (210.52)

E3901.2 General purpose receptacle distribution.

In every kitchen, family room, dining room, living room, parlor, library, den, sun room, bedroom, recreation room, or similar room or area of dwelling units, receptacle outlets shall be installed in accordance with the general provisions specified in Sections E3901.2.1 through E3901.2.3 (see Figure E3901.2).



~~For SI: 1 foot = 304.8 mm.~~

~~FIGURE E3901.2~~

~~GENERAL USE RECEPTACLE DISTRIBUTION~~

~~E3901.2.1 Spacing.~~

~~Receptacles shall be installed so that no point measured horizontally along the floor line of any wall space is more than 6 feet (1829 mm), from a receptacle outlet. [210.52(A)(1)]~~

~~E3901.2.2 Wall space.~~

~~As used in this section, a wall space shall include the following: [210.52(A)(2)]~~

~~1.Any space that is 2 feet (610 mm) or more in width, including space measured around corners, and that is unbroken along the floor line by doorways and similar openings, fireplaces, and fixed cabinets.~~

~~2.The space occupied by fixed panels in exterior walls, excluding sliding panels.~~

~~3.The space created by fixed room dividers such as railings and freestanding bar-type counters.~~

~~E3901.2.3 Floor receptacles.~~

~~Receptacle outlets in floors shall not be counted as part of the required number of receptacle outlets except where located within 18 inches (457 mm) of the wall. [210.52(A)(3)]~~

~~E3901.2.4 Countertop receptacles.~~

~~Receptacles installed for countertop surfaces as specified in Section E3901.4 shall not be considered as the receptacles required by Section E3901.2. [210.52(A)(4)]~~

~~E3901.3 Small appliance receptacles.~~

~~In the kitchen, pantry, breakfast room, dining room, or similar area of a dwelling unit, the two or more 20-ampere small-appliance branch circuits required by Section E3703.2, shall serve all wall and floor receptacle outlets covered by Sections E3901.2 and E3901.4 and those receptacle outlets provided for refrigeration appliances. [210.52(B)(1)]~~

~~Exceptions:~~

~~1.In addition to the required receptacles specified by Sections E3901.1 and E3901.2, switched receptacles supplied from a general-purpose branch circuit as defined in Section E3903.2, Exception 1 shall be permitted. [210.52(B)(1) Exception No. 1]~~

~~2.The receptacle outlet for refrigeration appliances shall be permitted to be supplied from an individual branch circuit rated at 15 amperes or greater. [210.52(B)(1) Exception No. 2]~~

~~E3901.3.1 Other outlets prohibited.~~

~~The two or more small-appliance branch circuits specified in Section E3901.3 shall serve no other outlets. [210.52(B)(2)]~~

~~Exceptions:~~

~~1.A receptacle installed solely for the electrical supply to and support of an electric clock in any of the rooms specified in Section E3901.3. [210.52(B)(2) Exception No.1]~~

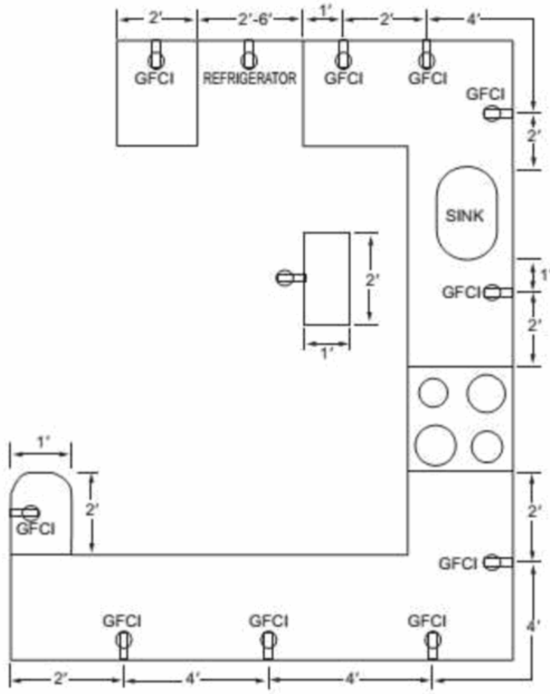
~~2.Receptacles installed to provide power for supplemental equipment and lighting on gas-fired ranges, ovens, and counter-mounted cooking units. [210.52(B)(2) Exception No.2]~~

~~E3901.3.2 Limitations.~~

~~Receptacles installed in a kitchen to serve countertop surfaces shall be supplied by not less than two small-appliance branch circuits, either or both of which shall also be permitted to supply receptacle outlets in the same kitchen and in other rooms specified in Section E3901.3. Additional small-appliance branch circuits shall be permitted to supply receptacle outlets in the kitchen and other rooms specified in Section E3901.3. A small-appliance branch circuit shall not serve more than one kitchen. [210.52(B)(3)]~~

~~E3901.4 Countertop receptacles.~~

~~In kitchens pantries, breakfast rooms, dining rooms and similar areas of dwelling units, receptacle outlets for countertop spaces shall be installed in accordance with Sections E3901.4.1 through E3901.4.5 (see Figure E3901.4). [210.52(C)]~~



~~For SI: 1 foot = 304.8 mm.~~

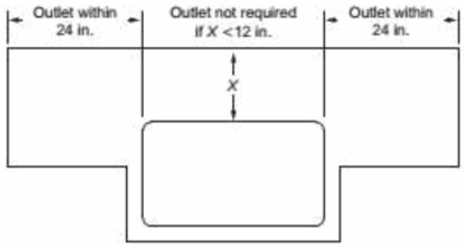
~~FIGURE E3901.4~~

~~COUNTERTOP RECEPTACLES~~

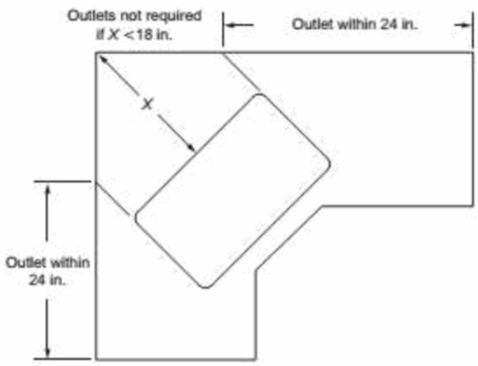
~~E3901.4.1 Wall countertop space.~~

~~A receptacle outlet shall be installed at each wall countertop space 12 inches (305 mm) or wider. Receptacle outlets shall be installed so that no point along the wall line is more than 24 inches (610 mm), measured horizontally from a receptacle outlet in that space. [210.52(C)(1)]~~

~~Exception: Receptacle outlets shall not be required on a wall directly behind a range, counter-mounted cooking unit or sink in the installation described in Figure E3901.4.1. [210.52(C)(1) Exception]~~



Sink, range or counter-mounted cooking unit extending from face of counter



Sink, range or counter-mounted cooking unit mounted in corner

~~For SI: 1 inch = 25.4 mm.~~

~~FIGURE E3901.4.1~~

~~DETERMINATION OF AREA BEHIND SINK OR RANGE~~

~~E3901.4.2 Island countertop spaces.~~

~~At least one receptacle outlet shall be installed at each island countertop space with a long dimension of 24 inches (610 mm) or greater and a short dimension of 12 inches (305 mm) or greater. [210.52(C)(2)]~~

~~E3901.4.3 Peninsular countertop space.~~

~~At least one receptacle outlet shall be installed at each peninsular countertop space with a long dimension of 24 inches (610 mm) or greater and a short dimension of 12 inches (305 mm) or greater. A peninsular countertop is measured from the connecting edge. [210.52(C)(3)]~~

~~E3901.4.4 Separate spaces.~~

~~Countertop spaces separated by range tops, refrigerators, or sinks shall be considered as separate countertop spaces in applying the requirements of Sections E3901.4.1, E3901.4.2 and E3901.4.3. Where a range, counter-mounted cooking unit, or sink is installed in an island or peninsular countertop and the depth of the countertop behind the range, counter-mounted cooking unit, or sink is less than 12 inches (305 mm), the range, counter-mounted cooking unit, or sink has divided the countertop space into two~~

~~separate countertop spaces as defined in Section E3901.4.4. Each separate countertop space shall comply with the applicable requirements of this section. [210.52(C)(4)]~~

~~E3901.4.5 Receptacle outlet location.~~

~~Receptacle outlets shall be located not more than 20 inches (508 mm) above the countertop. Receptacle outlet assemblies installed in countertops shall be listed for the application. Receptacle outlets shall not be installed in a face-up position in the work surfaces or countertops. Receptacle outlets rendered not readily accessible by appliances fastened in place, appliance garages, sinks or rangetops as addressed in the exception to Section E3901.4.1, or appliances occupying dedicated space shall not be considered as these required outlets. [210.52(C)(5)]~~

~~Exception: Receptacle outlets shall be permitted to be mounted not more than 12 inches (305 mm) below the countertop in construction designed for the physically impaired and for island and peninsular countertops where the countertop is flat across its entire surface and there are no means to mount a receptacle within 20 inches (508 mm) above the countertop, such as in an overhead cabinet. Receptacles mounted below the countertop in accordance with this exception shall not be located where the countertop extends more than 6 inches (152 mm) beyond its support base. [210.52(C)(5) Exception]~~

~~E3901.5 Appliance receptacle outlets.~~

~~Appliance receptacle outlets installed for specific appliances, such as laundry equipment, shall be installed within 6 feet (1829 mm) of the intended location of the appliance. (210.50(C)]~~

~~E3901.6 Bathroom.~~

~~At least one wall receptacle outlet shall be installed in bathrooms and such outlet shall be located within 36 inches (914 mm) of the outside edge of each lavatory basin. The receptacle outlet shall be located on a wall or partition that is adjacent to the lavatory basin location, located on the countertop, or installed on the side or face of the basin cabinet. The receptacle shall be located not more than 12 inches (305 mm) below the top of the basin.~~

~~Receptacle outlets shall not be installed in a face-up position in the work surfaces or countertops in a bathroom basin location. Receptacle outlet assemblies installed in countertops shall be listed for the application. [210.52(D)]~~

~~E3901.7 Outdoor outlets.~~

~~Not less than one receptacle outlet that is readily accessible from grade level and located not more than 6 feet, 6 inches (1981 mm) above grade, shall be installed outdoors at the front and back of each dwelling unit having direct access to grade level. Balconies, decks, and porches that are accessible from inside of the dwelling unit shall have at least one receptacle outlet installed within the perimeter of the balcony, deck, or porch. The receptacle shall be located not more than 6 feet, 6 inches (1981 mm) above the balcony, deck, or porch surface. [210.52(E)]~~

~~E3901.8 Laundry areas.~~

~~Not less than one receptacle outlet shall be installed in areas designated for the installation of laundry equipment.~~

~~E3901.9 Basements, garages and accessory buildings.~~

~~Not less than one receptacle outlet, in addition to any provided for specific equipment, shall be installed in each separate unfinished portion of a basement, in each attached garage, and in each detached garage or accessory building that is provided with electrical power. The branch circuit supplying the receptacle(s) in a garage shall not supply outlets outside of the garage and not less than one receptacle outlet shall be installed for each motor vehicle space. [210.52(G)(1), (2), and (3)]~~

~~E3901.10 Hallways.~~

~~Hallways of 10 feet (3048 mm) or more in length shall have at least one receptacle outlet. The hall length shall be considered the length measured along the centerline of the hall without passing through a doorway. [210.52(H)]~~

~~E3901.11 Foyers.~~

~~Foyers that are not part of a hallway in accordance with Section E3901.10 and that have an area that is greater than 60 ft2 (5.57 m2) shall have a receptacle(s) located in each wall space that is 3 feet (914 mm) or more in width. Doorways, door-side windows that extend to the floor, and similar openings shall not be considered as wall space. [210.52(H)]~~

~~E3901.12 HVAC outlet.~~

~~A 125-volt, single-phase, 15- or 20-ampere-rated receptacle outlet shall be installed at an accessible location for the servicing of heating, air-conditioning and refrigeration equipment. The receptacle shall be located on the same level and within 25 feet (7620 mm) of the heating, air-conditioning and refrigeration equipment. The receptacle outlet shall not be connected to the load side of the HVAC equipment disconnecting means. (210.63)~~

~~Exception: A receptacle outlet shall not be required for the servicing of evaporative coolers. (210.63 Exception)~~

~~SECTIONE3902~~
~~GROUND-FAULT AND ARC-FAULT~~
~~CIRCUIT-INTERRUPTER PROTECTION~~

~~E3902.1 Bathroom receptacles.~~

~~125-volt, single-phase, 15- and 20-ampere receptacles installed in bathrooms shall have ground-fault circuit-interrupter protection for personnel. [210.8(A)(1)]~~

~~E3902.2 Garage and accessory building receptacles.~~

~~125-volt, single-phase, 15- or 20-ampere receptacles installed in garages and grade-level portions of unfinished accessory buildings used for storage or work areas shall have ground-fault circuit-interrupter protection for personnel. [210.8(A)(2)]~~

~~E3902.3 Outdoor receptacles.~~

~~125-volt, single-phase, 15- and 20-ampere receptacles installed outdoors shall have ground-fault circuit-interrupter protection for personnel. [210.8(A)(3)]~~

~~Exception: Receptacles as covered in Section E4101.7. [210.8(A)(3) Exception]~~

~~E3902.4 Crawl space receptacles.~~

~~Where a crawl space is at or below grade level, 125-volt, single-phase, 15- and 20-ampere receptacles installed in such spaces shall have ground-fault circuit-interrupter protection for personnel. [210.8(A)(4)]~~

~~E3902.5 Unfinished basement receptacles.~~

~~125-volt, single-phase, 15- and 20-ampere receptacles installed in unfinished basements shall have ground-fault circuit-interrupter protection for personnel. For purposes of this section, unfinished basements are defined as portions or areas of the basement not intended as habitable rooms and limited to storage areas, work areas, and similar areas. [210.8(A)(5)]~~

~~Exception: A receptacle supplying only a permanently installed fire alarm or burglar alarm system. Receptacles installed in accordance with this exception shall not be considered as meeting the requirement of Section E3901.9. [210.8(A)(5) Exception]~~

~~E3902.6 Kitchen receptacles.~~

~~125-volt, single-phase, 15- and 20-ampere receptacles that serve countertop surfaces shall have ground-fault circuit-interrupter protection for personnel. [210.8(A)(6)]~~

~~E3902.7 Sink receptacles.~~

~~125-volt, single-phase, 15- and 20-ampere receptacles that are located within 6 feet (1829 mm) of the outside edge of a sink shall have ground-fault circuit-interrupter protection for personnel. Receptacle outlets shall not be installed in a face-up position in the work surfaces or countertops. [210.8(A)(7)]~~

~~E3902.8 Bathtub or shower stall receptacles.~~

~~125-volt, single-phase, 15- and 20-ampere receptacles that are located within 6 feet (1829 mm) of the outside edge of a bathtub or shower stall shall have ground-fault circuit interrupter protection for personnel. [210.8(A)(8)]~~

~~E3902.9 Laundry areas.~~

~~125-volt, single-phase, 15- and 20-ampere receptacles installed in laundry areas shall have ground-fault circuit-interrupter protection for personnel. [210.8(A)(9)]~~

~~E3902.10 Kitchen dishwasher branch circuit.~~

~~Ground-fault circuit-interrupter protection shall be provided for outlets that supply dishwashers in dwelling unit locations. [210.8(D)]~~

~~E3902.11 Boathouse receptacles.~~

~~125-volt, single-phase, 15- or 20-ampere receptacles installed in boathouses shall have ground-fault circuit-interrupter protection for personnel. [210.8(A)(8)]~~

~~E3902.12 Boat hoists.~~

~~Ground-fault circuit-interrupter protection for personnel shall be provided for 240-volt and less outlets that supply boat hoists. [210.8(C)]~~

~~E3902.13 Electrically heated floors.~~

~~Ground-fault circuit-interrupter protection for personnel shall be provided for electrically heated floors in bathrooms, kitchens and in hydromassage bathtub, spa and hot tub locations. [424.44(G)]~~

~~E3902.14 Location of ground-fault circuit interrupters.~~

~~Ground-fault circuit interrupters shall be installed in a readily accessible location. [210.8(A)]~~

~~E3902.15 Location of arc-fault circuit interrupters.~~

~~Arc-fault circuit interrupters shall be installed in readily accessible locations.~~

~~E3902.16 Arc-fault circuit-interrupter protection.~~

~~Branch circuits that supply 120-volt, single-phase, 15- and 20-ampere outlets installed in kitchens, family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sun-rooms, recreations rooms, closets, hallways, laundry areas and similar rooms or areas shall be protected by any of the following: [210.12(A)]~~

~~1.A listed combination-type arc-fault circuit interrupter, installed to provide protection of the entire branch circuit. [210.12(A)(1)]~~

~~2.A listed branch/feeder-type AFCI installed at the origin of the branch-circuit in combination with a listed outlet branch-circuit type arc-fault circuit interrupter installed at the first outlet box on the branch circuit. The first outlet box in the branch circuit shall be marked to indicate that it is the first outlet of the circuit. [210.12(A)(2)]~~

~~3.A listed supplemental arc protection circuit breaker installed at the origin of the branch circuit in combination with a listed outlet branch-circuit type arc-fault circuit interrupter installed at the first outlet box on the branch circuit where all of the following conditions are met:~~

~~3.1.The branch-circuit wiring shall be continuous from the branch-circuit overcurrent device to the outlet branch-circuit arc-fault circuit interrupter.~~

~~3.2.The maximum length of the branch-circuit wiring from the branch-circuit overcurrent device to the first outlet shall not exceed 50 feet (15.2 m) for 14 AWG conductors and 70 feet (21.3 m) for 12 AWG conductors.~~

~~3.3.The first outlet box on the branch circuit shall be marked to indicate that it is the first outlet on the circuit. [210.12(A)(3)]~~

~~4.A listed outlet branch-circuit type arc-fault circuit interrupter installed at the first outlet on the branch circuit in combination with a listed branch-circuit overcurrent protective device where all of the following conditions are met:~~

~~4.1.The branch-circuit wiring shall be continuous from the branch-circuit overcurrent device to the outlet branch-circuit arc-fault circuit interrupter.~~

~~4.2.The maximum length of the branch-circuit wiring from the branch-circuit overcurrent device to the first outlet shall not exceed 50 feet (15.2 m) for 14 AWG conductors and 70 feet (21.3 m) for 12 AWG conductors.~~

~~4.3.The first outlet box on the branch circuit shall be marked to indicate that it is the first outlet on the circuit.~~

~~4.4.The combination of the branch-circuit overcurrent device and outlet branch-circuit AFCI shall be identified as meeting the requirements for a system combination-type AFCI and shall be listed as such. [210.12(A)(4)]~~

~~5.Where metal outlet boxes and junction boxes and RMC, IMC, EMT, Type MC or steel-armored Type AC cables meeting the requirements of Section E3908.8, metal wireways or metal auxiliary gutters are installed for the portion of the branch circuit between the branch-circuit overcurrent device and the first outlet, a listed outlet branch-circuit type AFCI installed at the first outlet shall be considered as providing protection for the remaining portion of the branch circuit. [210.12(A)(5)]~~

~~6.Where a listed metal or nonmetallic conduit or tubing or Type MC cable is encased in not less than 2 inches (50.8 mm) of concrete for the portion of the branch circuit between the branch-circuit overcurrent device and the first outlet, a listed outlet branch-circuit type AFCI installed at the first outlet shall be considered as providing protection for the remaining portion of the branch circuit. [210.12(A)(6)]~~

Exception: AFCI protection is not required for an individual branch circuit supplying only a fire alarm system where the branch circuit is wired with metal outlet and junction boxes and RMC, IMC, EMT or steel sheathed armored cable Type AC or Type MC meeting the requirements of Section E3908.8.

E3902.17 Arc fault circuit interrupter protection for branch circuit extensions or modifications.

Where branch-circuit wiring is modified, replaced, or extended in any of the areas specified in Section E3902.16, the branch circuit shall be protected by one of the following:

1.A combination-type AFCI located at the origin of the branch circuit

2.An outlet branch-circuit type AFCI located at the first receptacle outlet of the existing branch circuit. [210.12(B)]

Exception: AFCI protection shall not be required where the extension of the existing conductors is not more than 6 feet (1.8 m) in length and does not include any additional outlets or devices. [210.12(B) Exception]

SECTIONE3903
LIGHTING OUTLETS

E3903.1 General.

Lighting outlets shall be provided in accordance with Sections E3903.2 through E3903.4. [210.70(A)]

E3903.2 Habitable rooms.

At least one wall switch-controlled lighting outlet shall be installed in every habitable room and bathroom. [210.70(A)(1)]

Exceptions:

1.In other than kitchens and bathrooms, one or more receptacles controlled by a wall switch shall be considered equivalent to the required lighting outlet. [210.70(A)(1) Exception No. 1]

2.Lighting outlets shall be permitted to be controlled by occupancy sensors that are in addition to wall switches, or that are located at a customary wall switch location and equipped with a manual override that will allow the sensor to function as a wall switch. [210.70(A)(1) Exception No. 2]

E3903.3 Additional locations.

At least one wall-switch-controlled lighting outlet shall be installed in hallways, stairways, attached garages, and detached garages with electric power. At least one wall-switch-controlled lighting outlet shall be installed to provide illumination on the exterior side of each outdoor egress door having grade level access, including outdoor egress doors for attached garages and detached garages with electric power. A vehicle door in a garage shall not be considered as an outdoor egress door. Where one or more lighting outlets are installed for interior stairways, there shall be a wall switch at each floor level

~~and landing level that includes an entryway to control the lighting outlets where the stairway between floor levels has six or more risers. [210.70(A)(2)]~~

~~Exception: In hallways, stairways, and at outdoor egress doors, remote, central, or automatic control of lighting shall be permitted. [210.70(A)(2) Exception]~~

~~E3903.4 Storage or equipment spaces.~~

~~In attics, under floor spaces, utility rooms and basements, at least one lighting outlet shall be installed where these spaces are used for storage or contain equipment requiring servicing. Such lighting outlet shall be controlled by a wall switch or shall have an integral switch. At least one point of control shall be at the usual point of entry to these spaces. The lighting outlet shall be provided at or near the equipment requiring servicing. [210.70(A)(3)]~~

~~SECTIONE3904~~
~~GENERAL INSTALLATION REQUIREMENTS~~

~~E3904.1 Electrical continuity of metal raceways and enclosures.~~

~~Metal raceways, cable armor and other metal enclosures for conductors shall be mechanically joined together into a continuous electric conductor and shall be connected to all boxes, fittings and cabinets so as to provide effective electrical continuity. Raceways and cable assemblies shall be mechanically secured to boxes, fittings cabinets and other enclosures. (300.10)~~

~~Exception: Short sections of raceway used to provide cable assemblies with support or protection against physical damage. (300.10 Exception No. 1)~~

~~E3904.2 Mechanical continuity—raceways and cables.~~

~~Metal or nonmetallic raceways, cable armors and cable sheaths shall be continuous between cabinets, boxes, fittings or other enclosures or outlets.~~

~~Exception: Short sections of raceway used to provide cable assemblies with support or protection against physical damage. (300.12 Exception No. 1)~~

~~E3904.3 Securing and supporting.~~

~~Raceways, cable assemblies, boxes, cabinets and fittings shall be securely fastened in place. (300.11)~~

~~E3904.3.1 Prohibited means of support.~~

~~Cable wiring methods shall not be used as a means of support for other cables, raceways and nonelectrical equipment. [300.11(C)]~~

~~E3904.4 Raceways as means of support.~~

~~Raceways shall be used as a means of support for other raceways, cables or non-electric equipment only under the following conditions:~~

~~1.Where the raceway or means of support is identified as a means of support; or~~

~~2.Where the raceway contains power supply conductors for electrically controlled equipment and is used to support Class 2 circuit conductors or cables that are solely for the purpose of connection to the control circuits of the equipment served by such raceway; or~~

~~3.Where the raceway is used to support boxes or conduit bodies in accordance with Sections E3906.8.4 and E3906.8.5. [300.11(B)]~~

~~E3904.5 Raceway installations.~~

~~Raceways shall be installed complete between outlet, junction or splicing points prior to the installation of conductors. (300.18)~~

~~Exception: Short sections of raceways used to contain conductors or cable assemblies for protection from physical damage shall not be required to be installed complete between outlet, junction, or splicing points. (300.18 Exception)~~

~~E3904.6 Conduit and tubing fill.~~

~~The maximum number of conductors installed in conduit or tubing shall be in accordance with Tables E3904.6(1) through E3904.6(10). (300.17, Chapter 9, Table 1 and Annex C)~~

~~TABLE E3904.6(1) (Annex C, Table C.1)~~

~~MAXIMUM NUMBER OF CONDUCTORS IN ELECTRICAL METALLIC TUBING (EMT)a~~

~~TYPE LETTERS~~	~~CONDUCTOR SIZE AWG/kcmil~~	~~TRADE SIZES (inches)~~					
		~~1/2~~	~~3/4~~	~~1~~	~~11/4~~	~~11/2~~	~~2~~
	~~14~~	~~4~~	~~7~~	~~11~~	~~20~~	~~27~~	~~46~~
	~~12~~	~~3~~	~~6~~	~~9~~	~~17~~	~~23~~	~~38~~
~~RHH, RHW, RHW-2~~	~~10~~	~~2~~	~~5~~	~~8~~	~~13~~	~~18~~	~~30~~
	~~8~~	~~1~~	~~2~~	~~4~~	~~7~~	~~9~~	~~16~~
	~~6~~	~~1~~	~~1~~	~~3~~	~~5~~	~~8~~	~~13~~

	4	1	1	2	4	6	10
	3	1	1	1	4	5	9
	2	1	1	1	3	4	7
	1	0	1	1	1	3	5
	1/0	0	1	1	1	2	4
	2/0	0	1	1	1	2	4
	3/0	0	0	1	1	1	3
	4/0	0	0	1	1	1	3
TW, THHW, THW, THW-2	14	8	15	25	43	58	96
	12	6	11	19	33	45	74
	10	5	8	14	24	33	55
	8	2	5	8	13	18	30
RHHa, RHWa, RHW-2a	14	6	10	16	28	39	64
	12	4	8	13	23	31	51
	10	3	6	10	18	24	40
	8	1	4	6	10	14	24
RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2	6	1	3	4	8	11	18
	4	1	1	3	6	8	13
	3	1	1	3	5	7	12
	2	1	1	2	4	6	10

	1	1	1	1	3	4	7
	1/0	0	1	1	2	3	6
	2/0	0	1	1	1	3	5
	3/0	0	1	1	1	2	4
	4/0	0	0	1	1	1	3
THHN, THWN, THWN-2	14	12	22	35	61	84	138
	12	9	16	26	45	61	101
	10	5	10	16	28	38	63
	8	3	6	9	16	22	36
	6	2	4	7	12	16	26
	4	1	2	4	7	10	16
	3	1	1	3	6	8	13
	2	1	1	3	5	7	11
	1	1	1	1	4	5	8
	1/0	1	1	1	3	4	7
	2/0	0	1	1	2	3	6
	3/0	0	1	1	1	3	5
	4/0	0	1	1	1	2	4
XHH, XHHW, XHHW-2	14	8	15	25	43	58	96
	12	6	11	19	33	45	74

	10	5	8	14	24	33	55
	8	2	5	8	13	18	30
	6	1	3	6	10	14	22
	4	1	2	4	7	10	16
	3	1	1	3	6	8	14
	2	1	1	3	5	7	11
	1	1	1	1	4	5	8
	1/0	1	1	1	3	4	7
	2/0	0	1	1	2	3	6
	3/0	0	1	1	1	3	5
	4/0	0	1	1	1	2	4

~~For SI: 1 inch = 25.4 mm.~~

~~a.Types RHW, and RHW-2 without outer covering.~~

~~TABLE E3904.6(2) (Annex C, Table C.2)~~

~~MAXIMUM NUMBER OF CONDUCTORS IN ELECTRICAL NONMETALLIC TUBING (ENT)a~~

~~TYPE LETTERS~~	~~CONDUCTOR SIZE AWG/kcmil~~	~~TRADE SIZES (inches)~~					
		~~1/2~~	~~3/4~~	~~1~~	~~11/4~~	~~11/2~~	~~2~~
~~RHH, RHW, RHW-2~~	~~14~~	~~3~~	~~6~~	~~10~~	~~19~~	~~26~~	~~43~~
	~~12~~	~~2~~	~~5~~	~~9~~	~~16~~	~~22~~	~~36~~
	~~10~~	~~1~~	~~4~~	~~7~~	~~13~~	~~17~~	~~29~~
	~~8~~	~~1~~	~~1~~	~~3~~	~~6~~	~~9~~	~~15~~

	~~6~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~12~~
	~~4~~	~~1~~	~~1~~	~~2~~	~~4~~	~~6~~	~~9~~
	~~3~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~8~~
	~~2~~	~~0~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~1/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~2/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
~~RHH, RHW, RHW-2~~	~~3/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~4/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~
	~~14~~	~~7~~	~~13~~	~~22~~	~~40~~	~~55~~	~~92~~
~~TW, THHW, THW, THW-2~~	~~12~~	~~5~~	~~10~~	~~17~~	~~31~~	~~42~~	~~71~~
	~~10~~	~~4~~	~~7~~	~~13~~	~~23~~	~~32~~	~~52~~
	~~8~~	~~1~~	~~4~~	~~7~~	~~13~~	~~17~~	~~29~~
	~~14~~	~~4~~	~~8~~	~~15~~	~~27~~	~~37~~	~~61~~
~~RHHa, RHWa, RHW-2a~~	~~12~~	~~3~~	~~7~~	~~12~~	~~21~~	~~29~~	~~49~~
	~~10~~	~~3~~	~~5~~	~~9~~	~~17~~	~~23~~	~~38~~
	~~8~~	~~1~~	~~3~~	~~5~~	~~10~~	~~14~~	~~23~~
	~~6~~	~~1~~	~~2~~	~~4~~	~~7~~	~~10~~	~~17~~
~~RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2~~	~~4~~	~~1~~	~~1~~	~~3~~	~~5~~	~~8~~	~~13~~
	~~3~~	~~1~~	~~1~~	~~2~~	~~5~~	~~7~~	~~11~~

	2	1	1	2	4	6	9
	1	0	1	1	3	4	6
	1/0	0	1	1	2	3	5
	2/0	0	1	1	1	3	5
	3/0	0	0	1	1	2	4
	4/0	0	0	1	1	1	3
	14	10	18	32	58	80	132
	12	7	13	23	42	58	96
	10	4	8	15	26	36	60
	8	2	5	8	15	21	35
THHN, THWN, THWN-2	6	1	3	6	11	15	25
	4	1	1	4	7	9	15
	3	1	1	3	5	8	13
	2	1	1	2	5	6	11
	1	1	1	1	3	5	8
	1/0	0	1	1	3	4	7
THHN, THWN, THWN-2	2/0	0	1	1	2	3	5
	3/0	0	1	1	1	3	4
	4/0	0	0	1	1	2	4
XHH, XHHW, XHHW-2	14	7	13	22	40	55	92

	12	5	10	17	31	42	71
	10	4	7	13	23	32	52
	8	1	4	7	13	17	29
	6	1	3	5	9	13	21
	4	1	1	4	7	9	15
	3	1	1	3	6	8	13
	2	1	1	2	5	6	11
	1	1	1	1	3	5	8
	1/0	0	1	1	3	4	7
	2/0	0	1	1	2	3	6
	3/0	0	1	1	1	3	5
	4/0	0	0	1	1	2	4

For SI: 1 inch = 25.4 mm.

a.Types RHW, and RHW-2 without outer covering.

TABLE E3904.6(3) (Annex C, Table C.3)

MAXIMUM NUMBER OF CONDUCTORS IN FLEXIBLE METALLIC CONDUIT (FMC)a

TYPE LETTERS	CONDUCTOR SIZE AWG/kcmil	TRADE SIZES (inches)					
		1/2	3/4	1	11/4	11/2	2
	14	4	7	11	17	25	44
RHH, RHW, RHW-2	12	3	6	9	14	21	37
	10	3	5	7	11	17	30

	~~8~~	~~1~~	~~2~~	4	~~6~~	~~9~~	~~15~~
	~~6~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~12~~
	4	~~1~~	~~1~~	~~2~~	4	~~5~~	~~10~~
	~~3~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~
	~~2~~	~~1~~	~~1~~	~~1~~	~~3~~	4	~~7~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~5~~
~~RHH, RHW, RHW-2~~	~~1/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	4
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~3/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~14~~	~~9~~	~~15~~	~~23~~	~~36~~	~~53~~	~~94~~
~~TW, THHW, THW, THW-2~~	~~12~~	~~7~~	~~11~~	~~18~~	~~28~~	~~41~~	~~72~~
	~~10~~	~~5~~	~~8~~	~~13~~	~~21~~	~~30~~	~~54~~
	~~8~~	~~3~~	~~5~~	~~7~~	~~11~~	~~17~~	~~30~~
	~~14~~	~~6~~	~~10~~	~~15~~	~~24~~	~~35~~	~~62~~
~~RHHa, RHWa, RHW-2a~~	~~12~~	~~5~~	~~8~~	~~12~~	~~19~~	~~28~~	~~50~~
	~~10~~	4	~~6~~	~~10~~	~~15~~	~~22~~	~~39~~
	~~8~~	~~1~~	4	~~6~~	~~9~~	~~13~~	~~23~~
	~~6~~	~~1~~	~~3~~	4	~~7~~	~~10~~	~~18~~
~~RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2~~	4	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~13~~
	~~3~~	~~1~~	~~1~~	~~3~~	4	~~6~~	~~11~~

	2	1	1	2	4	5	10
	1	1	1	1	2	4	7
	1/0	0	1	1	1	3	6
	2/0	0	1	1	1	3	5
	3/0	0	1	1	1	2	4
	4/0	0	0	1	1	1	3
	4/0	0	0	1	1	1	2
	14	13	22	33	52	76	134
	12	9	16	24	38	56	98
THHN, THWN, THWN-2	10	6	10	15	24	35	62
	8	3	6	9	14	20	35
	6	2	4	6	10	14	25
	4	1	2	4	6	9	16
	3	1	1	3	5	7	13
	2	1	1	3	4	6	11
THHN, THWN, THWN-2	1	1	1	1	3	4	8
	1/0	1	1	1	2	4	7
	2/0	0	1	1	1	3	6
	3/0	0	1	1	1	2	5
	4/0	0	1	1	1	1	4

	14	9	15	23	36	53	94
	12	7	11	18	28	41	72
	10	5	8	13	21	30	54
	8	3	5	7	11	17	30
	6	1	3	5	8	12	22
	4	1	2	4	6	9	16
XHH, XHHW, XHHW-2	3	1	1	3	5	7	13
	2	1	1	3	4	6	11
	1	1	1	1	3	5	8
	1/0	1	1	1	2	4	7
	2/0	0	1	1	2	3	6
	3/0	0	1	1	1	3	5
	4/0	0	1	1	1	2	4

~~For SI: 1 inch = 25.4 mm.~~

~~a.Types RHW, and RHW-2 without outer covering.~~

~~TABLE E3904.6(4) (Annex C, Table C.4)~~

~~MAXIMUM NUMBER OF CONDUCTORS IN INTERMEDIATE METALLIC CONDUIT (IMC)a~~

TYPE LETTERS	CONDUCTOR SIZE AWG/kcmil	TRADE SIZES (inches)					
		1/2	3/4	1	11/4	11/2	2
RHH, RHW, RHW-2	14	4	8	13	22	30	49
	12	4	6	11	18	25	41

	10	3	5	8	15	20	33
	8	1	3	4	8	10	17
	6	1	1	3	6	8	14
	4	1	1	3	5	6	11
	3	1	1	2	4	6	9
	2	1	1	1	3	5	8
	1	0	1	1	2	3	5
	1/0	0	1	1	1	3	4
	2/0	0	1	1	1	2	4
	3/0	0	0	1	1	1	3
	4/0	0	0	1	1	1	3
	14	10	17	27	47	64	104
TW, THHW, THW, THW-2	12	7	13	21	36	49	80
	10	5	9	15	27	36	59
	8	3	5	8	15	20	33
	14	6	11	18	31	42	69
RHHa, RHWa, RHW-2a	12	5	9	14	25	34	56
	10	4	7	11	19	26	43
	8	2	4	7	12	16	26
RHHa, RHWa, RHW-2a, TW, THW, THHW,	6	1	3	5	9	12	20

THW-2	4	1	2	4	6	9	15
	3	1	1	3	6	8	13
	2	1	1	3	5	6	11
	1	1	1	1	3	4	7
	1/0	1	1	1	3	4	6
	2/0	0	1	1	2	3	5
	3/0	0	1	1	1	3	4
	4/0	0	1	1	1	2	4
	14	14	24	39	68	91	149
	12	10	17	29	49	67	109
	10	6	11	18	31	42	68
	8	3	6	10	18	24	39
	6	2	4	7	13	17	28
THHN, THWN, THWN-2	4	1	3	4	8	10	17
	3	1	2	4	6	9	15
	2	1	1	3	5	7	12
	1	1	1	2	4	5	9
	1/0	1	1	1	3	4	8
	2/0	1	1	1	3	4	6
THHN, THWN, THWN-2	3/0	0	1	1	2	3	5

	2/0	0	1	1	1	2	4
	14	10	17	27	47	64	104
	12	7	13	21	36	49	80
	10	5	9	15	27	36	59
	8	3	5	8	15	20	33
	6	1	4	6	11	15	24
	4	1	3	4	8	11	18
XHH, XHHW, XHHW-2	3	1	2	4	7	9	15
	2	1	1	3	5	7	12
	1	1	1	2	4	5	9
	1/0	1	1	1	3	5	8
	2/0	1	1	1	3	4	6
	3/0	0	1	1	2	3	5
	4/0	0	1	1	1	2	4

~~For SI: 1 inch = 25.4 mm.~~

~~a.Types RHW, and RHW-2 without outer covering.~~

~~TABLE E3904.6(5) (Annex C, Table C.5)~~

~~MAXIMUM NUMBER OF CONDUCTORS IN LIQUID-TIGHT FLEXIBLE NONMETALLIC CONDUIT (FNMC-B)a~~

TYPE LETTERS	CONDUCTOR SIZE AWG/kcmil	TRADE SIZES (inches)						
		3/8	1/2	3/4	1	11/4	11/2	2
RHH, RHW, RHW-2	14	2	4	7	12	21	27	44

	~~12~~	~~1~~	~~3~~	~~6~~	~~10~~	~~17~~	~~22~~	~~36~~
	~~10~~	~~1~~	~~3~~	~~5~~	~~8~~	~~14~~	~~18~~	~~29~~
	~~8~~	~~1~~	~~1~~	~~2~~	~~4~~	~~7~~	~~9~~	~~1~~
	~~6~~	~~1~~	~~1~~	~~1~~	~~3~~	~~6~~	~~7~~	~~12~~
	~~4~~	~~0~~	~~1~~	~~1~~	~~2~~	~~4~~	~~6~~	~~9~~
	~~3~~	~~0~~	~~1~~	~~1~~	~~1~~	~~4~~	~~5~~	~~8~~
	~~2~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~1~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
~~RHH, RHW, RHW-2~~	~~1/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~2/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~3/0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~4/0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~
	~~14~~	~~5~~	~~9~~	~~15~~	~~25~~	~~44~~	~~57~~	~~93~~
~~TW, THHW, THW, THW-2~~	~~12~~	~~4~~	~~7~~	~~12~~	~~19~~	~~33~~	~~43~~	~~71~~
	~~10~~	~~3~~	~~5~~	~~9~~	~~14~~	~~25~~	~~32~~	~~53~~
	~~8~~	~~1~~	~~3~~	~~5~~	~~8~~	~~14~~	~~18~~	~~29~~
	~~14~~	~~3~~	~~6~~	~~10~~	~~16~~	~~29~~	~~38~~	~~62~~
~~RHHa, RHWa, RGW-2a~~	~~12~~	~~3~~	~~5~~	~~8~~	~~13~~	~~23~~	~~30~~	~~50~~
	~~10~~	~~1~~	~~3~~	~~6~~	~~10~~	~~18~~	~~23~~	~~39~~
	~~8~~	~~1~~	~~1~~	~~4~~	~~6~~	~~11~~	~~14~~	~~23~~

	~~6~~	~~1~~	~~1~~	~~3~~	~~5~~	~~8~~	~~11~~	~~18~~
	~~4~~	~~1~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
	~~3~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~11~~
	~~2~~	~~0~~	~~1~~	~~1~~	~~2~~	~~4~~	~~6~~	~~9~~
~~RHHa, RHWa, RHW-2a,TW, THW, THHW, THW-2~~	~~1~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~1/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~2/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~5~~
	~~3/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~4/0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~14~~	~~8~~	~~13~~	~~22~~	~~36~~	~~63~~	~~81~~	~~133~~
	~~12~~	~~5~~	~~9~~	~~16~~	~~26~~	~~46~~	~~59~~	~~97~~
~~THHN, THWN, THWN-2~~	~~10~~	~~3~~	~~6~~	~~10~~	~~16~~	~~29~~	~~37~~	~~61~~
	~~8~~	~~1~~	~~3~~	~~6~~	~~9~~	~~16~~	~~21~~	~~35~~
	~~6~~	~~1~~	~~2~~	~~4~~	~~7~~	~~12~~	~~15~~	~~25~~
	~~4~~	~~1~~	~~1~~	~~2~~	~~4~~	~~7~~	~~9~~	~~15~~
	~~3~~	~~1~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
~~THHN, THWN, THWN-2~~	~~2~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~11~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~1~~	~~4~~	~~5~~	~~8~~
	~~1/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~2/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~

	3/0	0	0	1	1	1	3	5
	4/0	0	0	1	1	1	2	4
	14	5	9	15	25	44	57	93
	12	4	7	12	19	33	43	71
	10	3	5	9	14	25	32	53
	8	1	3	5	8	14	18	29
	6	1	1	3	6	10	13	22
	4	1	1	2	4	7	9	16
XHH, XHHW, XHHW-2	3	1	1	1	3	6	8	13
	2	1	1	1	3	5	7	11
	1	0	1	1	1	4	5	8
	1/0	0	1	1	1	3	4	7
	2/0	0	0	1	1	2	3	6
	3/0	0	0	1	1	1	3	5
	4/0	0	0	1	1	1	2	4

~~For SI: 1 inch = 25.4 mm.~~

~~a.Types RHW, and RHW-2 without outer covering.~~

~~TABLE E3904.6(6) (Annex C, Table C.6)~~

~~MAXIMUM NUMBER OF CONDUCTORS IN LIQUID-TIGHT FLEXIBLE NONMETALLIC CONDUIT (FNMC-A)a~~

TYPE LETTERS	CONDUCTOR SIZE AWG/kcmil	TRADE SIZES (inches)						
		3/8	1/2	3/4	1	11/4	11/2	2

	~~14~~	~~2~~	~~4~~	~~7~~	~~11~~	~~20~~	~~27~~	~~45~~
	~~12~~	~~1~~	~~3~~	~~6~~	~~9~~	~~17~~	~~23~~	~~38~~
	~~10~~	~~1~~	~~3~~	~~5~~	~~8~~	~~13~~	~~18~~	~~30~~
	~~8~~	~~1~~	~~1~~	~~2~~	~~4~~	~~7~~	~~9~~	~~16~~
	~~6~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~13~~
	~~4~~	~~0~~	~~1~~	~~1~~	~~2~~	~~4~~	~~6~~	~~10~~
~~RHH, RHW, RHW-2~~	~~3~~	~~0~~	~~1~~	~~1~~	~~1~~	~~4~~	~~5~~	~~8~~
	~~2~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~1~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~1/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~2/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~1~~	~~4~~
	~~3/0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~4/0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~14~~	~~5~~	~~9~~	~~15~~	~~24~~	~~43~~	~~58~~	~~96~~
~~TW, THHW, THW, THW-2~~	~~12~~	~~4~~	~~7~~	~~12~~	~~19~~	~~33~~	~~44~~	~~74~~
	~~10~~	~~3~~	~~5~~	~~9~~	~~14~~	~~24~~	~~33~~	~~55~~
	~~8~~	~~1~~	~~3~~	~~5~~	~~8~~	~~13~~	~~18~~	~~30~~
	~~14~~	~~3~~	~~6~~	~~10~~	~~16~~	~~28~~	~~38~~	~~64~~
~~RHHa, RHWa, RHW-2a~~	~~12~~	~~3~~	~~4~~	~~8~~	~~13~~	~~23~~	~~31~~	~~51~~
	~~10~~	~~1~~	~~3~~	~~6~~	~~10~~	~~18~~	~~24~~	~~40~~

	~~8~~	~~1~~	~~1~~	~~4~~	~~6~~	~~10~~	~~14~~	~~24~~
	~~6~~	~~1~~	~~1~~	~~3~~	~~4~~	~~8~~	~~11~~	~~18~~
	~~4~~	~~1~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
~~RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2~~	~~3~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~11~~
	~~2~~	~~0~~	~~1~~	~~1~~	~~2~~	~~4~~	~~6~~	~~10~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~1/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
~~RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2~~	~~2/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~3/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~4/0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~14~~	~~8~~	~~13~~	~~22~~	~~35~~	~~62~~	~~83~~	~~137~~
	~~12~~	~~5~~	~~9~~	~~16~~	~~25~~	~~45~~	~~60~~	~~100~~
	~~10~~	~~3~~	~~6~~	~~10~~	~~16~~	~~28~~	~~38~~	~~63~~
	~~8~~	~~1~~	~~3~~	~~6~~	~~9~~	~~16~~	~~22~~	~~36~~
~~THHN, THWN, THWN-2~~	~~6~~	~~1~~	~~2~~	~~4~~	~~6~~	~~12~~	~~16~~	~~26~~
	~~4~~	~~1~~	~~1~~	~~2~~	~~4~~	~~7~~	~~9~~	~~16~~
	~~3~~	~~1~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
	~~2~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~11~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~1~~	~~4~~	~~5~~	~~8~~
	~~1/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~

	2/0	0	0	1	1	2	3	6
	3/0	0	0	1	1	1	3	5
	4/0	0	0	1	1	1	2	4
XHH, XHHW, XHHW-2	14	5	9	15	24	43	58	96
	12	4	7	12	19	33	44	74
	10	3	5	9	14	24	33	55
	8	1	3	5	8	13	18	30
	6	1	1	3	5	10	13	22
	4	1	1	2	4	7	10	16
	3	1	1	1	3	6	8	14
	2	1	1	1	3	5	7	11
	1	0	1	1	1	4	5	8
XHH, XHHW, XHHW-2	1/0	0	1	1	1	3	4	7
	2/0	0	0	1	1	2	3	6
	3/0	0	0	1	1	1	3	5
	4/0	0	0	1	1	1	2	4

For SI: 1 inch = 25.4 mm.

a.Types RHW, and RHW-2 without outer covering.

TABLE E3904.6(7) (Annex C, Table C.7)

MAXIMUM NUMBER OF CONDUCTORS IN LIQUID-TIGHT FLEXIBLE METAL CONDUIT (LFMC)a

TYPE LETTERS	CONDUCTOR SIZE	TRADE SIZES (inches)

	AWG/kcmil	1/2	3/4	1	1 1/4	1 1/2	2
RHH, RHW, RHW-2	14	4	7	12	21	27	44
	12	3	6	10	17	22	36
	10	3	5	8	14	18	29
	8	1	2	4	7	9	15
	6	1	1	3	6	7	12
	4	1	1	2	4	6	9
	3	1	1	1	4	5	8
	2	1	1	1	3	4	7
	1	0	1	1	1	3	5
	1/0	0	1	1	1	2	4
	2/0	0	1	1	1	1	3
	3/0	0	0	1	1	1	3
	4/0	0	0	1	1	1	2
TW, THHW, THW, THW-2	14	9	15	25	44	57	93
	12	7	12	19	33	43	71
	10	5	9	14	25	32	53
	8	3	5	8	14	18	29
RHHa, RHWa, RHW-2a, THHW, THW, THW-2	14	6	10	16	29	38	62
	12	5	8	13	23	30	50

	10	3	6	10	18	23	39
	8	1	4	6	11	14	23
	6	1	3	5	8	11	18
	4	1	1	3	6	8	13
	3	1	1	3	5	7	11
	2	1	1	2	4	6	9
RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2	1	1	1	1	3	4	7
	1/0	0	1	1	2	3	6
	2/0	0	1	1	2	3	5
	3/0	0	1	1	1	2	4
	4/0	0	0	1	1	1	3
	14	13	22	36	63	81	133
	12	9	16	26	46	59	97
	10	6	10	16	29	37	61
	8	3	6	9	16	21	35
THHN, THWN, THWN-2	6	2	4	7	12	15	25
	4	1	2	4	7	9	15
	3	1	1	3	6	8	13
	2	1	1	3	5	7	11
	1	1	1	1	4	5	8

	~~1/0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~3/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~4/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~14~~	~~9~~	~~15~~	~~25~~	~~44~~	~~57~~	~~93~~
	~~12~~	~~7~~	~~12~~	~~19~~	~~33~~	~~43~~	~~71~~
~~XHH, XHHW, XHHW-2~~	~~10~~	~~5~~	~~9~~	~~14~~	~~25~~	~~32~~	~~53~~
	~~8~~	~~3~~	~~5~~	~~8~~	~~14~~	~~18~~	~~29~~
	~~6~~	~~1~~	~~3~~	~~6~~	~~10~~	~~13~~	~~22~~
	~~4~~	~~1~~	~~2~~	~~4~~	~~7~~	~~9~~	~~16~~
	~~3~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
	~~2~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~11~~
~~XHH, XHHW, XHHW-2~~	~~1~~	~~1~~	~~1~~	~~1~~	~~4~~	~~5~~	~~8~~
	~~1/0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~3/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~4/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~

~~For SI: 1 inch = 25.4 mm.~~

~~a.Types RHW, and RHW-2 without outer covering.~~

~~TABLE E3904.6(8) (Annex C, Table C.8)~~

~~MAXIMUM NUMBER OF CONDUCTORS IN RIGID METAL CONDUIT (RMC)a~~

~~TYPE LETTERS~~	~~CONDUCTOR SIZE AWG/kcmil~~	~~TRADE SIZES (inches)~~					
		~~1/2~~	~~3/4~~	~~1~~	~~11/4~~	~~11/2~~	~~2~~
~~RHH, RHW, RHW-2~~	~~14~~	~~4~~	~~7~~	~~12~~	~~21~~	~~28~~	~~46~~
	~~12~~	~~3~~	~~6~~	~~10~~	~~17~~	~~23~~	~~38~~
	~~10~~	~~3~~	~~5~~	~~8~~	~~14~~	~~19~~	~~31~~
	~~8~~	~~1~~	~~2~~	4	~~7~~	~~10~~	~~16~~
	~~6~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
	4	~~1~~	~~1~~	~~2~~	4	~~6~~	~~10~~
	~~3~~	~~1~~	~~1~~	~~2~~	4	~~5~~	~~9~~
	~~2~~	~~1~~	~~1~~	~~1~~	~~3~~	4	~~7~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~1/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	4
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	4
	~~3/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~4/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
~~TW, THHW, THW, THW-2~~	~~14~~	~~9~~	~~15~~	~~25~~	44	~~59~~	~~98~~
	~~12~~	~~7~~	~~12~~	~~19~~	~~33~~	~~45~~	~~75~~
	~~10~~	~~5~~	~~9~~	~~14~~	~~25~~	~~34~~	~~56~~
	~~8~~	~~3~~	~~5~~	~~8~~	~~14~~	~~19~~	~~31~~
~~RHHa, RHWa, RHW-2a~~	~~14~~	~~6~~	~~10~~	~~17~~	~~29~~	~~39~~	~~65~~

	12	5	8	13	23	32	52
	10	3	6	10	18	25	41
	8	1	4	6	11	15	24
	6	1	3	5	8	11	18
	4	1	1	3	6	8	14
	3	1	1	3	5	7	12
	2	1	1	2	4	6	10
RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2	1	1	1	1	3	4	7
	1/0	0	1	1	2	3	6
	2/0	0	1	1	2	3	5
	3/0	0	1	1	1	2	4
	4/0	0	0	1	1	1	3
	14	13	22	36	63	85	140
	12	9	16	26	46	62	102
	10	6	10	17	29	39	64
THHN, THWN, THWN-2	8	3	6	9	16	22	37
	6	2	4	7	12	16	27
	4	1	2	4	7	10	16
	3	1	1	3	6	8	14
	2	1	1	3	5	7	11

	~~1~~	~~1~~	~~1~~	~~1~~	~~4~~	~~5~~	~~8~~
	~~1/0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
~~THHN, THWN, THWN-2~~	~~3/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~4/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~14~~	~~9~~	~~15~~	~~25~~	~~44~~	~~59~~	~~98~~
	~~12~~	~~7~~	~~12~~	~~19~~	~~33~~	~~45~~	~~75~~
	~~10~~	~~5~~	~~9~~	~~14~~	~~25~~	~~34~~	~~56~~
	~~8~~	~~3~~	~~5~~	~~8~~	~~14~~	~~19~~	~~31~~
	~~6~~	~~1~~	~~3~~	~~6~~	~~10~~	~~14~~	~~23~~
	~~4~~	~~1~~	~~2~~	~~4~~	~~7~~	~~10~~	~~16~~
~~XHH, XHHW, XHHW-2~~	~~3~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~14~~
	~~2~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~12~~
	~~1~~	~~1~~	~~1~~	~~1~~	~~4~~	~~5~~	~~9~~
	~~1/0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~3/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~4/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~

~~For SI: 1 inch = 25.4 mm.~~

~~a.Types RHW, and RHW-2 without outer covering.~~

~~TABLE E3904.6(9) (Annex C, Table C.9)~~

~~MAXIMUM NUMBER OF CONDUCTORS IN RIGID PVC CONDUIT, SCHEDULE 80 (PVC-80)a~~

~~TYPE LETTERS~~	~~CONDUCTOR SIZE AWG/kcmil~~	~~TRADE SIZES (inches)~~					
		~~1/2~~	~~3/4~~	~~1~~	~~11/4~~	~~11/2~~	~~2~~
	~~14~~	~~3~~	~~5~~	~~9~~	~~17~~	~~23~~	~~39~~
	~~12~~	~~2~~	~~4~~	~~7~~	~~14~~	~~19~~	~~32~~
	~~10~~	~~1~~	~~3~~	~~6~~	~~11~~	~~15~~	~~26~~
~~RHH, RHW, RHW-2~~	~~8~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
	~~6~~	~~1~~	~~1~~	~~2~~	4	~~6~~	~~11~~
	4	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~8~~
	~~3~~	~~0~~	~~1~~	~~1~~	~~3~~	4	~~7~~
	~~2~~	~~0~~	~~1~~	~~1~~	~~3~~	4	~~6~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	4
~~RHH, RHW, RHW-2~~	~~1/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~2/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~3/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~4/0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~2~~
	~~14~~	~~6~~	~~11~~	~~20~~	~~35~~	~~49~~	~~82~~
	~~12~~	~~5~~	~~9~~	~~15~~	~~27~~	~~38~~	~~63~~
~~TW, THHW, THW, THW-2~~	~~10~~	~~3~~	~~6~~	~~11~~	~~20~~	~~28~~	~~47~~
	~~8~~	~~1~~	~~3~~	~~6~~	~~11~~	~~15~~	~~26~~

	~~14~~	4	~~8~~	~~13~~	~~23~~	~~32~~	~~55~~
~~RHHa, RHWa, RHW-2a~~	~~12~~	~~3~~	~~6~~	~~10~~	~~19~~	~~26~~	~~44~~
	~~10~~	~~2~~	~~5~~	~~8~~	~~15~~	~~20~~	~~34~~
	~~8~~	~~1~~	~~3~~	~~5~~	~~9~~	~~12~~	~~20~~
	~~6~~	~~1~~	~~1~~	~~3~~	~~7~~	~~9~~	~~16~~
	4	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~12~~
~~RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2~~	~~3~~	~~1~~	~~1~~	~~2~~	4	~~6~~	~~10~~
	~~2~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~8~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~1/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	4
~~RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2~~	~~3/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~4/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~14~~	~~9~~	~~17~~	~~28~~	~~51~~	~~70~~	~~118~~
	~~12~~	~~6~~	~~12~~	~~20~~	~~37~~	~~51~~	~~86~~
	~~10~~	4	~~7~~	~~13~~	~~23~~	~~32~~	~~54~~
~~THHN, THWN, THWN-2~~	~~8~~	~~2~~	4	~~7~~	~~13~~	~~18~~	~~31~~
	~~6~~	~~1~~	~~3~~	~~5~~	~~9~~	~~13~~	~~22~~
	4	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~14~~
	~~3~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~12~~

	~~2~~	~~1~~	~~1~~	~~2~~	4	~~6~~	~~10~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~1/0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~3/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~4/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~14~~	~~6~~	~~11~~	~~20~~	~~35~~	~~49~~	~~82~~
	~~12~~	~~5~~	~~9~~	~~15~~	~~27~~	~~38~~	~~63~~
~~XHH, XHHW, XHHW-2~~	~~10~~	~~3~~	~~6~~	~~11~~	~~20~~	~~28~~	~~47~~
	~~8~~	~~1~~	~~3~~	~~6~~	~~118~~	~~15~~	~~26~~
	~~6~~	~~1~~	~~2~~	4		~~11~~	~~19~~
	~~14~~	~~6~~	~~11~~	~~20~~	~~35~~	~~49~~	~~82~~
	~~12~~	~~5~~	~~9~~	~~15~~	~~27~~	~~38~~	~~63~~
	~~10~~	~~3~~	~~6~~	~~11~~	~~20~~	~~28~~	~~47~~
	~~8~~	~~1~~	~~3~~	6	~~11~~	~~15~~	~~26~~
~~XHH, XHHW, XHHW-2~~	~~6~~	~~1~~	~~2~~	4	~~8~~	~~11~~	~~19~~
	4	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~14~~
	~~3~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~12~~
	~~2~~	~~1~~	~~1~~	~~2~~	4	~~6~~	~~10~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~3~~	4	~~7~~

	1/0	0	1	1	2	3	6
	2/0	0	1	1	1	3	5
	3/0	0	1	1	1	2	4
	4/0	0	0	1	1	1	3

For SI: 1 inch = 25.4 mm.

a.Types RHW, and RHW-2 without outer covering.

TABLE E3904.6(10) (Annex C, Table C.10)

MAXIMUM NUMBER OF CONDUCTORS IN RIGID PVC CONDUIT SCHEDULE 40 (PVC-40)a

TYPE LETTERS	CONDUCTOR SIZE AWG/kcmil	TRADE SIZES (inches)					
		1/2	3/4	1	11/4	11/2	2
RHH, RHW, RHW-2	14	4	7	11	20	27	45
	12	3	5	9	16	22	37
	10	2	4	7	13	18	30
	8	1	2	4	7	9	15
	6	1	1	3	5	7	12
	4	1	1	2	4	6	10
	3	1	1	1	4	5	8
	2	1	1	1	3	4	7
	1	0	1	1	1	3	5
RHH, RHW, RHW-2	1/0	0	1	1	1	2	4
	2/0	0	0	1	1	1	3

	~~3/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
	~~4/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~
~~TW, THHW, THW, THW-2~~	~~14~~	~~8~~	~~14~~	~~24~~	~~42~~	~~57~~	~~94~~
	~~12~~	~~6~~	~~11~~	~~18~~	~~32~~	~~44~~	~~72~~
	~~10~~	~~4~~	~~8~~	~~13~~	~~24~~	~~32~~	~~54~~
	~~8~~	~~2~~	~~4~~	~~7~~	~~13~~	~~18~~	~~30~~
~~RHHa, RHWa, RHW-2a~~	~~14~~	~~5~~	~~9~~	~~16~~	~~28~~	~~38~~	~~63~~
	~~12~~	~~4~~	~~8~~	~~13~~	~~22~~	~~30~~	~~50~~
	~~10~~	~~3~~	~~6~~	~~10~~	~~17~~	~~24~~	~~39~~
	~~8~~	~~1~~	~~3~~	~~6~~	~~10~~	~~14~~	~~23~~
~~RHHa, RHWa, RHW-2a, TW, THW, THHW, THW-2~~	~~6~~	~~1~~	~~2~~	~~4~~	~~8~~	~~11~~	~~18~~
	~~4~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
	~~3~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~11~~
	~~2~~	~~1~~	~~1~~	~~2~~	~~4~~	~~6~~	~~10~~
	~~1~~	~~0~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~1/0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~3/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~4/0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~
~~THHN, THWN, THWN-2~~	~~14~~	~~11~~	~~21~~	~~34~~	~~60~~	~~82~~	~~135~~

	~~12~~	~~8~~	~~15~~	~~25~~	~~43~~	~~59~~	~~99~~
	~~10~~	~~5~~	~~9~~	~~15~~	~~27~~	~~37~~	~~62~~
	~~8~~	~~3~~	~~5~~	~~9~~	~~16~~	~~21~~	~~36~~
	~~6~~	~~1~~	~~4~~	~~6~~	~~11~~	~~15~~	~~26~~
	~~4~~	~~1~~	~~2~~	~~4~~	~~7~~	~~9~~	~~16~~
	~~3~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
	~~2~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~11~~
~~THHN, THWN, THWN-2~~	~~1~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~8~~
	~~1/0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~3/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~4/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~
	~~14~~	~~8~~	~~14~~	~~24~~	~~42~~	~~57~~	~~94~~
	~~12~~	~~6~~	~~11~~	~~18~~	~~32~~	~~44~~	~~72~~
	~~10~~	~~4~~	~~8~~	~~13~~	~~24~~	~~32~~	~~54~~
	~~8~~	~~2~~	~~4~~	~~7~~	~~13~~	~~18~~	~~30~~
~~XHH, XHHW, XHHW-2~~	~~6~~	~~1~~	~~3~~	~~5~~	~~10~~	~~13~~	~~22~~
	~~4~~	~~1~~	~~2~~	~~4~~	~~7~~	~~9~~	~~16~~
	~~3~~	~~1~~	~~1~~	~~3~~	~~6~~	~~8~~	~~13~~
	~~2~~	~~1~~	~~1~~	~~3~~	~~5~~	~~7~~	~~11~~

	~~1~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~	~~8~~
	~~1/0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~4~~	~~7~~
	~~2/0~~	~~0~~	~~1~~	~~1~~	~~2~~	~~3~~	~~6~~
	~~3/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~3~~	~~5~~
	~~4/0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~2~~	~~4~~

~~For SI: 1 inch = 25.4 mm.~~

~~a.Types RHW, and RHW-2 without outer covering.~~

~~E3904.7 Air handling stud cavity and joist spaces.~~

~~Where wiring methods having a nonmetallic covering pass through stud cavities and joist spaces used for air handling, such wiring shall pass through such spaces perpendicular to the long dimension of the spaces. [300.22(C) Exception]~~

~~SECTIONE3905~~
~~BOXES, CONDUIT BODIES AND FITTINGS~~

~~E3905.1 Box, conduit body or fitting—where required.~~

~~A box or conduit body shall be installed at each conductor splice point, outlet, switch point, junction point and pull point except as otherwise permitted in Sections E3905.1.1 through E3905.1.6.~~

~~Fittings and connectors shall be used only with the specific wiring methods for which they are designed and listed. (300.15)~~

~~E3905.1.1 Equipment.~~

~~An integral junction box or wiring compartment that is part of listed equipment shall be permitted to serve as a box or conduit body. [300.15(B)]~~

~~E3905.1.2 Protection.~~

~~A box or conduit body shall not be required where cables enter or exit from conduit or tubing that is used to provide cable support or protection against physical damage. A fitting shall be provided on the end(s) of the conduit or tubing to protect the cable from abrasion. [300.15(C)]~~

~~E3905.1.3 Integral enclosure.~~

A wiring device with integral enclosure identified for the use, having brackets that securely fasten the device to walls or ceilings of conventional on-site frame construction, for use with nonmetallic-sheathed cable, shall be permitted in lieu of a box or conduit body. [300.15(E)]

E3905.1.4 Fitting.

A fitting identified for the use shall be permitted in lieu of a box or conduit body where such fitting is accessible after installation and does not contain spliced or terminated conductors. [300.15(F)]

E3905.1.5 Buried conductors.

Splices and taps in buried conductors and cables shall not be required to be enclosed in a box or conduit body where installed in accordance with Section E3803.4.

E3905.1.6 Luminaires.

Where a luminaire is listed to be used as a raceway, a box or conduit body shall not be required for wiring installed therein. [300.15(J)]

E3905.2 Metal boxes.

Metal boxes shall be grounded. (314.4)

E3905.3 Nonmetallic boxes.

Nonmetallic boxes shall be used only with cabled wiring methods with entirely nonmetallic sheaths, flexible cords and nonmetallic raceways. (314.3)

Exceptions:

1.Where internal bonding means are provided between all entries, nonmetallic boxes shall be permitted to be used with metal raceways and metal-armored cables. (314.3 Exception No. 1)

2.Where integral bonding means with a provision for attaching an equipment grounding jumper inside the box are provided between all threaded entries in nonmetallic boxes listed for the purpose, nonmetallic boxes shall be permitted to be used with metal raceways and metal-armored cables. (314.3 Exception No. 2)

E3905.3.1 Nonmetallic-sheathed cable and nonmetallic boxes.

Where nonmetallic-sheathed cable is used, the cable assembly, including the sheath, shall extend into the box not less than 1/4 inch (6.4 mm) through a nonmetallic-sheathed cable knockout opening. (314.7(C))

E3905.3.2 Securing to box.

Wiring methods shall be secured to the boxes. [314.17(C)]

Exception: Where nonmetallic-sheathed cable is used with boxes not larger than a nominal size of 21/4 inches by 4 inches (57 mm by 102 mm) mounted in walls or ceilings, and where the cable is fastened within 8 inches (203 mm) of the box measured along the sheath, and where the sheath extends through a cable knockout not less than 1/4 inch (6.4 mm), securing the cable to the box shall not be required. [314.17(C) Exception]

E3905.3.3 Conductor rating.

Nonmetallic boxes shall be suitable for the lowest temperature-rated conductor entering the box. [314.17(C)]

E3905.4 Minimum depth of boxes for outlets, devices, and utilization equipment.

Outlet and device boxes shall have an approved depth to allow equipment installed within them to be mounted properly and without the likelihood of damage to conductors within the box. (314.24)

E3905.4.1 Outlet boxes without enclosed devices or utilization equipment.

Outlet boxes that do not enclose devices or utilization equipment shall have an internal depth of not less than 1/2 inch (12.7 mm). [314.24(A)]

E3905.4.2 Utilization equipment.

Outlet and device boxes that enclose devices or utilization equipment shall have a minimum internal depth that accommodates the rearward projection of the equipment and the size of the conductors that supply the equipment. The internal depth shall include that of any extension boxes, plaster rings, or raised covers. The internal depth shall comply with all of the applicable provisions that follow. [314.24(B)]

Exception: Utilization equipment that is listed to be installed with specified boxes.

1.Large equipment. Boxes that enclose devices or utilization equipment that projects more than 17/8 inches (48 mm) rearward from the mounting plane of the box shall have a depth that is not less than the depth of the equipment plus 1/4 inch (6.4 mm). [314.24(B)(1)]

2.Conductors larger than 4 AWG. Boxes that enclose devices or utilization equipment supplied by conductors larger than 4 AWG shall be identified for their specific function. [314.24(B)(2)]

3.Conductors 8, 6, or 4 AWG. Boxes that enclose devices or utilization equipment supplied by 8, 6, or 4 AWG conductors shall have an internal depth that is not less than 21/16 inches (52.4 mm). [314.24(B)(3)]

4.Conductors 12 or 10 AWG. Boxes that enclose devices or utilization equipment supplied by 12 or 10 AWG conductors shall have an internal depth that is not less than 13/16 inches (30.2 mm). Where the equipment projects rearward from the mounting plane of the box by more than 1 inch (25.4 mm), the box shall have a depth that is not less than that of the equipment plus 1/4 inch (6.4 mm). [314.24(B)(4)]

~~5.Conductors 14 AWG and smaller. Boxes that enclose devices or utilization equipment supplied by 14 AWG or smaller conductors shall have a depth that is not less than 15/16 inch (23.8 mm). [314.24(B)(5)]~~

~~E3905.5 Boxes enclosing flush-mounted devices.~~

~~Boxes enclosing flush-mounted devices shall be of such design that the devices are completely enclosed at the back and all sides and shall provide support for the devices. Screws for supporting the box shall not be used for attachment of the device contained therein. (314.19)~~

~~E3905.6 Boxes at luminaire outlets.~~

~~Outlet boxes used at luminaire or lampholder outlets shall be designed for the support of luminaires and lampholders and shall be installed as required by Section E3904.3. [314.27(A)]~~

~~E3905.6.1 Vertical surface outlets.~~

~~Boxes used at luminaire or lampholder outlets in or on a vertical surface shall be identified and marked on the interior of the box to indicate the maximum weight of the luminaire or lamp holder that is permitted to be supported by the box if other than 50 pounds (22.7 kg). [314.27(A)(1)]~~

~~Exception: A vertically-mounted luminaire or lampholder weighing not more than 6 pounds (2.7 kg) shall be permitted to be supported on other boxes or plaster rings that are secured to other boxes, provided that the luminaire or its supporting yoke is secured to the box with not fewer than two No. 6 or larger screws. [314.27(A)(1) Exception]~~

~~E3905.6.2 Ceiling outlets.~~

~~For outlets used exclusively for lighting, the box shall be designed or installed so that a luminaire or lampholder can be attached. Such boxes shall be capable of supporting a luminaire weighing up to 50 pounds (22.7 kg). A luminaire that weighs more than 50 pounds (22.7 kg) shall be supported independently of the outlet box, unless the outlet box is listed and marked on the interior of the box to indicate the maximum weight that the box is permitted to support. [314.27(A)(2)]~~

~~E3905.7 Floor boxes.~~

~~Where outlet boxes for receptacles are installed in the floor, such boxes shall be listed specifically for that application. [314.27(B)]~~

~~E3905.8 Boxes at fan outlets.~~

~~Outlet boxes and outlet box systems used as the sole support of ceiling-suspended fans (paddle) shall be marked by their manufacturer as suitable for this purpose and shall not support ceiling-suspended fans (paddle) that weigh more than 70 pounds (31.8 kg). For outlet boxes and outlet box systems designed to support ceiling-suspended fans (paddle) that weigh more than 35 pounds (15.9 kg), the required marking shall include the maximum weight to be supported.~~

~~Where spare, separately switched, ungrounded conductors are provided to a ceiling-mounted outlet box and such box is in a location acceptable for a ceiling-suspended (paddle) fan, the outlet box or outlet box system shall be listed for sole support of a ceiling-suspended (paddle) fan. [314.27(C)]~~

~~E3905.9 Utilization equipment.~~

~~Boxes used for the support of utilization equipment other than ceiling-suspended (paddle) fans shall meet the requirements of Sections E3905.6.1 and E3905.6.2 for the support of a luminaire that is the same size and weight. [314.27(D)]~~

~~Exception: Utilization equipment weighing not more than 6 pounds (2.7 kg) shall be permitted to be supported on other boxes or plaster rings that are secured to other boxes, provided that the equipment or its supporting yoke is secured to the box with not fewer than two No. 6 or larger screws. [314.27(D) Exception]~~

~~E3905.10 Conduit bodies and junction, pull and outlet boxes to be accessible.~~

~~Conduit bodies and junction, pull and outlet boxes shall be installed so that the wiring therein can be accessed without removing any part of the building or structure or, in underground circuits, without excavating sidewalks, paving, earth or other substance used to establish the finished grade. (314.29)~~

~~Exception: Boxes covered by gravel, light aggregate or noncohesive granulated soil shall be listed for the application, and the box locations shall be effectively identified and access shall be provided for excavation. (314.29 Exception)~~

~~E3905.11 Damp or wet locations.~~

~~In damp or wet locations, boxes, conduit bodies and fittings shall be placed or equipped so as to prevent moisture from entering or accumulating within the box, conduit body or fitting. Boxes, conduit bodies and fittings installed in wet locations shall be listed for use in wet locations. Where drainage openings are installed in the field in boxes or conduit bodies listed for use in damp or wet locations, such openings shall be approved and not larger than 1/4 inch (6.4 mm). For listed drain fittings, larger openings are permitted where installed in the field in accordance with the manufacturer's instructions. (314.15)~~

~~E3905.12 Number of conductors in outlet, device, and junction boxes, and conduit bodies.~~

~~Boxes and conduit bodies shall be of an approved size to provide free space for all enclosed conductors. In no case shall the volume of the box, as calculated in Section E3905.12.1, be less than the box fill calculation as calculated in Section E3905.12.2. The minimum volume for conduit bodies shall be as calculated in Section E3905.12.3. The provisions of this section shall not apply to terminal housings supplied with motors or generators. (314.16)~~

~~E3905.12.1 Box volume calculations.~~

~~The volume of a wiring enclosure (box) shall be the total volume of the assembled sections, and, where used, the space provided by plaster rings, domed covers, extension rings, etc., that are marked with~~

~~their volume in cubic inches or are made from boxes the dimensions of which are listed in Table E3905.12.1. [314.16(A)]~~

~~TABLE E3905.12.1 [Table 314.16(A)]~~

~~MAXIMUM NUMBER OF CONDUCTORS IN METAL BOXESa~~

~~BOX DIMENSIONS (inches trade size and type)~~	~~MAXIMUM CAPACITY (cubic inches)~~	~~MAXIMUM NUMBER OF CONDUCTORSa~~						
		~~18 Awg~~	~~16 Awg~~	~~14 Awg~~	~~12 Awg~~	~~10 Awg~~	~~8 Awg~~	~~6 Awg~~
~~4 × 11/4 round or octagonal~~	~~12.5~~	~~8~~	~~7~~	~~6~~	~~5~~	~~5~~	~~4~~	~~2~~
~~4 × 11/2 round or octagonal~~	~~15.5~~	~~10~~	~~8~~	~~7~~	~~6~~	~~6~~	~~5~~	~~3~~
~~4 × 21/8 round or octagonal~~	~~21.5~~	~~14~~	~~12~~	~~10~~	~~9~~	~~8~~	~~7~~	~~4~~
~~4 × 11/4 square~~	~~18.0~~	~~12~~	~~10~~	~~9~~	~~8~~	~~7~~	~~6~~	~~3~~
~~4 × 11/2 square~~	~~21.0~~	~~14~~	~~12~~	~~10~~	~~9~~	~~8~~	~~7~~	~~4~~
~~4 × 21/8 square~~	~~30.3~~	~~20~~	~~17~~	~~15~~	~~13~~	~~12~~	~~10~~	~~6~~
~~411/16 × 11/4 square~~	~~25.5~~	~~17~~	~~14~~	~~12~~	~~11~~	~~10~~	~~8~~	~~5~~
~~411/16 × 11/2 square~~	~~29.5~~	~~19~~	~~16~~	~~14~~	~~13~~	~~11~~	~~9~~	~~5~~
~~411/16 × 21/8 square~~	~~42.0~~	~~28~~	~~24~~	~~21~~	~~18~~	~~16~~	~~14~~	~~8~~
~~3 × 2 × 11/2 device~~	~~7.5~~	~~5~~	~~4~~	~~3~~	~~3~~	~~3~~	~~2~~	~~1~~
~~3 × 2 × 2 device~~	~~10.0~~	~~6~~	~~5~~	~~5~~	~~4~~	~~4~~	~~3~~	~~2~~
~~3 × 2 × 21/4 device~~	~~10.5~~	~~7~~	~~6~~	~~5~~	~~4~~	~~4~~	~~3~~	~~2~~
~~3 × 2 × 21/2 device~~	~~12.5~~	~~8~~	~~7~~	~~6~~	~~5~~	~~5~~	~~4~~	~~2~~
~~3 × 2 × 23/4 device~~	~~14.0~~	~~9~~	~~8~~	~~7~~	~~6~~	~~5~~	~~4~~	~~2~~
~~3 × 2 × 31/2 device~~	~~18.0~~	~~12~~	~~10~~	~~9~~	~~8~~	~~7~~	~~6~~	~~3~~

4 × 21/8 × 11/2 device	10.3	6	5	5	4	4	3	2
4 × 21/8 × 17/8 device	13.0	8	7	6	5	5	4	2
4 × 21/8 × 21/8 device	14.5	9	8	7	6	5	4	2
33/4 × 2 × 21/2 masonry box/gang	14.0	9	8	7	6	5	4	2
33/4 × 2 × 31/2 masonry box/gang	21.0	14	12	10	9	8	7	4

For SI: 1 inch = 25.4 mm, 1 cubic inch = 16.4 cm3.

a.Where volume allowances are not required by Sections E3905.12.2.2 through E3905.12.2.5.

E3905.12.1.1 Standard boxes.

The volumes of standard boxes that are not marked with a cubic-inch capacity shall be as given in Table E3905.12.1. [314.16(A)(1)]

E3905.12.1.2 Other boxes.

Boxes 100 cubic inches (1640 cm3) or less, other than those described in Table E3905.12.1, and nonmetallic boxes shall be durably and legibly marked by the manufacturer with their cubic-inch capacity. Boxes described in Table E3905.12.1 that have a larger cubic inch capacity than is designated in the table shall be permitted to have their cubic-inch capacity marked as required by this section. [314.16(A)(2)]

E3905.12.2 Box fill calculations.

The volumes in Section E3905.12.2.1 through Section E3905.12.2.5, as applicable, shall be added together. No allowance shall be required for small fittings such as locknuts and bushings. [314.16(B)]

E3905.12.2.1 Conductor fill.

Each conductor that originates outside the box and terminates or is spliced within the box shall be counted once, and each conductor that passes through the box without splice or termination shall be counted once. Each loop or coil of unbroken conductor having a length equal to or greater than twice that required for free conductors by Section E3406.11.3, shall be counted twice. The conductor fill, in cubic inches, shall be computed using Table E3905.12.2.1. A conductor, no part of which leaves the box, shall not be counted. [314.16(B)(1)]

~~Exception: An equipment grounding conductor or not more than four fixture wires smaller than No. 14, or both, shall be permitted to be omitted from the calculations where such conductors enter a box from a domed fixture or similar canopy and terminate within that box. [314.16(B)(1) Exception]~~

~~TABLE E3905.12.2.1 [Table 314.16(B)]~~

~~VOLUME ALLOWANCE REQUIRED PER CONDUCTOR~~

~~SIZE OF CONDUCTOR~~	~~FREE SPACE WITHIN BOX FOR EACH CONDUCTOR (cubic inches)~~
~~18 AWG~~	~~1.50~~
~~16 AWG~~	~~1.75~~
~~14 AWG~~	~~2.00~~
~~12 AWG~~	~~2.25~~
~~10 AWG~~	~~2.50~~
~~8 AWG~~	~~3.00~~
~~6 AWG~~	~~5.00~~

~~For SI: 1 cubic inch = 16.4 cm3.~~

~~E3905.12.2.2 Clamp fill.~~

~~Where one or more internal cable clamps, whether factory or field supplied, are present in the box, a single volume allowance in accordance with Table E3905.12.2.1 shall be made based on the largest conductor present in the box. An allowance shall not be required for a cable connector having its clamping mechanism outside of the box. A clamp assembly that incorporates a cable termination for the cable conductors shall be listed and marked for use with specific nonmetallic boxes. Conductors that originate within the clamp assembly shall be included in conductor fill calculations provided in Section E3905.12.2.1 as though they entered from outside of the box. The clamp assembly shall not require a fill allowance, but, the volume of the portion of the assembly that remains within the box after installation shall be excluded from the box volume as marked in accordance with Section E3905.12.1.2. [314.16(B)(2)]~~

~~E3905.12.2.3 Support fittings fill.~~

~~Where one or more fixture studs or hickeys are present in the box, a single volume allowance in accordance with Table E3905.12.2.1 shall be made for each type of fitting based on the largest conductor present in the box. [314.16(B)(3)]~~

E3905.12.2.4 Device or equipment fill.

For each yoke or strap containing one or more devices or equipment, a double volume allowance in accordance with Table E3905.12.2.1 shall be made for each yoke or strap based on the largest conductor connected to a device(s) or equipment supported by that yoke or strap. For a device or utilization equipment that is wider than a single 2-inch (51 mm) device box as described in Table E3905.12.1, a double volume allowance shall be made for each ganged portion required for mounting of the device or equipment. [314.16(B)(4)]

E3905.12.2.5 Equipment grounding conductor fill.

Where one or more equipment grounding conductors or equipment bonding jumpers enters a box, a single volume allowance in accordance with Table E3905.12.2.1 shall be made based on the largest equipment grounding conductor or equipment bonding jumper present in the box. [314.16(B)(5)]

E3905.12.3 Conduit bodies.

Conduit bodies enclosing 6 AWG conductors or smaller, other than short-radius conduit bodies, shall have a cross-sectional area not less than twice the cross-sectional area of the largest conduit or tubing to which they can be attached. The maximum number of conductors permitted shall be the maximum number permitted by Section E3904.6 for the conduit to which it is attached. [314.16(C)(1)]

E3905.12.3.1 Splices, taps or devices.

Only those conduit bodies that are durably and legibly marked by the manufacturer with their cubic inch capacity shall be permitted to contain splices, taps or devices. The maximum number of conductors shall be calculated using the same procedure for similar conductors in other than standard boxes. [314.16(C)(2)]

E3905.12.3.2 Short-radius conduit bodies.

Conduit bodies such as capped elbows and service-entrance elbows that enclose conductors 6 AWG or smaller and that are only intended to enable the installation of the raceway and the contained conductors, shall not contain splices, taps, or devices and shall be of sufficient size to provide free space for all conductors enclosed in the conduit body. [314.16(C)(3)]

SECTIONE3906
INSTALLATION OF BOXES,
CONDUIT BODIES AND FITTINGS

E3906.1 Conductors entering boxes, conduit bodies or fittings.

Conductors entering boxes, conduit bodies or fittings shall be protected from abrasion. (314.17)

E3906.1.1 Insulated fittings.

~~Where raceways contain 4 AWG or larger insulated circuit conductors and these conductors enter a cabinet, box enclosure, or raceway, the conductors shall be protected by an identified fitting providing a smoothly rounded insulating surface, unless the conductors are separated from the fitting or raceway by identified insulating material securely fastened in place. [300.4(G)]~~

~~Exception: Where threaded hubs or bosses that are an integral part of a cabinet, box enclosure, or raceway provide a smoothly rounded or flared entry for conductors. [300.4(G) Exception]~~

~~Conduit bushings constructed wholly of insulating material shall not be used to secure a fitting or raceway. The insulating fitting or insulating material shall have a temperature rating not less than the insulation temperature rating of the installed conductors. [330.4(G)]~~

~~E3906.2 Openings.~~

~~Openings through which conductors enter shall be closed in an approved manner. [314.17(A)]~~

~~E3906.3 Metal boxes and conduit bodies.~~

~~Where raceway or cable is installed with metal boxes, or conduit bodies, the raceway or cable shall be secured to such boxes and conduit bodies. [314.17(B)]~~

~~E3906.4 Unused openings.~~

~~Unused openings other than those intended for the operation of equipment, those intended for mounting purposes, or those permitted as part of the design for listed equipment, shall be closed to afford protection substantially equivalent to that of the wall of the equipment. Metal plugs or plates used with nonmetallic boxes or conduit bodies shall be recessed at least 1/4 inch (6.4 mm) from the outer surface of the box or conduit body. [110.12(A)]~~

~~E3906.5 In wall or ceiling.~~

~~In walls or ceilings of concrete, tile or other noncombustible material, boxes employing a flush-type cover or faceplate shall be installed so that the front edge of the box, plaster ring, extension ring, or listed extender will not be set back from the finished surface more than 1/4 inch (6.4 mm). In walls and ceilings constructed of wood or other combustible material, boxes, plaster rings, extension rings and listed extenders shall be flush with the finished surface or project therefrom. (314.20)~~

~~E3906.6 Noncombustible surfaces.~~

~~Openings in noncombustible surfaces that accommodate boxes employing a flush-type cover or faceplate shall be made so that there are no gaps or open spaces greater than 1/8 inch (3.2 mm) around the edge of the box. (314.21)~~

~~E3906.7 Surface extensions.~~

~~Surface extensions shall be made by mounting and mechanically securing an extension ring over the box. (314.22)~~

~~Exception: A surface extension shall be permitted to be made from the cover of a flush-mounted box where the cover is designed so it is unlikely to fall off, or be removed if its securing means becomes loose. The wiring method shall be flexible for an approved length that permits removal of the cover and provides access to the box interior and shall be arranged so that any bonding or grounding continuity is independent of the connection between the box and cover. (314.22 Exception)~~

~~E3906.8 Supports.~~

~~Boxes and enclosures shall be supported in accordance with one or more of the provisions in Sections E3906.8.1 through E3906.8.6. (314.23)~~

~~E3906.8.1 Surface mounting.~~

~~An enclosure mounted on a building or other surface shall be rigidly and securely fastened in place. If the surface does not provide rigid and secure support, additional support in accordance with other provisions of Section E3906.8 shall be provided. [314.23(A)]~~

~~E3906.8.2 Structural mounting.~~

~~An enclosure supported from a structural member or from grade shall be rigidly supported either directly, or by using a metal, polymeric or wood brace. [314.23(B)]~~

~~E3906.8.2.1 Nails and screws.~~

~~Nails and screws, where used as a fastening means, shall be attached by using brackets on the outside of the enclosure, or they shall pass through the interior within 1/4 inch (6.4 mm) of the back or ends of the enclosure. Screws shall not be permitted to pass through the box except where exposed threads in the box are protected by an approved means to avoid abrasion of conductor insulation. [314.23(B)(1)]~~

~~E3906.8.2.2 Braces.~~

~~Metal braces shall be protected against corrosion and formed from metal that is not less than 0.020 inch (0.508 mm) thick uncoated. Wood braces shall have a cross section not less than nominal 1 inch by 2 inches (25.4 mm by 51 mm). Wood braces in wet locations shall be treated for the conditions. Polymeric braces shall be identified as being suitable for the use. [314.23(B)(2)]~~

~~E3906.8.3 Mounting in finished surfaces.~~

~~An enclosure mounted in a finished surface shall be rigidly secured there to by clamps, anchors, or fittings identified for the application. [314.23(C)]~~

~~E3906.8.4 Raceway supported enclosures without devices or fixtures.~~

~~An enclosure that does not contain a device(s), other than splicing devices, or support a luminaire, lampholder or other equipment, and that is supported by entering raceways shall not exceed 100 cubic inches (1640 cm3) in size. The enclosure shall have threaded entries or identified hubs. The enclosure shall be supported by two or more conduits threaded wrenchtight into the enclosure or hubs. Each~~

~~conduit shall be secured within 3 feet (914 mm) of the enclosure, or within 18 inches (457 mm) of the enclosure if all entries are on the same side of the enclosure. [314.23(E)]~~

~~Exception: Rigid metal, intermediate metal, or rigid polyvinyl chloride nonmetallic conduit or electrical metallic tubing shall be permitted to support a conduit body of any size, provided that the conduit body is not larger in trade size than the largest trade size of the supporting conduit or electrical metallic tubing. [314.23(E) Exception]~~

~~E3906.8.5 Raceway supported enclosures, with devices or luminaire.~~

~~An enclosure that contains a device(s), other than splicing devices, or supports a luminaire, lampholder or other equipment and is supported by entering raceways shall not exceed 100 cubic inches (1640 cm3) in size. The enclosure shall have threaded entries or identified hubs. The enclosure shall be supported by two or more conduits threaded wrench-tight into the enclosure or hubs. Each conduit shall be secured within 18 inches (457 mm) of the enclosure. [314.23(F)]~~

~~Exceptions:~~

~~1.Rigid metal or intermediate metal conduit shall be permitted to support a conduit body of any size, provided that the conduit bodies are not larger in trade size than the largest trade size of the supporting conduit. [314.23(F) Exception No. 1]~~

~~2.An unbroken length(s) of rigid or intermediate metal conduit shall be permitted to support a box used for luminaire or lampholder support, or to support a wiring enclosure that is an integral part of a luminaire and used in lieu of a box in accordance with Section E3905.1.1, where all of the following conditions are met:~~

~~2.1.The conduit is securely fastened at a point so that the length of conduit beyond the last point of conduit support does not exceed 3 feet (914 mm).~~

~~2.2.The unbroken conduit length before the last point of conduit support is 12 inches (305 mm) or greater, and that portion of the conduit is securely fastened at some point not less than 12 inches (305 mm) from its last point of support.~~

~~2.3.Where accessible to unqualified persons, the luminaire or lampholder, measured to its lowest point, is not less than 8 feet (2438 mm) above grade or standing area and at least 3 feet (914 mm) measured horizontally to the 8-foot (2438 mm) elevation from windows, doors, porches, fire escapes, or similar locations.~~

~~2.4.A luminaire supported by a single conduit does not exceed 12 inches (305 mm) in any direction from the point of conduit entry.~~

~~2.5.The weight supported by any single conduit does not exceed 20 pounds (9.1 kg).~~

~~2.6.At the luminaire or lampholder end, the conduit(s) is threaded wrenchtight into the box, conduit body, or integral wiring enclosure, or into hubs identified for the purpose. Where a box or conduit body~~

~~is used for support, the luminaire shall be secured directly to the box or conduit body, or through a threaded conduit nipple not over 3 inches (76 mm) long. [314.23(F) Exception No. 2]~~

~~E3906.8.6 Enclosures in concrete or masonry.~~

~~An enclosure supported by embedment shall be identified as being suitably protected from corrosion and shall be securely embedded in concrete or masonry. [314.23(G)]~~

~~E3906.9 Covers and canopies.~~

~~Outlet boxes shall be effectively closed with a cover, faceplate or fixture canopy. Screws used for the purpose of attaching covers, or other equipment to the box shall be either machine screws matching the thread gauge or size that is integral to the box or shall be in accordance with the manufacturer's instructions. (314.25)~~

~~E3906.10 Covers and plates.~~

~~Covers and plates shall be nonmetallic or metal. Metal covers and plates shall be grounded. [314.25(A)]~~

~~E3906.11 Exposed combustible finish.~~

~~Combustible wall or ceiling finish exposed between the edge of a fixture canopy or pan and the outlet box shall be covered with noncombustible material where required by Section E4004.2. [314.25(B)]~~

~~SECTIONE3907~~
~~CABINETS AND PANELBOARDS~~

~~E3907.1 Switch and overcurrent device enclosures with splices, taps, and feed-through conductors.~~

~~Where the wiring space of enclosures for switches or overcurrent devices contains conductors that are feeding through, spliced, or tapping off to other enclosures, switches, or overcurrent devices, all of the following conditions shall apply:~~

~~1.The total area of all conductors installed at any cross section of the wiring space shall not exceed 40 percent of the cross-sectional area of that space.~~

~~2.The total area of all conductors, splices, and taps installed at any cross section of the wiring space shall not exceed 75 percent of the cross-sectional area of that space.~~

~~3.A warning label shall be applied to the enclosure that identifies the closest disconnecting means for any feed-through conductors. (312.8)~~

~~E3907.2 Damp and wet locations.~~

~~In damp or wet locations, cabinets and panelboards of the surface type shall be placed or equipped so as to prevent moisture or water from entering and accumulating within the cabinet, and shall be mounted to provide an air-space not less than 1/4 inch (6.4 mm) between the enclosure and the wall or~~

~~other supporting surface. Cabinets installed in wet locations shall be weatherproof. For enclosures in wet locations, raceways and cables entering above the level of uninsulated live parts shall be installed with fittings listed for wet locations. (312.2)~~

~~Exception: Nonmetallic enclosures installed on concrete, masonry, tile, or similar surfaces shall not be required to be installed with an air space between the enclosure and the wall or supporting surface. (312.2 Exception)~~

~~E3907.3 Position in wall.~~

~~In walls of concrete, tile or other noncombustible material, cabinets and panelboards shall be installed so that the front edge of the cabinet will not set back of the finished surface more than 1/4 inch (6.4 mm). In walls constructed of wood or other combustible material, cabinets shall be flush with the finished surface or shall project there-from. (312.3)~~

~~E3907.4 Repairing noncombustible surfaces.~~

~~Noncombustible surfaces that are broken or incomplete shall be repaired so that there will not be gaps or open spaces greater than 1/8 inch (3.2 mm) at the edge of the cabinet or cutout box employing a flush-type cover. (312.4)~~

~~E3907.5 Unused openings.~~

~~Unused openings, other than those intended for the operation of equipment, those intended for mounting purposes, and those permitted as part of the design for listed equipment, shall be closed to afford protection substantially equivalent to that of the wall of the equipment. Metal plugs and plates used with nonmetallic cabinets shall be recessed at least 1/4 inch (6.4 mm) from the outer surface. Unused openings for circuit breakers and switches shall be closed using identified closures, or other approved means that provide protection substantially equivalent to the wall of the enclosure. (110.12(A))~~

~~E3907.6 Conductors entering cabinets.~~

~~Conductors entering cabinets and panelboards shall be protected from abrasion and shall comply with Section E3906.1.1. (312.5)~~

~~E3907.7 Openings to be closed.~~

~~Openings through which conductors enter cabinets, panelboards and meter sockets shall be closed in an approved manner. [312.5(A)]~~

~~E3907.8 Cables.~~

~~Where cables are used, each cable shall be secured to the cabinet, panelboard, cutout box, or meter socket enclosure. [312.5(C)]~~

Exception: Cables with entirely nonmetallic sheaths shall be permitted to enter the top of a surface-mounted enclosure through one or more sections of rigid raceway not less than 18 inches (457 mm) nor more than 10 feet (3048 mm) in length, provided all the following conditions are met:

1.Each cable is fastened within 12 inches (305 mm), measured along the sheath, of the outer end of the raceway.

2.The raceway extends directly above the enclosure and does not penetrate a structural ceiling.

3.A fitting is provided on each end of the raceway to protect the cable(s) from abrasion and the fittings remain accessible after installation.

4.The raceway is sealed or plugged at the outer end using approved means so as to prevent access to the enclosure through the raceway.

5.The cable sheath is continuous through the raceway and extends into the enclosure beyond the fitting not less than 1/4 inch (6.4 mm).

6.The raceway is fastened at its outer end and at other points in accordance with Section E3802.1.

7.The allowable cable fill shall not exceed that permitted by Table E3907.8. A multiconductor cable having two or more conductors shall be treated as a single conductor for calculating the percentage of conduit fill area. For cables that have elliptical cross sections, the cross-sectional area calculation shall be based on the major diameter of the ellipse as a circle diameter. [312.5(C) Exception]

TABLE E3907.8 (Chapter 9, Table 1)

PERCENT OF CROSS SECTION OF CONDUIT AND TUBING FOR CONDUCTORS

NUMBER OF CONDUCTORS	MAXIMUM PERCENT OF CONDUIT AND TUBING AREA FILLED BY CONDUCTORS
1	53
2	31
Over 2	40

E3907.9Wire-bending space within an enclosure containing a panelboard.

Wire-bending space within an enclosure containing a panelboard shall comply with the requirements of Sections E3907.9.1 through E3907.9.3.

E3907.9.1Top and bottom wire-bending space.

The top and bottom wire-bending space for a panelboard enclosure shall be sized in accordance with Table E3907.9.1(1) based on the largest conductor entering or leaving the enclosure. [408.55 (A)]

Exceptions:

1.For a panelboard rated at 225 amperes or less and designed to contain not more than 42 overcurrent devices, either the top or bottom wire-bending space shall be permitted to be sized in accordance with Table E3907.9.1(2). For the purposes of this exception, a 2-pole or a 3-pole circuit breaker shall be considered as two or three overcurrent devices, respectively. [408.55(A) Exception No. 1]

2.For any panelboard, either the top or bottom wire-bending space shall be permitted to be sized in accordance with Table E3907.9.1(2) where the wire-bending space on at least one side is sized in accordance with Table E3907.9.1(1) based on the largest conductor to be terminated in any side wire-bending space. [408.55(A) Exception No. 2]

3. Where the panelboard is designed and constructed for wiring using only a single 90-degree bend for each conductor, including the grounded circuit conductor, and the wiring diagram indicates and specifies the method of wiring that must be used, the top and bottom wire-bending space shall be permitted to be sized in accordance with Table E3907.9.1(2). [408.55(A) Exception No. 3]

4.Where there are no conductors terminated in that space, either the top or the bottom wire-bending space, shall be permitted to be sized in accordance with Table E3907.9.1(2). [408.55(A) Exception No. 4]

TABLE E3907.9.1(1) [Table 312.6(B)]

MINIMUM WIRE-BENDING SPACE AT TERMINALS (see note 1)

WIRE SIZE (AWG or kcmil)		WIRES PER TERMINAL			
All other conductors	Compact stranded AA-8000 aluminum alloy conductors (see Note 3)	One (see note 2)		Two	
		inches	mm	inches	mm
14-10	12-8	Not specified	Not specified	—	—
8	6	11/2	38.1	—	—
6	4	2	50.8	—	—
4	2	3	76.2	—	—

3	1	3	76.2	—	—
2	1/0	31/2	88.9	—	—
1	2/0	41/2	114	—	—
1/0	3/0	51/2	140	51/2	140
2/0	4/0	6	152	6	152
3/0	250	61/2a	165a	61/2a	165a
4/0	300	7b	178b	71/2c	190c
250	350	81/2d	216d	81/2d	229d
300	400	10c	254c	10d	254d
350	500	12c	305c	12c	305c
400	600	13c	330c	13c	330c
500	700-750	14c	356c	14c	356c
600	800-900	15c	381c	16c	406c
700	1000	16c	406c	18c	457c

1.Bending space at terminals shall be measured in a straight line from the end of the lug or wire connector in a direction perpendicular to the enclosure wall.

2.For removable and lay in wire terminals intended for only one wire, bending space shall be permitted to be reduced by the following number of millimeters (inches):

a.1/2 inches (12.7 mm)

b.1 inches (25.4 mm)

c.11/2 inches (38.1 mm)

d.2 inches (50.8 mm)

3.This column shall be permitted to determine the required wire-bending space for compact stranded aluminum conductors in sizes up to 1000 kcmil and manufactured using AA-8000 series electrical grade aluminum alloy conductor material.

TABLE E3907.9.1(2) [Table 312.6(A)]

MINIMUM WIRE-BENDING SPACE AT TERMINALS AND MINIMUM WIDTH OF WIRING GUTTERS (see note 1)

WIRE SIZE (AWG or kcmil)	WIRES PER TERMINAL			
	One		Two	
	inches	mm	inches	mm
14-10	Not specified	Not specified	—	—
8-6	11/2	38.1	—	—
4-3	2	50.8	—	—
2	21/2	63.5	—	—
1	2	76.2	—	—
1/0-2/0	31/2	88.9	5	127
3/0-4/0	4	102	6	152
250	41/2	114	6	152
300-350	5	127	8	203
400-500	6	152	8	203
600-700	8	203	10	254

1.Bending space at terminals shall be measured in a straight line from the end of the lug or wire connector in the direction that the wire leaves the terminal to the wall, barrier, or obstruction.

E3907.9.2 Side wire-bending space.

~~Side wire-bending space shall be in accordance with Table E3907.9.1(2) based on the largest conductor to be terminated in that space. [408.55(B)]~~

~~E3907.9.3 Back wire-bending space.~~

~~The distance between the center of the rear entry and the nearest termination for the entering conductors shall be not less than the distance given in Table E3907.9.1(1). Where a raceway or cable entry is in the wall of the enclosure, opposite a removable cover, the distance from that wall to the cover shall be permitted to comply with the distance required in Table E3907.9.1(2). [408.55 (C)]~~

~~SECTIONE3908~~
~~GROUNDING~~

~~E3908.1 Metal enclosures.~~

~~Metal enclosures of conductors, devices and equipment shall be connected to the equipment grounding conductor. (250.86)~~

~~Exceptions:~~

~~1.Short sections of metal enclosures or raceways used to provide cable assemblies with support or protection against physical damage. (250.86 Exception No. 2)~~

~~2.A metal elbow that is installed in an underground installation of rigid nonmetallic conduit and is isolated from possible contact by a minimum cover of 18 inches (457 mm) to any part of the elbow or that is encased in not less than 2 inches (51 mm) of concrete. (250.86 Exception No. 3)~~

~~E3908.2 Equipment fastened in place or connected by permanent wiring methods (fixed).~~

~~Exposed, normally noncurrent-carrying metal parts of fixed equipment supplied by or enclosing conductors or components that are likely to become energized shall be connected to the equipment grounding conductor where any of the following conditions apply:~~

~~1.Where within 8 feet (2438 mm) vertically or 5 feet (1524 mm) horizontally of earth or grounded metal objects and subject to contact by persons;~~

~~2.Where located in a wet or damp location and not isolated; or~~

~~3.Where in electrical contact with metal. (250.110)~~

~~E3908.3 Specific equipment fastened in place (fixed) or connected by permanent wiring methods.~~

~~Exposed, normally noncurrent-carrying metal parts of the following equipment and enclosures shall be connected to an equipment grounding conductor:~~

~~1.Luminaires as provided in Chapter 40. [250.112(J)]~~

~~2.Motor-operated water pumps, including submersible types.Where a submersible pump is used in a metal well casing, the well casing shall be connected to the pump circuit equipment grounding conductor. [250.112(L)]~~

~~E3908.4 Effective ground-fault current path.~~

~~Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems. Such circuit shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault might occur to the electrical supply source. [250.(A)(5)]~~

~~E3908.5 Earth as a ground-fault current path.~~

~~The earth shall not be considered as an effective ground-fault current path. [250.4(A)(5)]~~

~~E3908.6 Load-side grounded conductor neutral.~~

~~A grounded conductor shall not be connected to normally noncurrent-carrying metal parts of equipment, to equipment grounding conductor(s), or be reconnected to ground on the load side of the service disconnecting means. [250.24(A)(5)]~~

~~E3908.7 Load-side equipment.~~

~~A grounded circuit conductor shall not be used for grounding noncurrent-carrying metal parts of equipment on the load side of the service disconnecting means. [250.142(B)]~~

~~E3908.8 Types of equipment grounding conductors.~~

~~The equipment grounding conductor run with or enclosing the circuit conductors shall be one or more or a combination of the following:~~

~~1.A copper, aluminum or copper-clad conductor. This conductor shall be solid or stranded; insulated, covered or bare; and in the form of a wire or a busbar of any shape. [250.118(1)]~~

~~2.Rigid metal conduit. [250.118(2)]~~

~~3.Intermediate metal conduit. [250.118(3)]~~

~~4.Electrical metallic tubing. [250.118(4)]~~

~~5.Armor of Type AC cable in accordance with Section E3908.4. [250.118(8)]~~

~~6.Type MC cable that provides an effective ground-fault current path in accordance with one or more of the following:~~

~~6.1.It contains an insulated or uninsulated equipment grounding conductor in compliance with Item 1 of this section.~~

~~6.2.The combined metallic sheath and uninsulated equipment grounding/bonding conductor of interlocked metal tape-type MC cable that is listed and identified as an equipment grounding conductor.~~

~~6.3.The metallic sheath or the combined metallic sheath and equipment grounding conductors of the smooth or corrugated tube-type MC cable that is listed and identified as an equipment grounding conductor. [250.118(10)]~~

~~7.Other electrically continuous metal raceways and auxiliary gutters. [250.118(13)]~~

~~8.Surface metal raceways listed for grounding. [250.118(14)]~~

~~E3908.8.1 Flexible metal conduit.~~

~~Flexible metal conduit shall be permitted as an equipment grounding conductor where all of the following conditions are met:~~

~~1.The conduit is terminated in listed fittings.~~

~~2.The circuit conductors contained in the conduit are protected by overcurrent devices rated at 20 amperes or less.~~

~~3.The combined length of flexible metal conduit and flexible metallic tubing and liquid-tight flexible metal conduit in the same ground-return path does not exceed 6 feet (1829 mm).~~

~~If used to connect equipment where flexibility is necessary to minimize the transmission of vibration from equipment or to provide flexibility for equipment that requires movement after installation, an equipment grounding conductor shall be installed. [250.118(5)]~~

~~E3908.8.2 Liquid-tight flexible metal conduit.~~

~~Liquid-tight flexible metal conduit shall be permitted as an equipment grounding conductor where all of the following conditions are met:~~

~~1.The conduit is terminated in listed fittings.~~

~~2.For trade sizes 3/8 through 1/2 (metric designator 12 through 16), the circuit conductors contained in the conduit are protected by overcurrent devices rated at 20 amperes or less.~~

~~3.For trade sizes 3/4 through 11/4 (metric designator 21 through 35), the circuit conductors contained in the conduit are protected by overcurrent devices rated at not more than 60 amperes and there is no flexible metal conduit, flexible metallic tubing, or liquid-tight flexible metal conduit in trade sizes 3/8 inch or 1/2 inch (9.5 mm through 12.7 mm) in the ground fault current path.~~

~~4.The combined length of flexible metal conduit and flexible metallic tubing and liquid-tight flexible metal conduit in the same ground-return path does not exceed 6 feet (1829 mm).~~

~~If used to connect equipment where flexibility is necessary to minimize the transmission of vibration from equipment or to provide flexibility for equipment that requires movement after installation, an equipment grounding conductor shall be installed. [250.118(6)]~~

~~E3908.8.3 Nonmetallic sheathed cable (Type NM).~~

~~In addition to the insulated conductors, the cable shall have an insulated, covered, or bare equipment grounding conductor. Equipment grounding conductors shall be sized in accordance with Table E3908.12. (334.108)~~

~~E3908.9 Equipment fastened in place or connected by permanent wiring methods.~~

~~Noncurrent-carrying metal parts of equipment, raceways and other enclosures, where required to be grounded, shall be grounded by one of the following methods: (250.134)~~

~~1.By any of the equipment grounding conductors permitted by Sections E3908.8 through E3908.8.3. [250.134(A)]~~

~~2.By an equipment grounding conductor contained within the same raceway, cable or cord, or otherwise run with the circuit conductors. Equipment grounding conductors shall be identified in accordance with Section E3407.2. [250.134(B)]~~

~~E3908.10 Methods of equipment grounding.~~

~~Fixtures and equipment shall be considered grounded where mechanically connected to an equipment grounding conductor as specified in Sections E3908.8 through E3908.8.3. Wire type equipment grounding conductors shall be sized in accordance with Section E3908.12. (250 Part VII)~~

~~E3908.11 Equipment grounding conductor installation.~~

~~Where an equipment grounding conductor consists of a raceway, cable armor or cable sheath or where such conductor is a wire within a raceway or cable, it shall be installed in accordance with the provisions of this chapter and Chapters 34 and 38 using fittings for joints and terminations approved for installation with the type of raceway or cable used. All connections, joints and fittings shall be made tight using suitable tools. (250.120)~~

~~E3908.12 Equipment grounding conductor size.~~

~~Copper, aluminum and copper-clad aluminum equipment grounding conductors of the wire type shall be not smaller than shown in Table E3908.12, but they shall not be required to be larger than the circuit conductors supplying the equipment. Where a raceway or a cable armor or sheath is used as the equipment grounding conductor, as provided in Section E3908.8, it shall comply with Section E3908.4. Where ungrounded conductors are increased in size from the minimum size that has sufficient ampacity for the intended installation, wire type equipment grounding conductors shall be increased proportionally according to the circular mil area of the ungrounded conductors. [250.122(A) and (B)]~~

~~TABLE E3908.12 (Table 250.122)~~

~~EQUIPMENT GROUNDING CONDUCTOR SIZING~~

~~RATING OR SETTING OF AUTOMATIC OVERCURRENT DEVICE IN CIRCUIT AHEAD OF EQUIPMENT, CONDUIT, ETC., NOT EXCEEDING THE FOLLOWING RATINGS (amperes)~~	~~MINIMUM SIZE~~	
	~~Copper wire No. (AWG)~~	~~Aluminum or copper-clad aluminum wire No. (AWG)~~
~~15~~	~~14~~	~~12~~
~~20~~	~~12~~	~~10~~
~~60~~	~~10~~	~~8~~
~~100~~	~~8~~	~~6~~
~~200~~	~~6~~	~~4~~
~~300~~	~~4~~	~~2~~
~~400~~	~~3~~	~~1~~

~~E3908.12.1 Multiple circuits.~~

~~Where a single equipment grounding conductor is run with multiple circuits in the same raceway or cable, it shall be sized for the largest overcurrent device protecting conductors in the raceway or cable. [250.122(C)]~~

~~E3908.13 Continuity and attachment of equipment grounding conductors to boxes.~~

~~Where circuit conductors are spliced within a box or terminated on equipment within or supported by a box, any equipment grounding conductors associated with the circuit conductors shall be connected within the box or to the box with devices suitable for the use. Connections depending solely on solder shall not be used. Splices shall be made in accordance with Section E3406.10 except that insulation shall not be required. The arrangement of grounding connections shall be such that the disconnection or removal of a receptacle, luminaire or other device fed from the box will not interfere with or interrupt the grounding continuity. [250.146(A) and (C)]~~

~~E3908.14 Connecting receptacle grounding terminal to box.~~

An equipment bonding jumper, sized in accordance with Table E3908.12 based on the rating of the overcurrent device protecting the circuit conductors, shall be used to connect the grounding terminal of a grounding type receptacle to a grounded box except where grounded in accordance with one of the following: (250.146)

1.Surface mounted box. Where the box is mounted on the surface, direct metal-to-metal contact between the device yoke and the box shall be permitted to ground the receptacle to the box. At least one of the insulating washers shall be removed from receptacles that do not have a contact yoke or device designed and listed to be used in conjunction with the supporting screws to establish the grounding circuit between the device yoke and flush-type boxes. This provision shall not apply to cover-mounted receptacles except where the box and cover combination are listed as providing satisfactory ground continuity between the box and the receptacle. A listed exposed work cover shall be considered to be the grounding and bonding means where the device is attached to the cover with at least two fasteners that are permanent, such as a rivet or have a thread locking or screw locking means and where the cover mounting holes are located on a flat non-raised portion of the cover. [250.146(A)]

2.Contact devices or yokes. Contact devices or yokes designed and listed for the purpose shall be permitted in conjunction with the supporting screws to establish equipment bonding between the device yoke and flush-type boxes. [250.146(B)]

3.Floor boxes.The receptacle is installed in a floor box designed for and listed as providing satisfactory ground continuity between the box and the device. [250.146(C)]

E3908.15 Metal boxes.

A connection shall be made between the one or more equipment grounding conductors and a metal box by means of a grounding screw that shall be used for no other purpose, equipment listed for grounding or by means of a listed grounding device. Where screws are used to connect grounding conductors or connection devices to boxes, such screws shall be one or more of the following: [250.148(C)]

1.Machine screw-type fasteners that engage not less than two threads.

2.Machine screw-type fasteners that are secured with a nut.

3.Thread-forming machine screws that engage not less than two threads in the enclosure. [250.8(5) and (6)]

E3908.16 Nonmetallic boxes.

One or more equipment grounding conductors brought into a nonmetallic outlet box shall be arranged to allow connection to fittings or devices installed in that box. [250.148(D)]

E3908.17 Clean surfaces.

Nonconductive coatings such as paint, lacquer and enamel on equipment to be grounded shall be removed from threads and other contact surfaces to ensure electrical continuity or the equipment shall be connected by means of fittings designed so as to make such removal unnecessary. (250.12)

E3908.18 Bonding other enclosures.

Metal raceways, cable armor, cable sheath, enclosures, frames, fittings and other metal noncurrent-carrying parts that serve as equipment grounding conductors, with or without the use of supplementary equipment grounding conductors, shall be effectively bonded where necessary to ensure electrical continuity and the capacity to conduct safely any fault current likely to be imposed on them. Any nonconductive paint, enamel and similar coating shall be removed at threads, contact points and contact surfaces, or connections shall be made by means of fittings designed so as to make such removal unnecessary. [250.96(A)]

E3908.19 Size of equipment bonding jumper on load side of an overcurrent device.

The equipment bonding jumper on the load side of an overcurrent devices shall be sized, as a minimum, in accordance with Table E3908.12, but shall not be required to be larger than the circuit conductors supplying the equipment. An equipment bonding conductor shall be not smaller than No. 14 AWG.

A single common continuous equipment bonding jumper shall be permitted to connect two or more raceways or cables where the bonding jumper is sized in accordance with Table E3908.12 for the largest overcurrent device supplying circuits therein. [250.102(D) and 250.122]

E3908.20 Installation equipment bonding jumper.

Bonding jumpers or conductors and equipment bonding jumpers shall be installed either inside or outside of a raceway or an enclosure in accordance with Sections E3908.20.1 and E3908.20.2. [250.102(E)]

E3908.20.1 Inside raceway or enclosure.

Where installed inside a raceway or enclosure, equipment bonding jumpers and bonding jumpers or conductors shall comply with the requirements of Sections E3407.2 and E3908.13. [250.102(E)(1)]

E3908.20.2 Outside raceway or enclosure.

Where installed outside of a raceway or enclosure, the length of the bonding jumper or conductor or equipment bonding jumper shall not exceed 6 feet (1829 mm) and shall be routed with the raceway or enclosure. [250.102(E)(2)]

Equipment bonding jumpers and supply side bonding jumpers installed for bonding grounding electrodes and installed at outdoor pole locations for the purpose of bonding or grounding isolated sections of metal raceways or elbows installed in exposed risers of metal conduit or other metal raceway, shall not be limited in length and shall not be required to be routed with a raceway or enclosure. [250.102(E)(2) Exception]

~~E3908.20.3 Protection.~~

~~Bonding jumpers or conductors and equipment bonding jumpers shall be installed in accordance with Section E3610.2. [250.102(E)(3)]~~

~~SECTIONE3909~~
~~FLEXIBLE CORDS~~

~~E3909.1 Where permitted.~~

~~Flexible cords shall be used only for the connection of appliances where the fastening means and mechanical connections of such appliances are designed to permit ready removal for maintenance, repair or frequent interchange and the appliance is listed for flexible cord connection. Flexible cords shall not be installed as a substitute for the fixed wiring of a structure; shall not be run through holes in walls, structural ceilings, suspended ceilings, dropped ceilings or floors; shall not be concealed behind walls, floors, ceilings or located above suspended or dropped ceilings. (400.7 and 400.8)~~

~~E3909.2 Loading and protection.~~

~~The ampere load of flexible cords serving fixed appliances shall be in accordance with Table E3909.2. This table shall be used in conjunction with applicable end use product standards to ensure selection of the proper size and type. Where flexible cord is approved for and used with a specific listed appliance, it shall be considered to be protected where applied within the appliance listing requirements. [240.4, 240.5(A), 240.5(B)(1), 400.5, and 400.13]~~

~~TABLE E3909.2 [Table 400.5(A)(1)]~~

~~MAXIMUM AMPERE LOAD FOR FLEXIBLE CORDS~~

~~CORD SIZE (AWG)~~	~~CORD TYPES S, SE, SEO, SJ, SJE, SJEO, SJO, SJOO, SJT, SJTO, SJTOO, SO, SOO, SRD, SRDE, SRDT, ST, STD, SV, SVO, SVOO, SVTO, SVTOO~~	
	~~Maximum ampere load~~	
	~~Three current-carrying conductors~~	~~Two current-carrying conductors~~
~~18~~	~~7~~	~~10~~
~~16~~	~~10~~	~~13~~
~~14~~	~~15~~	~~18~~
~~12~~	~~20~~	~~25~~

E3909.3 Splices.

Flexible cord shall be used only in continuous lengths without splices or taps. (400.9)

E3909.4 Attachment plugs.

Where used in accordance with Section E3909.1, each flexible cord shall be equipped with an attachment plug and shall be energized from a receptacle outlet. [400.7(B)]

CHAPTER 40
DEVICES AND LUMINAIRES

RESERVED

SECTION E4001
SWITCHES

E4001.1Rating and application of snap switches.

General-use snap switches shall be used within their ratings and shall control only the following loads:

1. 1.Resistive and inductive loads not exceeding the ampere rating of the switch at the voltage involved.
2. 2.Tungsten-filament lamp loads not exceeding the ampere rating of the switch at 120 volts.
3. 3.Motor loads not exceeding 80 percent of the ampere rating of the switch at its rated voltage. [404.14(A)]

E4001.2CO/ALR snap switches.

Snap switches rated 20 amperes or less directly connected to aluminum conductors shall be marked CO/ALR. [404.14(C)]

E4001.3Indicating.

General-use and motor-circuit switches and circuit breakers shall clearly indicate whether they are in the open OFF or closed ON position. Where single-throw switches or circuit breaker handles are operated vertically rather than rotationally or horizontally, the up position of the handle shall be the closed (on) position.

E4001.4Time switches and similar devices.

Time switches and similar devices shall be of the enclosed type or shall be mounted in cabinets or boxes or equipment enclosures. A barrier shall be used around energized parts to prevent operator exposure when making manual adjustments or switching. (404.5)

E4001.5Grounding of enclosures.

Metal enclosures for switches or circuit breakers shall be connected to an equipment grounding conductor. Metal enclosures for switches or circuit breakers used as service equipment shall comply with the provisions of Section E3609.4. Where nonmetallic enclosures are used with metal raceways or metal-armored cables, provisions shall be made for connecting the equipment grounding conductor.

Nonmetallic boxes for switches shall be installed with a wiring method that provides or includes an equipment grounding conductor. (404.12)

E4001.6Access.

Switches and circuit breakers used as switches shall be located to allow operation from a readily accessible location. Such devices shall be installed so that the center of the grip of the operating handle of the switch or circuit breaker, when in its highest position, will not be more than 6 feet 7 inches (2007 mm) above the floor or working platform. [404.8(A)]

Exception: This section shall not apply to switches and circuit breakers that are accessible by portable means and are installed adjacent to the motors, appliances and other equipment that they supply. [404.8(A) Exception]

E4001.7Damp or wet locations.

A surface mounted switch or circuit breaker located in a damp or wet location or outside of a building shall be enclosed in a weatherproof enclosure or cabinet. A flush-mounted switch or circuit breaker in a damp or wet location shall be equipped with a weatherproof cover. Switches shall not be installed within wet locations in tub or shower spaces unless installed as part of a listed tub or shower assembly. [404.8(A), (B), and (C)]

E4001.8Grounded conductors.

Switches or circuit breakers shall not disconnect the grounded conductor of a circuit except where the switch or circuit breaker simultaneously disconnects all conductors of the circuit. [404.2(B)]

E4001.9Switch connections.

Three- and four-way switches shall be wired so that all switching occurs only in the ungrounded circuit conductor. Color coding of switch connection conductors shall comply with Section E3407.3. Where in metal raceways or metal-jacketed cables, wiring between switches and outlets shall be in accordance with Section E3406.7. [404.2(A)]

Exception: Switch loops do not require a grounded conductor. [404.2(A) Exception]

E4001.10Box mounted.

Flush-type snap switches mounted in boxes that are recessed from the finished wall surfaces as covered in Section E3906.5 shall be installed so that the extension plaster ears are seated against the surface of

~~the wall. Flush-type snap switches mounted in boxes that are flush with the finished wall surface or project therefrom shall be installed so that the mounting yoke or strap of the switch is seated against the box. Screws used for the purpose of attaching a snap switch to a box shall be of the type provided with a listed snap switch, or shall be machine screws having 32 threads per inch or part of listed assemblies or systems, in accordance with the manufacturer's instructions. [404.10(B)]~~

~~E4001.11Snap switch faceplates.~~

~~Faceplates provided for snap switches mounted in boxes and other enclosures shall be installed so as to completely cover the opening and, where the switch is flush mounted, seat against the finished surface. [404.9(A)]~~

~~E4001.11.1Faceplate grounding.~~

~~Snap switches, including dimmer and similar control switches, shall be connected to an equipment grounding conductor and shall provide a means to connect metal faceplates to the equipment grounding conductor, whether or not a metal faceplate is installed. Snap switches shall be considered to be part of an effective ground-fault current path if either of the following conditions is met:~~

4. ~~1.The switch is mounted with metal screws to a metal box or metal cover that is connected to an equipment grounding conductor or to a nonmetallic box with integral means for connecting to an equipment grounding conductor.~~
5. ~~2.An equipment grounding conductor or equipment bonding jumper is connected to an equipment grounding termination of the snap switch. [404.9(B)]~~

~~**Exceptions:**~~

6. ~~1.Where a means to connect to an equipment grounding conductor does not exist within the snap-switch enclosure or where the wiring method does not include or provide an equipment grounding conductor, a snap switch without a grounding connection to an equipment grounding conductor shall be permitted for replacement purposes only. A snap switch wired under the provisions of this exception and located within 8 feet (2438 mm) vertically or 5 feet (1524 mm) horizontally of ground or exposed grounded metal objects, shall be provided with a faceplate of nonconducting noncombustible material with nonmetallic attachment screws, except where the switch mounting strap or yoke is nonmetallic or the circuit is protected by a ground-fault circuit interrupter. [404.9(B) Exception No.1]~~
7. ~~2.Listed kits or listed assemblies shall not be required to be connected to an equipment grounding conductor if all of the following conditions apply:~~
    1. ~~2.1.The device is provided with a nonmetallic faceplate that cannot be installed on any other type of device.~~

~~2. 2.2.The device does not have mounting means to accept other configurations of faceplates.~~

~~3. 2.3.The device is equipped with a nonmetallic yoke.~~

~~4. 2.4.All parts of the device that are accessible after installation of the faceplate are manufactured of nonmetallic materials. [404.9(B) Exception No. 2]~~

~~8. 3.Connection to an equipment grounding conductor shall not be required for snap switches that have an integral nonmetallic enclosure complying with Section E3905.1.3. [404.9(B) Exception No. 3]~~

~~E4001.12Dimmer switches.~~

~~General-use dimmer switches shall be used only to control permanently installed incandescent luminaires (lighting fixtures) except where listed for the control of other loads and installed accordingly. [404.14(E)]~~

~~E4001.13Multipole snap switches.~~

~~A multipole, general-use snap switch shall not be fed from more than a single circuit unless it is listed and marked as a two-circuit or three-circuit switch. [404.8(C)]~~

~~E4001.14Cord-and-plug-connected loads.~~

~~Where snap switches are used to control cord-and-plug-connected equipment on a general-purpose branch circuit, each snap switch controlling receptacle outlets or cord connectors that are supplied by permanently connected cord pendants shall be rated at not less than the rating of the maximum permitted ampere rating or setting of the overcurrent device protecting the receptacles or cord connectors, as provided in Sections E4002.1.1 and E4002.1.2. [404.14(F)]~~

~~E4001.15Switches controlling lighting loads.~~

~~The grounded circuit conductor for the controlled lighting circuit shall be provided at the location where switches control lighting loads that are supplied by a grounded general-purpose branch circuit for other than the following:~~

~~9. 1.Where conductors enter the box enclosing the switch through a raceway, provided that the raceway is large enough for all contained conductors, including a grounded conductor.~~

~~10. 2.Where the box enclosing the switch is accessible for the installation of an additional or replacement cable without removing finish materials.~~

~~11. 3.Where snap switches with integral enclosures comply with E3905.1.3.~~

~~12. 4.Where the switch does not serve a habitable room or bathroom.~~

~~13. 5.Where multiple switch locations control the same lighting load such that the entire floor area of the room or space is visible from the single or combined switch locations.~~

~~14. 6.Where lighting in the area is controlled by automatic means.~~

~~15. 7.Where the switch controls a receptacle load. [404.2(C)]~~

~~**SECTION**E4002~~
~~RECEPTACLES~~

~~E4002.1Rating and type.~~

~~Receptacles and cord connectors shall be rated at not less than 15 amperes, 125 volts, or 15 amperes, 250 volts, and shall not be a lampholder type. Receptacles shall be rated in accordance with this section. [406.3(B)]~~

~~E4002.1.1Single receptacle.~~

~~A single receptacle installed on an individual branch circuit shall have an ampere rating not less than that of the branch circuit. [210.21(B)]~~

~~E4002.1.2Two or more receptacles.~~

~~Where connected to a branch circuit supplying two or more receptacles or outlets, receptacles shall conform to the values listed in Table E4002.1.2. [210.21(B)(3)]~~

~~TABLE E4002.1.2 [Table 210.21(B)(3)]~~

~~RECEPTACLE RATINGS FOR VARIOUS SIZE MULTI-OUTLET CIRCUITS~~

~~**CIRCUIT RATING (amperes)**~~	~~**RECEPTACLE RATING (amperes)**~~
~~15~~	~~15~~
~~20~~	~~15 or 20~~
~~30~~	~~30~~
~~40~~	~~40 or 50~~
~~50~~	~~50~~

~~E4002.2Grounding type.~~

~~Receptacles installed on 15- and 20-ampere-rated branch circuits shall be of the grounding type. [406.4(A)]~~

~~E4002.3CO/ALR receptacles.~~

~~Receptacles rated at 20 amperes or less and directly connected to aluminum conductors shall be marked CO/ALR. [406.3(C)]~~

~~E4002.4Faceplates.~~

~~Metal face plates shall be grounded. [406.6(B)]~~

~~E4002.5Position of receptacle faces.~~

~~After installation, receptacle faces shall be flush with or project from face plates of insulating material and shall project a minimum of 0.015 inch (0.381 mm) from metal face plates. Faceplates shall be installed so as to completely cover the opening and seat against the mounting surface. Receptacle faceplates mounted inside of a box having a recess-mounted receptacle shall effectively close the opening and seat against the mounting surface. [406.5(D), 406.6]~~

~~**Exception:** Listed kits or assemblies encompassing receptacles and nonmetallic faceplates that cover the receptacle face, where the plate cannot be installed on any other receptacle, shall be permitted. [406.5(D) Exception]~~

~~E4002.6Receptacle mounted in boxes.~~

~~Receptacles mounted in boxes that are set back from the finished wall surface as permitted by Section E3906.5 shall be installed so that the mounting yoke or strap of the receptacle is held rigidly at the finished surface of the wall. Screws used for the purpose of attaching receptacles to a box shall be of the type provided with a listed receptacle, or shall be machine screws having 32 threads per inch or part of listed assemblies or systems, in accordance with the manufacturer's instructions. Receptacles mounted in boxes that are flush with the wall surface or project therefrom shall be so installed that the mounting yoke or strap is seated against the box or raised cover. [406.5(A) and (B)]~~

~~E4002.7Receptacles mounted on covers.~~

~~Receptacles mounted to and supported by a cover shall be held rigidly against the cover by more than one screw or shall be a device assembly or box cover listed and identified for securing by a single screw. [406.5(C)]~~

~~E4002.8Damp locations.~~

~~A receptacle installed outdoors in a location protected from the weather or in other damp locations shall have an enclosure for the receptacle that is weatherproof when the receptacle cover(s) is closed and an attachment plug cap is not inserted. An installation suitable for wet locations shall also be considered suitable for damp locations. A receptacle shall be considered to be in a location protected from the weather where located under roofed open porches, canopies and similar structures and not subject to rain or water runoff. Fifteen- and 20-ampere, 125- and 250-volt nonlocking receptacles installed in damp locations shall be listed a weather-resistant type. [406.9(A)]~~

E4002.9Fifteen- and 20-ampere receptacles in wet locations.

Where installed in a wet location, 15- and 20-ampere, 125- and 250-volt receptacles shall have an enclosure that is weatherproof whether or not the attachment plug cap is inserted. An outlet box hood installed for this purpose shall be listed and identified as "extra-duty." Fifteen- and 20-ampere, 125- and 250-volt nonlocking receptacles installed in wet locations shall be a listed weather-resistant type. [406.9(B)(1)]

E4002.10Other receptacles in wet locations.

Where a receptacle other than a 15- or 20-amp, 125- or 250-volt receptacle is installed in a wet location and where the product intended to be plugged into it is not attended while in use, the receptacle shall have an enclosure that is weatherproof both when the attachment plug cap is inserted and when it is removed. Where such receptacle is installed in a wet location and where the product intended to be plugged into it will be attended while in use, the receptacle shall have an enclosure that is weatherproof when the attachment plug cap is removed. [406.9(B)(2)]

E4002.11Bathtub and shower space.

A receptacle shall not be installed within or directly over a bathtub or shower stall. [406.9(C)]

E4002.12Flush mounting with faceplate.

In damp or wet locations, the enclosure for a receptacle installed in an outlet box flush-mounted in a finished surface shall be made weatherproof by means of a weatherproof faceplate assembly that provides a water-tight connection between the plate and the finished surface. [406.9(E)]

E4002.13Exposed terminals.

Receptacles shall be enclosed so that live wiring terminals are not exposed to contact. [406.5(G)]

E4002.14Tamper-resistant receptacles.

In areas specified in Section E3901.1, 125-volt, 15- and 20-ampere receptacles shall be listed tamper-resistant receptacles. [406.12(A)]

Exception: Receptacles in the following locations shall not be required to be tamper resistant:

16. 1.Receptacles located more than 5.5 feet (1676 mm) above the floor.

17. 2.Receptacles that are part of a luminaire or appliance.

18. 3.A single receptacle for a single appliance or a duplex receptacle for two appliances where such receptacles are located in spaces dedicated for the appliances served and, under conditions of normal use, the appliances are not easily moved from one place to another. The appliances shall be cord-and-plug connected to such receptacles in accordance with Section E3909.4. [406.12(A) Exception]

~~E4002.15 Dimmer-controlled receptacles.~~

~~A receptacle supplying lighting loads shall not be connected to a dimmer except where the plug and receptacle combination is a nonstandard configuration type that is specifically listed and identified for each such unique combination.~~

~~**SECTION** E4003~~
~~LUMINAIRES~~

~~E4003.1 Energized parts.~~

~~Luminaires, lampholders, and lamps shall not have energized parts normally exposed to contact. (410.5)~~

~~E4003.2 Luminaires near combustible material.~~

~~Luminaires shall be installed or equipped with shades or guards so that combustible material will not be subjected to temperatures in excess of 90°C (194°F). (410.11)~~

~~E4003.3 Exposed conductive parts.~~

~~The exposed metal parts of luminaires shall be connected to an equipment grounding conductor or shall be insulated from the equipment grounding conductor and other conducting surfaces. Lamp tie wires, mounting screws, clips and decorative bands on glass spaced at least 1$^1/_2$ inches (38 mm) from lamp terminals shall not be required to be grounded. (410.42)~~

~~E4003.4 Screw-shell type.~~

~~Lampholders of the screw-shell type shall be installed for use as lampholders only. (410.90)~~

~~E4003.5 Recessed incandescent luminaires.~~

~~Recessed incandescent luminaires shall have thermal protection and shall be listed as thermally protected. [410.115(C)]~~

~~**Exceptions:**~~

19. ~~1.Thermal protection shall not be required in recessed luminaires listed for the purpose and installed in poured concrete. [410.115(C) Exception No.1]~~
20. ~~2.Thermal protection shall not be required in recessed luminaires having design, construction, and thermal performance characteristics equivalent to that of thermally protected luminaires, and such luminaires are identified as inherently protected. [410.115(C) Exception No. 2]~~

~~E4003.6 Thermal protection.~~

~~The ballast of a fluorescent luminaire installed indoors shall have integral thermal protection. Replacement ballasts shall also have thermal protection integral with the ballast. A simple reactance~~

ballast in a fluorescent luminaire with straight tubular lamps shall not be required to be thermally protected. [410.130(E)(1)]

E4003.7High-intensity discharge luminaires.

Recessed high-intensity luminaires designed to be installed in wall or ceiling cavities shall have thermal protection and be identified as thermally protected. Thermal protection shall not be required in recessed high-intensity luminaires having design, construction and thermal performance characteristics equivalent to that of thermally protected luminaires, and such luminaires are identified as inherently protected. Thermal protection shall not be required in recessed high-intensity discharge luminaires installed in and identified for use in poured concrete. A recessed remote ballast for a high-intensity discharge luminaire shall have thermal protection that is integral with the ballast and shall be identified as thermally protected. [110.130(F)(1), (2), (3), and (4)]

E4003.8Metal halide lamp containment.

Luminaires that use a metal halide lamp other than a thick-glass parabolic reflector lamp (PAR) shall be provided with a containment barrier that encloses the lamp, or shall be provided with a physical means that allows the use of only a lamp that is Type O. [(110.130(F)(5)]

E4003.9Wet or damp locations.

Luminaires installed in wet or damp locations shall be installed so that water cannot enter or accumulate in wiring compartments, lampholders or other electrical parts. All luminaires installed in wet locations shall be marked SUITABLE FOR WET LOCATIONS. All luminaires installed in damp locations shall be marked SUITABLE FOR WET LOCATIONS or SUITABLE FOR DAMP LOCATIONS. (410.10)

E4003.10Lampholders in wet or damp locations.

Lampholders installed in wet locations shall be listed for use in wet locations. Lampholders installed in damp locations shall be listed for damp locations or shall be listed for wet locations. (410.96)

E4003.11Bathtub and shower areas.

Cord-connected luminaires, chain-, cable-, or cord-suspended-luminaires, lighting track, pendants, and ceiling-suspended (paddle) fans shall not have any parts located within a zone measured 3 feet (914 mm) horizontally and 8 feet (2438 mm) vertically from the top of a bathtub rim or shower stall threshold. This zone is all encompassing and includes the space directly over the tub or shower. Luminaires within the actual outside dimension of the bathtub or shower to a height of 8 feet (2438 mm) vertically from the top of the bathtub rim or shower threshold shall be marked for damp locations and where subject to shower spray, shall be marked for wet locations. [410.4(D)]

E4003.12Luminaires in clothes closets.

For the purposes of this section, storage space shall be defined as a volume bounded by the sides and back closet walls and planes extending from the closet floor vertically to a height of 6 feet (1829 mm) or

~~the highest clothes-hanging rod and parallel to the walls at a horizontal distance of 24 inches (610 mm) from the sides and back of the closet walls respectively, and continuing vertically to the closet ceiling parallel to the walls at a horizontal distance of 12 inches (305 mm) or the width of the shelf, whichever is greater. For a closet that permits access to both sides of a hanging rod, the storage space shall include the volume below the highest rod extending 12 inches (305 mm) on either side of the rod on a plane horizontal to the floor extending the entire length of the rod (see Figure E4003.12). (410.2)~~

~~The types of luminaires installed in clothes closets shall be limited to surface-mounted or recessed incandescent or LED luminaires with completely enclosed light sources, surface-mounted or recessed fluorescent luminaires, and surface-mounted fluorescent or LED luminaires identified as suitable for installation within the closet storage area. Incandescent luminaires with open or partially enclosed lamps and pendant luminaires or lamp-holders shall be prohibited. The minimum clearance between luminaires installed in clothes closets and the nearest point of a closet storage area shall be as follows: [410.16(A) and (B)]~~

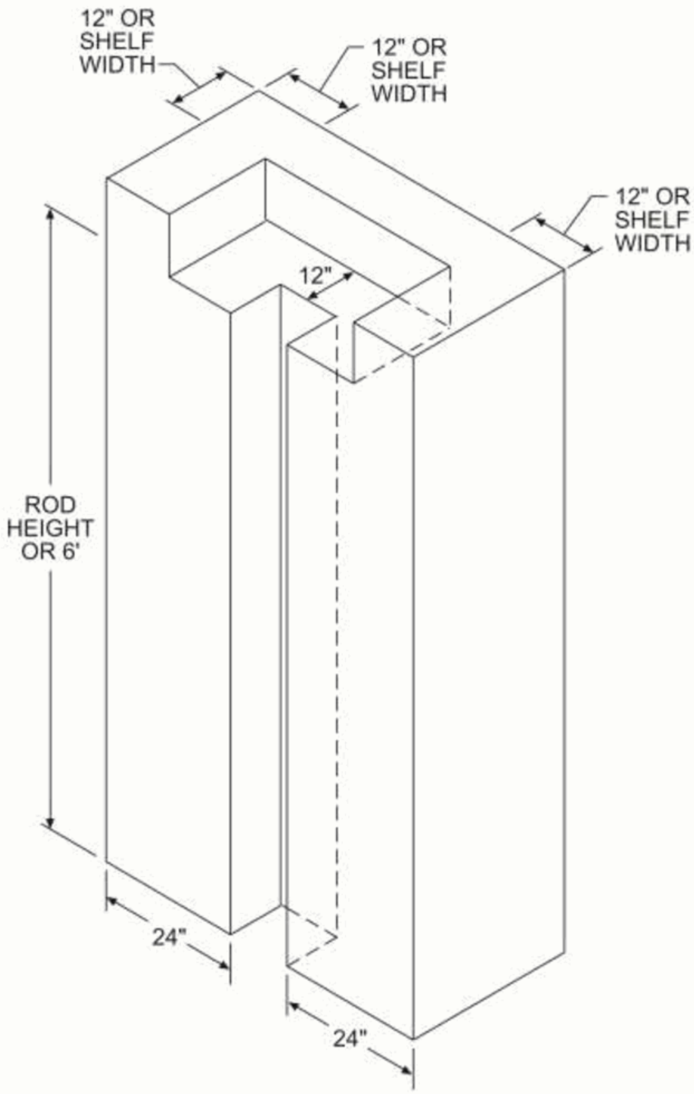
~~21. 1.Surface-mounted incandescent or LED luminaires with a completely enclosed light source shall be installed on the wall above the door or on the ceiling, provided that there is a minimum clearance of 12 inches (305 mm) between the fixture and the nearest point of a storage space.~~

~~22. 2.Surface-mounted fluorescent luminaires shall be installed on the wall above the door or on the ceiling, provided that there is a minimum clearance of 6 inches (152 mm).~~

~~23. 3.Recessed incandescent luminaires or LED luminaires with a completely enclosed light source shall be installed in the wall or the ceiling provided that there is a minimum clearance of 6 inches (152 mm).~~

~~24. 4.Recessed fluorescent luminaires shall be installed in the wall or on the ceiling provided that there is a minimum clearance of 6 inches (152 mm) between the fixture and the nearest point of a storage space.~~

~~25. 5.Surface-mounted fluorescent or LED luminaires shall be permitted to be installed within the closet storage space where identified for this use. [410.16(C)]~~



~~For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.~~

~~FIGURE E4003.12~~

~~CLOSET STORAGE SPACE~~

~~E4003.13Luminaire wiring—general.~~

~~Wiring on or within luminaires shall be neatly arranged and shall not be exposed to physical damage. Excess wiring shall be avoided. Conductors shall be arranged so that they are not subjected to temperatures above those for which the conductors are rated. (410.48)~~

~~E4003.13.1Polarization of luminaires.~~

~~Luminaires shall be wired so that the screw shells of lampholders will be connected to the same luminaire or circuit conductor or terminal. The grounded conductor shall be connected to the screw shell.~~

~~E4003.13.2Luminaires as raceways.~~

~~Luminaires shall not be used as raceways for circuit conductors except where such luminaires are listed and marked for use as a raceway or are identified for through-wiring. Luminaires designed for end-to-end connection to form a continuous assembly, and luminaires connected together by recognized wiring methods, shall not be required to be listed as a raceway where they contain the conductors of one 2-wire branch circuit or one multiwire branch circuit and such conductors supply the connected luminaires. One additional 2-wire branch circuit that separately supplies one or more of the connected luminaires shall also be permitted. [410.64(A), (B), and (C)]~~

~~**SECTION**E4004~~
~~LUMINAIRE INSTALLATION~~

~~E4004.1Outlet box covers.~~

~~In a completed installation, each outlet box shall be provided with a cover except where covered by means of a luminaire canopy, lampholder or device with a faceplate. (410.22)~~

~~E4004.2Combustible material at outlet boxes.~~

~~Combustible wall or ceiling finish exposed between the inside edge of a luminaire canopy or pan and the outlet box and having a surface area of 180 in.^{2} (116 129 mm^2) or more shall be covered with a noncombustible material. (410.23)~~

~~E4004.3Access.~~

~~Luminaires shall be installed so that the connections between the luminaire conductors and the circuit conductors can be accessed without requiring the disconnection of any part of the wiring. Luminaires that are connected by attachment plugs and receptacles meet the requirement of this section. (410.8)~~

~~E4004.4Supports.~~

~~Luminaires and lampholders shall be securely supported. A luminaire that weighs more than 6 pounds (2.72 kg) or exceeds 16 inches (406 mm) in any dimension shall not be supported by the screw shell of a lampholder. [410.30(A)]~~

~~E4004.5Means of support.~~

~~Outlet boxes or fittings installed as required by Sections E3905 and E3906 shall be permitted to support luminaires. [410.36(A)]~~

~~E4004.6Exposed components.~~

~~Luminaires having exposed ballasts, transformers, LED drivers or power supplies shall be installed so that such ballasts, transformers, LED drivers or power supplies are not in contact with combustible material unless listed for such condition. [410.136(A)]~~

~~E4004.7Combustible low-density cellulose fiberboard.~~

~~Where a surface-mounted luminaire containing a ballast, transformer, LED driver or power supply is installed on combustible low-density cellulose fiberboard, the luminaire shall be marked for this purpose or it shall be spaced not less than 1 1/2 inches (38 mm) from the surface of the fiberboard. Where such luminaires are partially or wholly recessed, the provisions of Sections E4004.8 and E4004.9 shall apply. [410.136(B)]~~

~~E4004.8Recessed luminaire clearance.~~

~~A recessed luminaire that is not identified for contact with insulation shall have all recessed parts spaced at least 1/2 inch (12.7 mm) from combustible materials. The points of support and the finish trim parts at the opening in the ceiling, wall or other finished surface shall be permitted to be in contact with combustible materials. A recessed luminaire that is identified for contact with insulation, Type IC, shall be permitted to be in contact with combustible materials at recessed parts, points of support, and portions passing through the building structure and at finish trim parts at the opening in the ceiling or wall. [410.116(A)(1) and (A)(2)]~~

~~E4004.9Recessed luminaire installation.~~

~~Thermal insulation shall not be installed above a recessed luminaire or within 3 inches (76 mm) of the recessed luminaire's enclosure, wiring compartment, ballast, transformer, LED driver or power supply except where such luminaire is identified for contact with insulation, Type IC. [410.116(B)]~~

~~**SECTION**E4005~~
~~TRACK LIGHTING~~

~~E4005.1Installation.~~

~~Lighting track shall be permanently installed and permanently connected to a branch circuit having a rating not more than that of the track. [410.151(A) and (B)]~~

~~E4005.2Fittings.~~

~~Fittings identified for use on lighting track shall be designed specifically for the track on which they are to be installed. Fittings shall be securely fastened to the track, shall maintain polarization and connection to the equipment grounding conductor, and shall be designed to be suspended directly from the track. Only lighting track fittings shall be installed on lighting track. Lighting track fittings shall not be equipped with general-purpose receptacles. [410.151(A) and (B)]~~

E4005.3Connected load.

The connected load on lighting track shall not exceed the rating of the track. [410.151(B)]

E4005.4Prohibited locations.

Lighting track shall not be installed in the following locations:

26. 1.Where likely to be subjected to physical damage.

27. 2.In wet or damp locations.

28. 3.Where subject to corrosive vapors.

29. 4.In storage battery rooms.

30. 5.In hazardous (classified) locations.

31. 6.Where concealed.

32. 7.Where extended through walls or partitions.

33. 8.Less than 5 feet (1524 mm) above the finished floor except where protected from physical damage or the track operates at less than 30 volts rms open-circuit voltage.

34. 9.Where prohibited by Section E4003.11. [410.151(C)]

E4005.5Fastening.

Lighting track shall be securely mounted so that each fastening will be suitable for supporting the maximum weight of luminaires that can be installed. Except where identified for supports at greater intervals, a single section 4 feet (1219 mm) or shorter in length shall have two supports and, where installed in a continuous row, each individual section of not more than 4 feet (1219 mm) in length shall have one additional support. (410.154)

E4005.6Grounding.

Lighting track shall be grounded in accordance with Chapter 39, and the track sections shall be securely coupled to maintain continuity of the circuitry, polarization and grounding throughout. [410.155(B)]

CHAPTER 41
APPLIANCE INSTALLATION

RESERVED

SECTIONE4101
GENERAL

E4101.1Scope.

~~This section covers installation requirements for appliances and fixed heating equipment. (422.1 and 424.1)~~

~~E4101.2Installation.~~

~~Appliances and equipment shall be installed in accordance with the manufacturer's installation instructions. Electrically heated appliances and equipment shall be installed with the required clearances to combustible materials. [110.3(B) and 422.17]~~

~~E4101.3Flexible cords.~~

~~Cord-and-plug-connected appliances shall use cords suitable for the environment and physical conditions likely to be encountered. Flexible cords shall be used only where the appliance is listed to be connected with a flexible cord. The cord shall be identified as suitable in the installation instructions of the appliance manufacturer. Receptacles for cord-and-plug-connected appliances shall be accessible and shall be located to avoid physical damage to the flexible cord. Except for a listed appliance marked to indicate that it is protected by a system of double-insulation, the flexible cord supplying an appliance shall terminate in a grounding-type attachment plug. A receptacle for a cord-andplug-connected range hood shall be supplied by an individual branch circuit. Specific appliances have additional requirements as specified in Table E4101.3 (see Section E3909). [422.16(B)(1), (B)(2)]~~

~~TABLE E4101.3~~

~~FLEXIBLE CORD LENGTH~~

~~**APPLIANCE**~~	~~**MINIMUM CORD LENGTH (inches)**~~	~~**MAXIMUM CORD LENGTH (inches)**~~
~~Electrically operated in-sink waste disposal~~	~~18~~	~~36~~
~~Built-in dishwasher~~	~~36~~	~~48~~
~~Trash compactor~~	~~36~~	~~48~~
~~Range hoods~~	~~18~~	~~36~~

~~For SI: 1 inch = 25.4 mm.~~

~~E4101.4Overcurrent protection.~~

~~Each appliance shall be protected against overcurrent in accordance with the rating of the appliance and its listing. [110.3(B), 422.11(A)]~~

~~E4101.4.1Single nonmotor-operated appliance.~~

~~The overcurrent protection for a branch circuit that supplies a single nonmotor-operated appliance shall not exceed that marked on the appliance. Where the overcurrent protection rating is not marked and the appliance is rated at over 13.3 amperes, the overcurrent protection shall not exceed 150 percent of the appliance rated current. Where 150 percent of the appliance rating does not correspond to a standard overcurrent device ampere rating, the next higher standard rating shall be permitted. Where the overcurrent protection rating is not marked and the appliance is rated at 13.3 amperes or less, the overcurrent protection shall not exceed 20 amperes. [422.11(E)]~~

~~E4101.5Disconnecting means.~~

~~Each appliance shall be provided with a means to disconnect all ungrounded supply conductors. For fixed electric space-heating equipment, means shall be provided to disconnect the heater and any motor controller(s) and supplementary overcurrent-protective devices. Switches and circuit breakers used as a disconnecting means shall be of the indicating type. Disconnecting means shall be as set forth in Table E4101.5. (422.30, 422.35, and 424.19)~~

~~TABLE E4101.5~~

~~DISCONNECTING MEANS [422.31(A), (B), and (C); 422.34; 422.35; 424.19; 424.20; and 440.14]~~

~~**DESCRIPTION**~~	~~**ALLOWED DISCONNECTING MEANS**~~
~~Permanently connected appliance rated at not over 300 volt-amperes or $^1/_8$ horsepower.~~	~~Branch-circuit overcurrent device.~~
~~Permanently connected appliances rated in excess of 300 volt-amperes.~~	~~Branch circuit breaker or switch located within sight of appliance or such devices in any location that are capable of being locked in the open position. The provision for locking or adding a lock to the disconnecting means shall be installed on or at the switch or circuit breaker used as the disconnecting means and shall remain in place with or without the lock installed.~~
~~Motor-operated appliances rated over $^1/_8$ horsepower.~~	~~For permanently connected motor-operated appliances with motors rated over $^1/_8$ horsepower, the branch-circuit switch or circuit breaker shall be permitted to serve as the disconnecting means where the switch or circuit breaker is within sight from the appliance. Where the branch circuit switch is not located within sight from the appliance, the disconnecting means shall be one of the following types: a listed motor-circuit switch rated in horsepower, a listed molded case circuit breaker, a listed molded case switch, a listed manual motor controller additionally marked "Suitable as Motor Disconnect" where installed~~

~~between the final motor branch-circuit short circuit protective device and the motor. For stationary motors rated at 2 hp or less and 300 volts or less, the disconnecting means shall be permitted to be one of the following devices:~~

1. ~~1.A general-use switch having an ampere rating not less than twice the full-load current rating of the motor.~~
2. ~~2.On AC circuits, a general-use snap switch suitable only for use on AC, not general-use AC—DC snap switches, where the motor full-load current rating is not more than 80 percent of the ampere rating of the switch.~~
3. ~~3.A listed manual motor controller having a horsepower rating not less than the rating of the motor and marked "Suitable as Motor Disconnect".~~

~~The disconnecting means for motor circuits rated 600 volts, nominal, or less shall have an ampere rating not less than 115 percent of the full-load current rating of the motor except that a listed unfused motor-circuit switch having a horsepower rating not less than the motor horsepower shall be permitted to have an ampere rating less than 115 percent of the full-load current rating of the motor. The disconnecting means shall be installed within sight of the appliance.~~

~~**Exception:** A unit switch with a marked-off position that is a part of an appliance and disconnects all ungrounded conductors shall be permitted as the disconnecting means and the switch or circuit breaker serving as the other disconnecting means shall be permitted to be out of sight from the appliance.~~

~~Appliances listed for cord-and-plug connection.~~	~~A separable connector or attachment plug and receptacle provided with access.~~
~~Permanently installed heating equipment with motors rated at not over 1/8 horsepower with supplementary overcurrent protection.~~	~~Disconnect, on the supply side of fuses, in sight from the supplementary overcurrent device, and in sight of the heating equipment or, in any location, if capable of being locked in the open position.~~
~~Heating equipment containing motors rated over 1/8 horsepower with~~	~~Disconnect permitted to serve as required disconnect for both the heating equipment and the controller where, on the supply side of fuses, and in sight from the supplementary overcurrent devices, if the~~

~~supplementary overcurrent protection.~~	~~disconnecting means is also in sight from the controller, or is capable of being locked off and simultaneously disconnects the heater, motor controller(s) and supplementary overcurrent protective devices from all ungrounded conductors. The provision for locking or adding a lock to the disconnecting means shall be installed on or at the switch or circuit breaker used as the disconnecting means and shall remain in place with or without the lock installed. The disconnecting means shall have an ampere rating not less than 125 percent of the total load of the motors and the heaters.~~
~~Heating equipment containing no motor rated over $^1/_8$ horsepower without supplementary overcurrent protection.~~	~~Branch-circuit switch or circuit breaker where within sight from the heating equipment or capable of being locked off and simultaneously disconnects the heater, motor controller(s) and supplementary overcurrent protective devices from all ungrounded conductors. The provision for locking or adding a lock to the disconnecting means shall be installed on or at the switch or circuit breaker used as the disconnecting means and shall remain in place with or without the lock installed. The disconnecting means shall have an ampere rating not less than 125 percent of the total load of the motors and the heaters.~~
~~Heating equipment containing motors rated over $^1/_8$ horsepower without supplementary overcurrent protection.~~	~~Disconnecting means in sight from motor controller or as provided for heating equipment with motor rated over $^1/_8$ horsepower with supplementary overcurrent protection and simultaneously disconnects the heater, motor controller(s) and supplementary overcurrent protective devices from all ungrounded conductors. The provision for locking or adding a lock to the disconnecting means shall be installed on or at the switch or circuit breaker used as the disconnecting means and shall remain in place with or without the lock installed. The disconnecting means shall have an ampere rating not less than 125 percent of the total load of the motors and the heaters.~~
~~Air-conditioning condensing units and heat pump units.~~	~~A readily accessible disconnect *within sight* from unit as the only allowable means.[a]~~
~~Appliances and fixed heating equipment with unit switches having a marked OFF position.~~	~~Unit switch where an additional individual switch or circuit breaker serves as a redundant disconnecting means.~~
~~Thermostatically controlled fixed heating equipment.~~	~~Thermostats with a marked OFF position that directly open all ungrounded conductors, which when manually placed in the OFF position are designed so that the circuit cannot be energized~~

~~automatically and that are located *within sight* of the equipment controlled.~~

~~For SI: 1 horsepower = 0.746 kW.~~

~~4. a.The disconnecting means shall be permitted to be installed on or within the unit. It shall not be located on panels designed to allow access to the unit or located so as to obscure the air-conditioning equipment nameplate(s).~~

~~E4101.6Support of ceiling-suspended paddle fans.~~

~~Ceiling suspended fans (paddle) shall be supported independently of an outlet box or by a listed outlet box or outlet box system identified for the use and installed in accordance with Section E3905.8. (422.18)~~

~~E4101.7Snow-melting and deicing equipment protection.~~

~~Outdoor receptacles that are not readily accessible and are supplied from a dedicated branch circuit for electric snow-melting or deicing equipment shall be permitted to be installed without ground-fault circuit-interrupter protection for personnel. However, ground-fault protection of equipment shall be provided for fixed outdoor electric deicing and snow-melting equipment. [210.8(A)(3) Exception, 426.28]~~

CHAPTER 42
SWIMMING POOLS [ELECTRICAL PROVISIONS]

RESERVED

~~**SECTION**E4201~~
~~GENERAL~~

~~E4201.1Scope.~~

~~The provisions of this chapter shall apply to the construction and installation of electric wiring and equipment associated with all swimming pools, wading pools, decorative pools, fountains, hot tubs and spas, and hydromassage bathtubs, whether permanently installed or storable, and shall apply to metallic auxiliary equipment, such as pumps, filters and similar equipment. Sections E4202 through E4206 provide general rules for permanent pools, spas and hot tubs. Section E4207 provides specific rules for storable pools and storable/portable spas and hot tubs. Section E4208 provides specific rules for spas and hot tubs. Section E4209 provides specific rules for hydromassage bathtubs. (680.1)~~

~~E4201.2Definitions.~~

~~(680.2)~~

~~**CORD-AND-PLUG CONNECTED LIGHTING ASSEMBLY.** A lighting assembly consisting of a cord-and-plug-connected transformer and a luminaire intended for installation in the wall of a spa, hot tub, or storable pool.~~

~~**DRY-NICHE LUMINAIRE.** A luminaire intended for installation in the floor or wall of a pool, spa or fountain in a niche that is sealed against the entry of water.~~

~~**FORMING SHELL.** A structure designed to support a wet-niche luminaire assembly and intended for mounting in a pool or fountain structure.~~

~~**FOUNTAIN.** Fountains, ornamental pools, display pools, and reflection pools. The definition does not include drinking fountains.~~

~~**HYDROMASSAGE BATHTUB.** A permanently installed bathtub equipped with a recirculating piping system, pump, and associated equipment. It is designed so it can accept, circulate and discharge water upon each use.~~

~~**LOW-VOLTAGE CONTACT LIMIT.** A voltage not exceeding the following values:~~

1. ~~1.15 volts (RMS) for sinusoidal AC~~
2. ~~2.21.2 volts peak for nonsinusoidal AC~~
3. ~~3.30 volts for continuous DC~~
4. ~~4.12.4 volts peak for DC that is interrupted at a rate of 10 to 200 Hz~~

~~**MAXIMUM WATER LEVEL.** The highest level that water can reach before it spills out.~~

~~**NO-NICHE LUMINAIRE.** A luminaire intended for installation above or below the water without a niche.~~

~~**PACKAGED SPA OR HOT TUB EQUIPMENT ASSEMBLY.** A factory-fabricated unit consisting of water-circulating, heating and control equipment mounted on a common base, intended to operate a spa or hot tub. Equipment may include pumps, air blowers, heaters, luminaires, controls and sanitizer generators.~~

~~**PERMANENTLY INSTALLED SWIMMING, WADING, IMMERSION AND THERAPEUTIC POOLS.** Those that are constructed in the ground or partially in the ground, and all others capable of holding water with a depth greater than 42 inches (1067 mm), and all pools installed inside of a building, regardless of water depth, whether or not served by electrical circuits of any nature.~~

~~**POOL.** Manufactured or field-constructed equipment designed to contain water on a permanent or semipermanent basis and used for swimming, wading, immersion, or therapeutic purposes.~~

~~**POOL COVER, ELECTRICALLY OPERATED.** Motor-driven equipment designed to cover and uncover the water surface of a pool by means of a flexible sheet or rigid frame.~~

~~**SELF-CONTAINED SPA OR HOT TUB.** A factory-fabricated unit consisting of a spa or hot tub vessel with all water-circulating, heating and control equipment integral to the unit. Equipment may include pumps, air blowers, heaters, luminaires, controls and sanitizer generators.~~

~~**SPA OR HOT TUB.** A hydromassage pool, or tub for recreational or therapeutic use, not located in health care facilities, designed for immersion of users, and usually having a filter, heater, and motor-driven blower. They are installed indoors or outdoors, on the ground or supporting structure, or in the ground or supporting structure. Generally, a spa or hot tub is not designed or intended to have its contents drained or discharged after each use.~~

~~**STORABLE SWIMMING, WADING OR IMMERSION POOLS; OR STORABLE/PORTABLE SPAS AND HOT TUBS.** Those that are constructed on or above the ground and are capable of holding water with a maximum depth of 42 inches (1067 mm), or a pool with nonmetallic, molded polymeric walls or inflatable fabric walls regardless of dimension~~

~~**THROUGH-WALL LIGHTING ASSEMBLY.** A lighting assembly intended for installation above grade, on or through the wall of a pool, consisting of two interconnected groups of components separated by the pool wall.~~

~~**WET-NICHE LUMINAIRE.** A luminaire intended for installation in a forming shell mounted in a pool or fountain structure where the luminaire will be completely surrounded by water.~~

~~**SECTION**E4202~~
~~WIRING METHODS FOR POOLS, SPAS, HOT TUBS~~
~~AND HYDROMASSAGE BATHTUBS~~

~~E4202.1General.~~

~~Wiring methods used in conjunction with permanently installed swimming pools, spas, hot tubs or hydromassage bathtubs shall be installed in accordance with Table E4202.1 and Chapter 38 except as otherwise stated in this section. Storable swimming pools shall comply with Section E4207. [680.7; 680.21(A); 680.23(B) and (F); 680.25(A); 680.42; 680.43; and 680.70]~~

~~TABLE E4202.1~~

~~ALLOWABLE APPLICATIONS FOR WIRING METHODS[a, b, c, d, e, f, g, h, k]~~

~~**WIRING LOCATION OR PURPOSE(Application allowed where marked with an "A")**~~	~~**AC, FMC,NM, SR, SE**~~	~~**EMT**~~	~~**ENT**~~	~~**IMC[i]RNC[i], RMC[h],**~~	~~**LFMC**~~	~~**LFNMC**~~	~~**UF**~~	~~**MC[j]**~~	~~**FLEXCORD**~~
~~Panelboard(s) that supply pool equipment: from service equipment to panelboard~~	~~A[b, e]SR not permitted~~	~~A[c]~~	~~A[b]~~	~~A~~	~~—~~	~~A~~	~~A[e]~~	~~A[e]~~	~~—~~

~~Wet-niche and no-niche luminaires: frombranch circuit OCPD to deck or junction box~~	~~AC[b] only~~	~~A[c]~~	~~A[b]~~	~~A~~	—	~~A~~	—	~~A[b]~~	—
~~Wet-niche and no-niche luminaires: from deck or junction box to forming shell~~	—	—	—	~~A[d]~~	—	~~A~~	—	—	~~A[g]~~
~~Dry niche: from branch circuit OCPD to luminaires~~	~~AC[b] only~~	~~A[c]~~	~~A[b]~~	~~A~~	—	~~A~~	—	~~A[b]~~	—
~~Pool-associated motors: from branch circuit OCPD to motor~~	~~A[b]~~	~~A[c]~~	~~A[b]~~	~~A~~	~~A[e]~~	~~A[e]~~	~~A[b]~~	~~A~~	~~A[g]~~
~~Packaged or self-contained outdoor spas and hot tubs with underwater luminaire: from branch circuit OCPD to spa or hot tub~~	~~AC[b] only~~	~~A[c]~~	~~A[b]~~	~~A~~	~~A[f]~~	~~A[f]~~	—	~~A[b]~~	~~A[g]~~
~~Packaged or self-contained outdoor spas and hot tubs without underwater luminaire: from branch circuit OCPD to spa or hot tub~~	~~A[b]~~	~~A[c]~~	~~A[b]~~	~~A~~	~~A[f]~~	~~A[f]~~	~~A[b]~~	~~A~~	~~A[g]~~
~~Indoor spas and hot tubs,hydromassage bathtubs, and other pool, spa or hot tub associated equipment: from branch circuit OCPD to equipment~~	~~A[b]~~	~~A[c]~~	~~A[b]~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A[g]~~
~~Connection at pool lighting transformers or power supplies~~	~~AC[b] only~~	~~A[c]~~	~~A[b]~~	~~A~~	~~A[b,f]~~	~~A[f]~~	—	~~A[b]~~	—

~~For SI:1 foot = 304.8 mm.~~

~~5. a.For all wiring methods, see Section E4205 for equipment grounding conductor requirements.~~

~~6. b.Limited to use within buildings.~~

~~7. c.Limited to use on or within buildings.~~

~~8. d.Metal conduit shall be constructed of brass or other approved corrosion-resistant metal.~~

~~9. e.Limited to where necessary to employ flexible connections at or adjacent to a pool motor.~~

~~10. f.Sections installed external to spa or hot tub enclosure limited to individual lengths not to exceed 6 feet. Length not limited inside spa or hot tub enclosure.~~

~~11. g.Flexible cord shall be installed in accordance with Section E4202.2.~~

~~12. h.Nonmetallic conduit shall be rigid polyvinyl chloride conduit Type PVC or reinforced thermosetting resin conduit Type RTRC.~~

~~13. i.Aluminum conduits shall not be permitted in the pool area where subject to corrosion.~~

~~14. j.Where installed as direct burial cable or in wet locations, Type MC cable shall be listed and identified for the location.~~

~~15. k.See Section E4202.3 for listed, double-insulated pool pump motors.~~

~~16. l.Limited to use in individual lengths not to exceed 6 feet. The total length of all individual runs of LFMC shall not exceed 10 feet.~~

~~E4202.2Flexible cords.~~

~~Flexible cords used in conjunction with a pool, spa, hot tub or hydromassage bathtub shall be installed in accordance with the following:~~

~~17. 1.For other than underwater luminaires, fixed or stationary equipment shall be permitted to be connected with a flexible cord to facilitate removal or disconnection for maintenance or repair. For other than storable pools, the flexible cord shall not exceed 3 feet (914 mm) in length. Cords that supply swimming pool equipment shall have a copper equipment grounding conductor not smaller than 12 AWG and shall terminate in a grounding type attachment plug. [680.7(A), (B), and (C); 680.21(A)(5)]~~

~~18. 2.Other than listed low-voltage lighting systems not requiring grounding, wet-niche luminaires that are supplied by a flexible cord or cable shall have all exposed noncurrent-carrying metal parts grounded by an insulated copper equipment grounding conductor that is an integral part of the cord or cable. Such grounding conductor shall be connected to a grounding terminal in the supply junction box, transformer enclosure, or other enclosure and shall be not smaller than the supply conductors and not smaller than 16 AWG. [680.23(B)(3)]~~

19. 3.A listed packaged spa or hot tub installed outdoors that is GFCI protected shall be permitted to be cord-andplug-connected provided that such cord does not exceed 15 feet (4572 mm) in length. [680.42(A)(2)]

20. 4.A listed packaged spa or hot tub rated at 20 amperes or less and installed indoors shall be permitted to be cordand-plug-connected to facilitate maintenance and repair. (680.43 Exception No. 1)

21. 5.For other than underwater and storable pool lighting luminaire, the requirements of Item 1 shall apply to any cord-equipped luminaire that is located within 16 feet (4877 mm) radially from any point on the water surface. [680.22(B)(5)]

E4202.3Double insulated pool pumps.

A listed cord-and-plug-connected pool pump incorporating an approved system of double insulation that provides a means for grounding only the internal and nonaccessible, noncurrent carrying metal parts of the pump shall be connected to any wiring method recognized in Chapter 38 that is suitable for the location. Where the bonding grid is connected to the equipment grounding conductor of the motor circuit in accordance with Section E4204.2, Item 6.1, the branch circuit wiring shall comply with Sections E4202.1 and E4205.5. [680.21(B)]

SECTIONE4203
EQUIPMENT LOCATION AND CLEARANCES

E4203.1Receptacle outlets.

Receptacles outlets shall be installed and located in accordance with Sections E4203.1.1 through E4203.1.5. Distances shall be measured as the shortest path that an appliance supply cord connected to the receptacle would follow without penetrating a floor, wall, ceiling, doorway with hinged or sliding door, window opening, or other effective permanent barrier. [680.22(A)(5)]

E4203.1.1Location.

Receptacles that provide power for water-pump motors or other loads directly related to the circulation and sanitation system shall be permitted to be located between 6 feet and 10 feet (1829 mm and 3048 mm) from the inside walls of pools and outdoor spas and hot tubs, where the receptacle is single and of the grounding type and protected by ground-fault circuit interrupters.

Other receptacles on the property shall be located not less than 6 feet (1829 mm) from the inside walls of pools and outdoor spas and hot tubs. [680.22(A)(2) and (A)(3)]

E4203.1.2Where required.

At least one 125-volt, 15- or 20-ampere receptacle supplied by a general-purpose branch circuit shall be located a minimum of 6 feet (1829 mm) from and not more than 20 feet (6096 mm) from the inside wall

~~of pools and outdoor spas and hot tubs. This receptacle shall be located not more than 6 feet, 6 inches (1981 mm) above the floor, platform or grade level serving the pool, spa or hot tub. [680.22(A)(1)]~~

~~E4203.1.3GFCI protection.~~

~~All 15- and 20-ampere, single-phase, 125-volt receptacles located within 20 feet (6096 mm) of the inside walls of pools and outdoor spas and hot tubs shall be protected by a ground-fault circuit interrupter. Outlets supplying pool pump motors supplied from branch circuits rated at 120 volts through 240 volts, single phase, whether by receptacle or direct connection, shall be provided with ground-fault circuit-interrupter protection for personnel. [680.21(C) and 680.22(A)(4)]~~

~~E4203.1.4Indoor locations.~~

~~Receptacles shall be located not less than 6 feet (1829 mm) from the inside walls of indoor spas and hot tubs. A minimum of one 125-volt receptacle shall be located between 6 feet (1829 mm) and 10 feet (3048 mm) from the inside walls of indoor spas or hot tubs. [680.43(A) and 680.43(A)(1)]~~

~~E4203.1.5Indoor GFCI protection.~~

~~All 125-volt receptacles rated 30 amperes or less and located within 10 feet (3048 mm) of the inside walls of spas and hot tubs installed indoors, shall be protected by ground-fault circuit-interrupters. [680.43(A)(2)]~~

~~E4203.2Switching devices.~~

~~Switching devices shall be located not less than 5 feet (1524 mm) horizontally from the inside walls of pools, spas and hot tubs except where separated from the pool, spa or hot tub by a solid fence, wall, or other permanent barrier or the switches are listed for use within 5 feet (1524 mm). Switching devices located in a room or area containing a hydromassage bathtub shall be located in accordance with the general requirements of this code. [680.22(C); 680.43(C); and 680.72]~~

~~E4203.3Disconnecting means.~~

~~One or more means to simultaneously disconnect all ungrounded conductors for all utilization equipment, other than lighting, shall be provided. Each of such means shall be readily accessible and within sight from the equipment it serves and shall be located at least 5 feet (1524 mm) horizontally from the inside walls of a pool, spa, or hot tub unless separated from the open water by a permanently installed barrier that provides a 5-foot (1524 mm) or greater reach path. This horizontal distance shall be measured from the water's edge along the shortest path required to reach the disconnect. (680.12)~~

~~E4203.4Luminaires and ceiling fans.~~

~~Lighting outlets, luminaires, and ceiling-suspended paddle fans shall be installed and located in accordance with Sections E4203.4.1 through E4203.4.6. [680.22(B)]~~

~~E4203.4.1Outdoor location.~~

In outdoor pool, outdoor spas and outdoor hot tubs areas, luminaires, lighting outlets, and ceiling-suspended paddle fans shall not be installed over the pool or over the area extending 5 feet (1524 mm) horizontally from the inside walls of a pool except where no part of the luminaire or ceiling-suspended paddle fan is less than 12 feet (3658 mm) above the maximum water level. [680.22(B)(1)]

E4203.4.2Indoor locations.

In indoor pool areas, the limitations of Section E4203.4.1 shall apply except where the luminaires, lighting outlets and ceiling-suspended-paddle fans comply with all of the following conditions:

22. 1.The luminaires are of a totally enclosed type;
23. 2.Ceiling-suspended paddle fans are identified for use beneath ceiling structures such as porches and patios.
24. 3.A ground-fault circuit-interrupter is installed in the branch circuit supplying the luminaires or ceiling-suspended paddle fans; and
25. 4.The distance from the bottom of the luminaire or ceiling-suspended paddle fan to the maximum water level is not less than 7 feet, 6 inches (2286 mm). [680.22(B)(2)]

E4203.4.3Low-voltage luminaires.

Listed low-voltage luminaires not requiring grounding, not exceeding the low-voltage contact limit, and supplied by listed transformers or power supplies that comply with Section E4206.1 shall be permitted to be located less than 1.5 m (5 ft) from the inside walls of the pool. [680.22(B)(6)]

E4203.4.4Existing lighting outlets and luminaires.

Existing lighting outlets and luminaires that are located within 5 feet (1524 mm) horizontally from the inside walls of pools and outdoor spas and hot tubs shall be permitted to be located not less than 5 feet (1524 mm) vertically above the maximum water level, provided that such luminaires and outlets are rigidly attached to the existing structure and are protected by a ground-fault circuit-interrupter. [680.22(B)(3)]

E4203.4.5Indoor spas and hot tubs.

26. 1.Luminaires, lighting outlets, and ceiling-suspended paddle fans located over the spa or hot tub or within 5 feet (1524 mm) from the inside walls of the spa or hot tub shall be not less than 7 feet, 6 inches (2286 mm) above the maximum water level and shall be protected by a ground-fault circuit interrupter. [680.43(B)(1)(b)]

Luminaires, lighting outlets, and ceiling-suspended paddle fans that are located 12 feet (3658 mm) or more above the maximum water level shall not require ground-fault circuit interrupter protection. [680.43(B)(1)(a)]

27. 2.Luminaires protected by a ground-fault circuit interrupter and complying with Item 2.1 or 2.2 shall be permitted to be installed less than 7 feet, 6 inches (2286 mm) over a spa or hot tub.

    1. 2.1.Recessed luminaires shall have a glass or plastic lens and nonmetallic or electrically isolated metal trim, and shall be suitable for use in damp locations.

    2. 2.2.Surface-mounted luminaires shall have a glass or plastic globe and a nonmetallic body or a metallic body isolated from contact. Such luminaires shall be suitable for use in damp locations. [680.43(B)(1)(c)]

E4203.4.6GFCI protection in adjacent areas.

Luminaires and outlets that are installed in the area extending between 5 feet (1524 mm) and 10 feet (3048 mm) from the inside walls of pools and outdoor spas and hot tubs shall be protected by ground-fault circuit-interrupters except where such fixtures and outlets are installed not less than 5 feet (1524 mm) above the maximum water level and are rigidly attached to the structure. [680.22(B)(4)]

E4203.5Other outlets.

Other outlets such as for remote control, signaling, fire alarm and communications shall be not less than 10 feet (3048 mm) from the inside walls of the pool. Measurements shall be determined in accordance with Section E4203.1. [680.22(D)]

E4203.6Overhead conductor clearances.

Except where installed with the clearances specified in Table E4203.6, the following parts of pools and outdoor spas and hot tubs shall not be placed under existing service-drop conductors, overhead service conductor, or any other open overhead wiring; nor shall such wiring be installed above the following:

28. 1.Pools and the areas extending not less than 10 feet, (3048 mm) horizontally from the inside of the walls of the pool.

29. 2.Diving structures and the areas extending not less than 10 feet (3048 mm) horizontally from the outer edge of such structures.

30. 3.Observation stands, towers, and platforms and the areas extending not less than 10 feet (3048 mm) horizontally from the outer edge of such structures.

Overhead conductors of network-powered broadband communications systems shall comply with the provisions in Table E4203.6 for conductors operating at 0 to 750 volts to ground.

Utility-owned, -operated and -maintained communications conductors, community antenna system coaxial cables and the supporting messengers shall be permitted at a height of not less than 10 feet (3048 mm) above swimming and wading pools, diving structures, and observation stands, towers, and platforms. [680.8(A), (B), and (C)]

~~TABLE E4203.6 [Table 680.8(A)]~~

~~OVERHEAD CONDUCTOR CLEARANCES~~

	~~INSULATED SUPPLY OR SERVICE DROP CABLES, 0-750 VOLTS TO GROUND, SUPPORTED ON AND CABLED TOGETHER WITH AN EFFECTIVELY GROUNDED BARE MESSENGER OR EFFECTIVELY GROUNDED NEUTRAL CONDUCTOR (feet)~~	~~ALL OTHER SUPPLY OR SERVICE DROP CONDUCTORS (feet)~~ ~~Voltage to ground~~	
		~~0-15 kV~~	~~Greater than 15 to 50 kV~~
~~A. Clearance in any direction to the water level, edge of water surface, base of diving platform, or permanently anchored raft~~	~~22.5~~	~~25~~	~~27~~
~~B. Clearance in any direction to the diving platform~~	~~14.5~~	~~17~~	~~18~~

~~For SI: 1 foot = 304.8 mm.~~

~~E4203.7Underground wiring.~~

~~Underground wiring shall not be installed under or within the area extending 5 feet (1524 mm) horizontally from the inside walls of pools and outdoor hot tubs and spas except where the wiring is installed to supply pool, spa or hot tub equipment or where space limitations prevent wiring from being routed 5 feet (1524 mm) or more horizontally from the inside walls. Where installed within 5 feet (1524 mm) of the inside walls, the wiring method shall be a complete raceway system of rigid metal conduit, intermediate metal conduit or a nonmetallic raceway system. Metal conduit shall be corrosion-resistant and suitable for the location. The minimum cover depth shall be in accordance with Table E4203.7. (680.10)~~

~~TABLE E4203.7 (680.10)~~

~~MINIMUM BURIAL DEPTHS~~

~~WIRING METHOD~~	~~UNDERGROUND WIRING (inches)~~

~~Rigid metal conduit~~	~~6~~
~~Intermediate metal conduit~~	~~6~~
~~Nonmetallic raceways listed for direct burial and under concrete exterior slab not less than 4 inches inthickness and extending not less than 6 inches (162 mm) beyond the underground installation~~	~~6~~
~~Nonmetallic raceways listed for direct burial without concrete encasement~~	~~18~~
~~Other approved raceways[a]~~	~~18~~

~~For SI: 1 inch = 25.4 mm.~~

~~31. a.Raceways approved for burial only where concrete-encased shall require a concrete envelope not less than 2 inches in thickness.~~

~~**SECTION**E4204~~
~~BONDING~~

~~E4204.1Performance.~~

~~The equipotential bonding required by this section shall be installed to reduce voltage gradients in the prescribed areas of permanently installed swimming pools and spas and hot tubs other than the storable/portable type.~~

~~E4204.2Bonded parts.~~

~~The parts of pools, spas, and hot tubs specified in Items 1 through 7 shall be bonded together using insulated, covered or bare solid copper conductors not smaller than 8 AWG or using rigid metal conduit of brass or other identified corrosion-resistant metal. An 8 AWG or larger solid copper bonding conductor provided to reduce voltage gradients in the pool, spa, or hot tub area shall not be required to be extended or attached to remote panelboards, service equipment, or electrodes. Connections shall be made by exothermic welding, by listed pressure connectors or clamps that are labeled as being suitable for the purpose and that are made of stainless steel, brass, copper or copper alloy, machine screw-type fasteners that engage not less than two threads or are secured with a nut, thread-forming machine screws that engage not less than two threads, or terminal bars. Connection devices or fittings that depend solely on solder shall not be used. Sheet metal screws shall not be used to connect bonding conductors or connection devices. [680.26(B)]~~

~~32. 1.Conductive pool shells. Bonding to conductive pool shells shall be provided as specified in Item 1.1 or 1.2. Poured concrete, pneumatically applied or sprayed concrete, and concrete block with painted or plastered coatings shall be considered to~~

be conductive materials because of their water permeability and porosity. Vinyl liners and fiberglass composite shells shall be considered to be nonconductive materials.

1. 1.1.Structural reinforcing steel. Unencapsulated structural reinforcing steel shall be bonded together by steel tie wires or the equivalent. Where structural reinforcing steel is encapsulated in a nonconductive compound, a copper conductor grid shall be installed in accordance with Item 1.2.

2. 1.2.Copper conductor grid. A copper conductor grid shall be provided and shall comply with Items 1.2.1 through 1.2.4:

   1. 1.2.1.It shall be constructed of minimum 8 AWG bare solid copper conductors bonded to each other at all points of crossing.

   2. 1.2.2.It shall conform to the contour of the pool .

   3. 1.2.3.It shall be arranged in a 12-inch (305 mm) by 12-inch (305 mm) network of conductors in a uniformly spaced perpendicular grid pattern with a tolerance of 4 inches (102 mm).

   4. 1.2.4.It shall be secured within or under the pool not more than 6 inches (152 mm) from the outer contour of the pool shell. [680.26(B)(1)]

33. 2.Perimeter surfaces. The perimeter surface shall extend for 3 feet (914 mm) horizontally beyond the inside walls of the pool and shall include unpaved surfaces, poured concrete surfaces and other types of paving. Perimeter surfaces that extend less than 3 feet (914 mm) beyond the inside wall of the pool and that are separated from the pool by a permanent wall or building 5 feet (1524 mm) or more in height shall require equipotential bonding on the pool side of the permanent wall or building. Bonding to perimeter surfaces shall be provided as specified in Item 2.1 or 2.2 and shall be attached to the pool, spa, or hot tub reinforcing steel or copper conductor grid at a minimum of four points uniformly spaced around the perimeter of the pool, spa, or hot tub. For nonconductive pool shells, bonding at four points shall not be required.

Exceptions:

1. 1.Equipotential bonding of perimeter surfaces shall not be required for spas and hot tubs where all of the following conditions apply:

   1. 1.1.The spa or hot tub is listed as a self-contained spa for above-ground use.

   2. 1.2.The spa or hot tub is not identified as suitable only for indoor use.

   3. 1.3.The installation is in accordance with the manufacturer’s instructions and is located on or above grade.

~~4. 1.4.The top rim of the spa or hot tub is not less than 28 in. (711 mm) above all perimeter surfaces that are within 30 in. (762 mm), measured horizontally from the spa or hot tub. The height of nonconductive external steps for entry to or exit from the self-contained spa is not used to reduce or increase this rim height measurement.~~

~~2. 2.The equipotential bonding requirements for perimeter surfaces shall not apply to a listed selfcontained spa or hot tub located indoors and installed above a finished floor.~~

~~3. 2.1.Structural reinforcing steel. Structural reinforcing steel shall be bonded in accordance with Item 1.1.~~

~~4. 2.2.Alternate means. Where structural reinforcing steel is not available or is encapsulated in a nonconductive compound, a copper conductor(s) shall be used in accordance with Items 2.2.1 through 2.2.5:~~

~~1. 2.2.1.At least one minimum 8 AWG bare solid copper conductor shall be provided.~~

~~2. 2.2.2.The conductors shall follow the contour of the perimeter surface.~~

~~3. 2.2.3.Splices shall be listed.~~

~~4. 2.2.4.The required conductor shall be 18 to 24 inches (457 to 610 mm) from the inside walls of the pool.~~

~~5. 2.2.5.The required conductor shall be secured within or under the perimeter surface 4 to 6 inches (102 mm to 152 mm) below the subgrade. [680.26(B)(2)]~~

~~34. 3.Metallic components. All metallic parts of the pool structure, including reinforcing metal not addressed in Item 1.1, shall be bonded. Where reinforcing steel is encapsulated with a nonconductive compound, the reinforcing steel shall not be required to be bonded. [680.26(B)(3)]~~

~~35. 4.Underwater lighting. All metal forming shells and mounting brackets of no-niche luminaires shall be bonded. [680.26(B)(4)]~~

~~**Exception:** Listed low-voltage lighting systems with nonmetallic forming shells shall not require bonding. [680.26(B)(4) Exception]~~

~~36. 5.Metal fittings. All metal fittings within or attached to the pool structure shall be bonded. Isolated parts that are not over 4 inches (102 mm) in any dimension and do not penetrate into the pool structure more than 1 inch (25.4 mm) shall not require bonding. [680.26(B)(5)]~~

37. 6.Electrical equipment. Metal parts of electrical equipment associated with the pool water circulating system, including pump motors and metal parts of equipment associated with pool covers, including electric motors, shall be bonded. [680.26(B)(6)]

Exception: Metal parts of listed equipment incorporating an approved system of double insulation shall not be bonded. [680.26(B)(6) Exception]

1. 6.1.Double-insulated water pump motors. Where a double-insulated water pump motor is installed under the provisions of this item, a solid 8 AWG copper conductor of sufficient length to make a bonding connection to a replacement motor shall be extended from the bonding grid to an accessible point in the vicinity of the pool pump motor. Where there is no connection between the swimming pool bonding grid and the equipment grounding system for the premises, this bonding conductor shall be connected to the equipment grounding conductor of the motor circuit. [680.26(B)(6)(a)]

2. 6.2.Pool water heaters. For pool water heaters rated at more than 50 amperes and having specific instructions regarding bonding and grounding, only those parts designated to be bonded shall be bonded and only those parts designated to be grounded shall be grounded. [680.26(B)(6)(b)]

38. 7.All fixed metal parts including, but not limited to, metal-sheathed cables and raceways, metal piping, metal awnings, metal fences and metal door and window frames. [680.26(B)(7)]

Exceptions:

1. 1.Those separated from the pool by a permanent barrier that prevents contact by a person shall not be required to be bonded. [680.26(B)(7) Exception No. 1]

2. 2.Those greater than 5 feet (1524 mm) horizontally from the inside walls of the pool shall not be required to be bonded. [680.26(B)(7) Exception No. 2]

3. 3.Those greater than 12 feet (3658 mm) measured vertically above the maximum water level of the pool, or as measured vertically above any observation stands, towers, or platforms, or any diving structures, shall not be required to be bonded. [680.26(B)(7) Exception No. 3]

E4204.3Pool water.

Where none of the bonded parts is in direct connection with the pool water, the pool water shall be in direct contact with an approved corrosion-resistant conductive surface that exposes not less than 9 in.^{2} (5800 mm^2) of surface area to the pool water at all times. The conductive surface shall be located where it is not exposed to physical damage or dislodgement during usual pool activities, and it shall be bonded in accordance with Section E4204.2.

~~E4204.4Bonding of outdoor hot tubs and spas.~~

~~Outdoor hot tubs and spas shall comply with the bonding requirements of Sections E4204.1 through E4204.3. Bonding by metal-to-metal mounting on a common frame or base shall be permitted. The metal bands or hoops used to secure wooden staves shall not be required to be bonded as required in Section E4204.2. [680.42 and 680.42(B)]~~

~~E4204.5Bonding of indoor hot tubs and spas.~~

~~The following parts of indoor hot tubs and spas shall be bonded together:~~

~~39. 1.All metal fittings within or attached to the hot tub or spa structure. [680.43(D)(1)]~~

~~40. 2.Metal parts of electrical equipment associated with the hot tub or spa water circulating system, including pump motors unless part of a listed self-contained spa or hot tub. [680.43(D)(2)]~~

~~41. 3.Metal raceway and metal piping that are within 5 feet (1524 mm) of the inside walls of the hot tub or spa and that are not separated from the spa or hot tub by a permanent barrier. [680.43(D)(3)]~~

~~42. 4.All metal surfaces that are within 5 feet (1524 mm) of the inside walls of the hot tub or spa and that are not separated from the hot tub or spa area by a permanent barrier. [680.43(D)(4)]~~

~~**Exception:** Small conductive surfaces not likely to become energized, such as air and water jets and drain fittings, where not connected to metallic piping, towel bars, mirror frames, and similar nonelectrical equipment, shall not be required to be bonded. [680.43(D)(4) Exception]~~

~~43. 5.Electrical devices and controls that are not associated with the hot tubs or spas and that are located less than 5 feet (1524 mm) from such units. [680.43(D)(5)]~~

~~E4204.5.1Methods.~~

~~All metal parts associated with the hot tub or spa shall be bonded by any of the following methods:~~

~~44. 1.The interconnection of threaded metal piping and fittings. [680.43(E)(1)]~~

~~45. 2.Metal-to-metal mounting on a common frame or base. [680.43(E)(2)]~~

~~46. 3.The provision of an insulated, covered or bare solid copper bonding jumper not smaller than 8 AWG.It shall not be the intent to require that the 8 AWG or larger solid copper bonding conductor be extended or attached to any remote panelboard, service equipment, or any electrode, but only that it shall be employed to eliminate voltage gradients in the hot tub or spa area as prescribed. [680.43(E)(3)]~~

~~E4204.5.2Connections.~~

~~Connections to bonded parts shall be made in accordance with Section E3406.13.1.~~

~~**SECTION**E4205~~
~~GROUNDING~~

~~E4205.1Equipment to be grounded.~~

~~The following equipment shall be grounded:~~

47. ~~1.Through-wall lighting assemblies and underwater luminaires other than those low-voltage lighting products listed for the application without a grounding conductor.~~
48. ~~2.All electrical equipment located within 5 feet (1524 mm) of the inside wall of the pool, spa or hot tub.~~
49. ~~3.All electrical equipment associated with the recirculating system of the pool, spa or hot tub.~~
50. ~~4.Junction boxes.~~
51. ~~5.Transformer and power supply enclosures.~~
52. ~~6.Ground-fault circuit-interrupters.~~
53. ~~7.Panelboards that are not part of the service equipment and that supply any electrical equipment associated with the pool, spa or hot tub. (680.7)~~

~~E4205.2Luminaires and related equipment.~~

~~Other than listed low-voltage luminaires not requiring grounding, all through-wall lighting assemblies, wet-niche, dry-niche, or no-niche luminaires shall be connected to an insulated copper equipment grounding conductor sized in accordance with Table E3908.12 but not smaller than 12 AWG. The equipment grounding conductor between the wiring chamber of the secondary winding of a transformer and a junction box shall be sized in accordance with the overcurrent device in such circuit. The junction box, transformer enclosure, or other enclosure in the supply circuit to a wet-niche or no-niche luminaire and the field-wiring chamber of a dry-niche luminaire shall be grounded to the equipment grounding terminal of the panelboard. The equipment grounding terminal shall be directly connected to the panelboard enclosure. The equipment grounding conductor shall be installed without joint or splice. [680.23(F)(2) and 680.23(F)(2) Exception]~~

~~**Exceptions:**~~

54. ~~1.Where more than one underwater luminaire is supplied by the same branch circuit, the equipment grounding conductor, installed between the junction boxes, transformer enclosures, or other enclosures in the supply circuit to wet-niche luminaires, or between the field-wiring compartments of dry-niche luminaires, shall be permitted to be terminated on grounding terminals. [680.23(F)(2)(a)]~~

55. 2.Where an underwater luminaire is supplied from a transformer, ground-fault circuit-interrupter, clock-operated switch, or a manual snap switch that is located between the panelboard and a junction box connected to the conduit that extends directly to the underwater luminaire, the equipment grounding conductor shall be permitted to terminate on grounding terminals on the transformer, ground-fault circuit-interrupter, clock-operated switch enclosure, or an outlet box used to enclose a snap switch. [680.23(F)(2)(b)]

E4205.3Nonmetallic conduit.

Where a nonmetallic conduit is installed between a forming shell and a junction box, transformer enclosure, or other enclosure, a 8 AWG insulated copper bonding jumper shall be installed in this conduit except where a listed low-voltage lighting system not requiring grounding is used. The bonding jumper shall be terminated in the forming shell, junction box or transformer enclosure, or ground-fault circuit-interrupter enclosure. The termination of the 8 AWG bonding jumper in the forming shell shall be covered with, or encapsulated in, a listed potting compound to protect such connection from the possible deteriorating effect of pool water. [680.23(B)(2)(b)]

E4205.4Flexible cords.

Other than listed low-voltage lighting systems not requiring grounding, wet-niche luminaires that are supplied by a flexible cord or cable shall have all exposed noncurrent-carrying metal parts grounded by an insulated copper equipment grounding conductor that is an integral part of the cord or cable. This grounding conductor shall be connected to a grounding terminal in the supply junction box, transformer enclosure, or other enclosure. The grounding conductor shall not be smaller than the supply conductors and not smaller than 16 AWG. [680.23(B)(3)]

E4205.5Motors.

Pool-associated motors shall be connected to an insulated copper equipment grounding conductor sized in accordance with Table E3908.12, but not smaller than 12 AWG. Where the branch circuit supplying the motor is installed in the interior of a one-family dwelling or in the interior of accessory buildings associated with a one-family dwelling, using a cable wiring method permitted by Table E4202.1, an uninsulated equipment grounding conductor shall be permitted provided that it is enclosed within the outer sheath of the cable assembly. [680.21(A)(1) and (A)(4)]

E4205.6Feeders.

An equipment grounding conductor shall be installed with the feeder conductors between the grounding terminal of the pool equipment panelboard and the grounding terminal of the applicable service equipment. The equipment grounding conductor shall be insulated, shall be sized in accordance with Table E3908.12, and shall be not smaller than 12 AWG.

E4205.6.1Separate buildings.

A feeder to a separate building or structure shall be permitted to supply swimming pool equipment branch circuits, or feeders supplying swimming pool equipment branch circuits, provided that the grounding arrangements in the separate building meet the requirements of Section E3607.3. The feeder equipment grounding conductor shall be an insulated conductor. (680.25(B)(2)]

E4205.7Cord-connected equipment.

Where fixed or stationary equipment is connected with a flexible cord to facilitate removal or disconnection for maintenance, repair, or storage, as provided in Section E4202.2, the equipment grounding conductors shall be connected to a fixed metal part of the assembly. The removable part shall be mounted on or bonded to the fixed metal part. [680.7(C)]

E4205.8Other equipment.

Other electrical equipment shall be grounded in accordance with Section E3908. (Article 250, Parts V, VI, and VII; and 680.6)

SECTIONE4206
EQUIPMENT INSTALLATION

E4206.1Transformers and power supplies.

Transformers and power supplies used for the supply of underwater luminaires, together with the transformer or power supply enclosure, shall be listed for swimming pool and spa use. The transformer or power supply shall incorporate either a transformer of the isolated-winding type with an ungrounded secondary that has a grounded metal barrier between the primary and secondary windings, or a transformer that incorporates an approved system of double insulation between the primary and secondary windings. [680.23(A)(2)]

E4206.2Ground-fault circuit-interrupters.

Ground-fault circuit-interrupters shall be self-contained units, circuit-breaker types, receptacle types or other approved types. (680.5)

E4206.3Wiring on load side of ground-fault circuit-interrupters and transformers.

For other than grounding conductors, conductors installed on the load side of a ground-fault circuit-interrupter or transformer used to comply with the provisions of Section E4206.4, shall not occupy raceways, boxes, or enclosures containing other conductors except where the other conductors are protected by ground-fault circuit interrupters or are grounding conductors. Supply conductors to a feed-through type ground-fault circuit interrupter shall be permitted in the same enclosure. Ground-fault circuit interrupters shall be permitted in a panelboard that contains circuits protected by other than ground-fault circuit interrupters. [680.23(F)(3)]

E4206.4Underwater luminaires.

~~The design of an underwater luminaire supplied from a branch circuit either directly or by way of a transformer or power supply meeting the requirements of Section E4206.1, shall be such that, where the fixture is properly installed without a ground-fault circuitinterrupter, there is no shock hazard with any likely combination of fault conditions during normal use (not relamping). In addition, a ground-fault circuit-interrupter shall be installed in the branch circuit supplying luminaires operating at more than the low-voltage contact limit, such that there is no shock hazard during relamping. The installation of the ground-fault circuit-interrupter shall be such that there is no shock hazard with any likely fault-condition combination that involves a person in a conductive path from any ungrounded part of the branch circuit or the luminaire to ground. Compliance with this requirement shall be obtained by the use of a listed underwater luminaire and by installation of a listed groundfault circuit-interrupter in the branch circuit or a listed transformer or power supply for luminaires operating at more than the low-voltage contact limit. Luminaires that depend on submersion for safe operation shall be inherently protected against the hazards of overheating when not submerged. [680.23(A)(1), (A)(3), (A)(7) and (A)(8)]~~

~~E4206.4.1Maximum voltage.~~

~~Luminaires shall not be installed for operation on supply circuits over 150 volts between conductors. [680.23(A)(4)]~~

~~E4206.4.2Luminaire location.~~

~~Luminaires mounted in walls shall be installed with the top of the fixture lens not less than 18 inches (457 mm) below the normal water level of the pool, except where the luminaire is listed and identified for use at a depth of not less than 4 inches (102 mm) below the normal water level of the pool. A luminaire facing upward shall have the lens adequately guarded to prevent contact by any person or shall be listed for use without a guard. [680.23(A)(5) and (A)(6)]~~

~~E4206.5Wet-niche luminaires.~~

~~Forming shells shall be installed for the mounting of all wet-niche underwater luminaires and shall be equipped with provisions for conduit entries. Conduit shall extend from the forming shell to a suitable junction box or other enclosure located as provided in Section E4206.9. Metal parts of the luminaire and forming shell in contact with the pool water shall be of brass or other approved corrosion-resistant metal. [680.23(B)(1)]~~

~~The end of flexible-cord jackets and flexible-cord conductor terminations within a luminaire shall be covered with, or encapsulated in, a suitable potting compound to prevent the entry of water into the luminaire through the cord or its conductors. If present, the grounding connection within a luminaire shall be similarly treated to protect such connection from the deteriorating effect of pool water in the event of water entry into the luminaire. [680.23(B)(4)]~~

Luminaires shall be bonded to and secured to the forming shell by a positive locking device that ensures a low-resistance contact and requires a tool to remove the luminaire from the forming shell. [680.23(B)(5)]

E4206.5.1Servicing.

All wet-niche luminaires shall be removable from the water for inspection, relamping, or other maintenance. The forming shell location and length of cord in the forming shell shall permit personnel to place the removed luminaire on the deck or other dry location for such maintenance. The luminaire maintenance location shall be accessible without entering or going into the pool water. [680.23(B)(6)]

E4206.6Dry-niche luminaires.

Dry-niche luminaires shall have provisions for drainage of water. Other than listed low-voltage luminaires not requiring grounding, a dry-niche luminaire shall have means for accommodating one equipment grounding conductor for each conduit entry. Junction boxes shall not be required but, if used, shall not be required to be elevated or located as specified in Section E4206.9 if the luminaire is specifically identified for the purpose. [680.23(C)(1) and (C)(2)]

E4206.7No-niche luminaires.

No-niche luminaires shall be listed for the purpose and shall be installed in accordance with the requirements of Section E4206.5. Where connection to a forming shell is specified, the connection shall be to the mounting bracket. [680.23(D)]

E4206.8Through-wall lighting assembly.

A through-wall lighting assembly shall be equipped with a threaded entry or hub, or a nonmetallic hub, for the purpose of accommodating the termination of the supply conduit. A through-wall lighting assembly shall meet the construction requirements of Section E4205.4 and be installed in accordance with the requirements of Section E4206.5 Where connection to a forming shell is specified, the connection shall be to the conduit termination point. [680.23(E)]

E4206.9Junction boxes and enclosures for transformers or ground-fault circuit interrupters.

Junction boxes for underwater luminaires and enclosures for transformers and ground-fault circuit interrupters that supply underwater luminaires shall comply with the following: [680.24(A)]

E4206.9.1Junction boxes.

A junction box connected to a conduit that extends directly to a forming shell or mounting bracket of a no-niche luminaire shall be:

56. 1.Listed as a swimming pool junction box; [680.24(A)(1)]

57. 2.Equipped with threaded entries or hubs or a nonmetallic hub; [680.24(A)(1)(1)]

58. 3.Constructed of copper, brass, suitable plastic, or other approved corrosion-resistant material; [680.24(A)(1)(2)]

59. 4.Provided with electrical continuity between every connected metal conduit and the grounding terminals by means of copper, brass, or other approved corrosion-resistant metal that is integral with the box; and [680.24(A)(1)(3)]

60. 5.Located not less than 4 inches (102 mm), measured from the inside of the bottom of the box, above the ground level, or pool deck, or not less than 8 inches (203 mm) above the maximum pool water level, whichever provides the greatest elevation, and shall be located not less than 4 feet (1219 mm) from the inside wall of the pool, unless separated from the pool by a solid fence, wall or other permanent barrier. Where used on a lighting system operating at the low-voltage contact limit or less, a flush deck box shall be permitted provided that an approved potting compound is used to fill the box to prevent the entrance of moisture; and the flush deck box is located not less than 4 feet (1219 mm) from the inside wall of the pool. [680.24(A)(2)]

E4206.9.2Other enclosures.

An enclosure for a transformer, ground-fault circuit-interrupter or a similar device connected to a conduit that extends directly to a forming shell or mounting bracket of a no-niche luminaire shall be:

61. 1.Listed and labeled for the purpose, comprised of copper, brass, suitable plastic, or other approved corrosion-resistant material; [680.24(B)(1)]

62. 2.Equipped with threaded entries or hubs or a nonmetallic hub; [680.24(B)(2)]

63. 3.Provided with an approved seal, such as duct seal at the conduit connection, that prevents circulation of air between the conduit and the enclosures; [680.24(B)(3)]

64. 4.Provided with electrical continuity between every connected metal conduit and the grounding terminals by means of copper, brass or other approved corrosion-resistant metal that is integral with the enclosures; and [680.24(B)(4)]

65. 5.Located not less than 4 inches (102 mm), measured from the inside bottom of the enclosure, above the ground level or pool deck, or not less than 8 inches (203 mm) above the maximum pool water level, whichever provides the greater elevation, and shall be located not less than 4 feet (1219 mm) from the inside wall of the pool, except where separated from the pool by a solid fence, wall or other permanent barrier. [680.24(B)(2)]

E4206.9.3Protection of junction boxes and enclosures.

Junction boxes and enclosures mounted above the grade of the finished walkway around the pool shall not be located in the walkway unless afforded additional protection, such as by location under diving boards or adjacent to fixed structures. [680.24(C)]

E4206.9.4Grounding terminals.

Junction boxes, transformer and power supply enclosures, and ground-fault circuit-interrupter enclosures connected to a conduit that extends directly to a forming shell or mounting bracket of a no-niche luminaire shall be provided with grounding terminals in a quantity not less than the number of conduit entries plus one. [680.24(D)]

E4206.9.5Strain relief.

The termination of a flexible cord of an underwater luminaire within a junction box, transformer or power supply enclosure, ground-fault circuit-interrupter, or other enclosure shall be provided with a strain relief. [680.24(E)]

E4206.10Underwater audio equipment.

Underwater audio equipment shall be identified for the purpose. [680.27(A)]

E4206.10.1Speakers.

Each speaker shall be mounted in an approved metal forming shell, the front of which is enclosed by a captive metal screen, or equivalent, that is bonded to and secured to the forming shell by a positive locking device that ensures a low-resistance contact and requires a tool to open for installation or servicing of the speaker. The forming shell shall be installed in a recess in the wall or floor of the pool. [680.27(A)(1)]

E4206.10.2Wiring methods.

Rigid metal conduit of brass or other identified corrosion-resistant metal, rigid polyvinyl chloride conduit, rigid thermosetting resin conduit or liquid-tight flexible nonmetallic conduit (LFNC-B) shall extend from the forming shell to a suitable junction box or other enclosure as provided in Section E4206.9. Where rigid nonmetallic conduit or liquid-tight flexible nonmetallic conduit is used, an 8 AWG solid or stranded insulated copper bonding jumper shall be installed in this conduit with provisions for terminating in the forming shell and the junction box. The termination of the 8 AWG bonding jumper in the forming shell shall be covered with, or encapsulated in, a suitable potting compound to protect such connection from the possible deteriorating effect of pool water. [680.27(A)(2)]

E4206.10.3Forming shell and metal screen.

The forming shell and metal screen shall be of brass or other approved corrosion-resistant metal. Forming shells shall include provisions for terminating an 8 AWG copper conductor. [680.27(A)(3)]

E4206.11Electrically operated pool covers.

~~The electric motors, controllers, and wiring for pool covers shall be located not less than 5 feet (1524 mm) from the inside wall of the pool except where separated from the pool by a wall, cover, or other permanent barrier. Electric motors installed below grade level shall be of the totally enclosed type. The electric motor and controller shall be connected to a branch circuit protected by a ground-fault circuit-interrupter. The device that controls the operation of the motor for an electrically operated pool cover shall be located so that the operator has full view of the pool. [680.27(B)(1) and (B)(2)]~~

~~E4206.12Electric pool water heaters.~~

~~Electric pool water heaters shall have the heating elements subdivided into loads not exceeding 48 amperes and protected at not more than 60 amperes. The ampacity of the branch-circuit conductors and the rating or setting of overcurrent protective devices shall be not less than 125 percent of the total nameplate load rating. (680.9)~~

~~E4206.13Pool area heating.~~

~~The provisions of Sections E4206.13.1 through E4206.13.3 shall apply to all pool deck areas, including a covered pool, where electrically operated comfort heating units are installed within 20 feet (6096 mm) of the inside wall of the pool. [680.27(C)]~~

~~E4206.13.1Unit heaters.~~

~~Unit heaters shall be rigidly mounted to the structure and shall be of the totally enclosed or guarded types. Unit heaters shall not be mounted over the pool or within the area extending 5 feet (1524 mm) horizontally from the inside walls of a pool. [680.27(C)(1)]~~

~~E4206.13.2Permanently wired radiant heaters.~~

~~Electric radiant heaters shall be suitably guarded and securely fastened to their mounting devices. Heaters shall not be installed over a pool or within the area extending 5 feet (1524 mm) horizontally from the inside walls of the pool and shall be mounted not less than 12 feet (3658 mm) vertically above the pool deck. [680.27(C)(2)]~~

~~E4206.13.3Radiant heating cables prohibited.~~

~~Radiant heating cables embedded in or below the deck shall be prohibited. [680.27(C)(3)]~~

~~**SECTION**E4207~~
~~STORABLE SWIMMING POOLS,~~
~~STORABLE SPAS, AND STORABLE HOT TUBS~~

~~E4207.1Pumps.~~

~~A cord-and-plug-connected pool filter pump for use with storable pools shall incorporate an approved system of double insulation or its equivalent and shall be provided with means for grounding only the internal and nonaccessible noncurrent-carrying metal parts of the appliance.~~

~~The means for grounding shall be an equipment grounding conductor run with the power-supply conductors in a flexible cord that is properly terminated in a grounding-type attachment plug having a fixed grounding contact. Cord-and-plug-connected pool filter pumps shall be provided with a ground-fault circuit interrupter that is an integral part of the attachment plug or located in the power supply cord within 12 inches (305 mm) of the attachment plug.~~

~~(680.31)~~

~~E4207.2Ground-fault circuit-interrupters required.~~

~~Electrical equipment, including power-supply cords, used with storable pools shall be protected by ground-fault circuit-interrupters. 125-volt, 15- and 20-ampere receptacles located within 20 feet (6096 mm) of the inside walls of a storable pool, storable spa, or storable hot tub shall be protected by a ground-fault circuit interrupter. In determining these dimensions, the distance to be measured shall be the shortest path that the supply cord of an appliance connected to the receptacle would follow without passing through a floor, wall, ceiling, doorway with hinged or sliding door, window opening, or other effective permanent barrier. (680.32)~~

~~E4207.3Luminaires.~~

~~Luminaires for storable pools, storable spas, and storable hot tubs shall not have exposed metal parts and shall be listed for the purpose as an assembly. In addition, luminaires for storable pools shall comply with the requirements of Section E4207.3.1 or E4207.3.2. (680.33)~~

~~E4207.3.1Within the low-voltage contact limit.~~

~~A luminaire installed in or on the wall of a storable pool shall be part of a cord-and-plug-connected lighting assembly. The assembly shall:~~

~~66. 1.Have a luminaire lamp that is suitable for the use at the supplied voltage;~~

~~67. 2.Have an impact-resistant polymeric lens, luminaire body, and transformer enclosure;~~

~~68. 3.Have a transformer meeting the requirements of Section E4206.1 with a primary rating not over 150 volts; and~~

~~69. 4.Have no exposed metal parts. [680.33(A)]~~

~~E4207.3.2Over the low-voltage contact limit but not over 150 volts.~~

~~A lighting assembly without a transformer or power supply, and with the luminaire lamp(s) operating at over the low-voltage contact limit, but not over 150 volts, shall be permitted to be cord-and-plug-connected where the assembly is listed as an assembly for the purpose and complies with all of the following:~~

~~70. 1.It has an impact-resistant polymeric lens and luminaire body.~~

71. 2.A ground-fault circuit interrupter with open-neutral conductor protection is provided as an integral part of the assembly.

72. 3.The luminaire lamp is permanently connected to the ground-fault circuit interrupter with open-neutral protection.

73. 4.It complies with the requirements of Section E4206.4.

74. 5.It has no exposed metal parts. [680.33(B)]

E4207.4Receptacle locations.

Receptacles shall be located not less than 6 feet (1829 mm) from the inside walls of a storable pool, storable spa or storable hot tub. In determining these dimensions, the distance to be measured shall be the shortest path that the supply cord of an appliance connected to the receptacle would follow without passing through a floor, wall, ceiling, doorway with hinged or sliding door, window opening, or other effective permanent barrier. (680.34)

E4207.5Clearances.

Overhead conductor installations shall comply with Section E4203.6 and underground conductor installations shall comply with Section E4203.7.

E4207.6Disconnecting means.

Disconnecting means for storable pools and storable/portable spas and hot tubs shall comply with Section E4203.3.

E4207.7Ground-fault circuit interrupters.

Ground-fault circuit interrupters shall comply with Section E4206.2.

E4207.8Grounding of equipment.

Equipment shall be grounded as required by Section E4205.1.

E4207.9Pool water heaters.

Electric pool water heaters shall comply with Section E4206.12.

SECTIONE4208
SPAS AND HOT TUBS

E4208.1Ground-fault circuit-interrupters.

The outlet(s) that supplies a self-contained spa or hot tub, or a packaged spa or hot tub equipment assembly, or a field-assembled spa or hot tub with a heater load of 50 amperes or less, shall be protected by a ground-fault circuit-interrupter. (680.44)

~~A listed self-contained unit or listed packaged equipment assembly marked to indicate that integral ground-fault circuit-interrupter protection is provided for all electrical parts within the unit or assembly, including pumps, air blowers, heaters, lights, controls, sanitizer generators and wiring, shall not require that the outlet supply be protected by a ground fault circuit interrupter. [680.44(A)]~~

~~E4208.2Electric water heaters.~~

~~Electric spa and hot tub water heaters shall be listed and shall have the heating elements subdivided into loads not exceeding 48 amperes and protected at not more than 60 amperes. The ampacity of the branch-circuit conductors, and the rating or setting of overcurrent protective devices, shall be not less than 125 percent of the total nameplate load rating. (680.9)~~

~~E4208.3Underwater audio equipment.~~

~~Underwater audio equipment used with spas and hot tubs shall comply with the provisions of Section E4206.10. [680.43(G)]~~

~~E4208.4Emergency switch for spas and hot tubs.~~

~~A clearly labeled emergency shutoff or control switch for the purpose of stopping the motor(s) that provides power to the recirculation system and jet system shall be installed at a point that is readily accessible to the users, adjacent to and within sight of the spa or hot tub and not less than 5 feet (1524 mm) away from the spa or hot tub. This requirement shall not apply to single-family dwellings. (680.41)~~

~~**SECTION**E4209~~
~~HYDROMASSAGE BATHTUBS~~

~~E4209.1Ground-fault circuit-interrupters.~~

~~Hydromassage bathtubs and their associated electrical components shall be supplied by an individual branch circuit(s) and protected by a readily accessible ground-fault circuit-interrupter. All 125-volt, single-phase receptacles not exceeding 30 amperes and located within 6 feet (1829 mm) measured horizontally of the inside walls of a hydromassage tub shall be protected by a ground-fault circuit interrupter(s). (680.71)~~

~~E4209.2Other electric equipment.~~

~~Luminaires, switches, receptacles, and other electrical equipment located in the same room, and not directly associated with a hydromassage bathtub, shall be installed in accordance with the requirements of this code relative to the installation of electrical equipment in bathrooms. (680.72)~~

~~E4209.3Accessibility.~~

~~Hydromassage bathtub electrical equipment shall be accessible without damaging the building structure or building finish. Where the hydromassage bathtub is cord- and plug-connected with the supply~~

receptacle accessible only through a service access opening, the receptacle shall be installed so that its face is within direct view and not more than 12 inches (305 mm) from the plane of the opening. (680.73)

E4209.4Bonding.

Both metal piping systems and grounded metal parts in contact with the circulating water shall be bonded together using an insulated, covered or bare solid copper bonding jumper not smaller than 8 AWG. The bonding jumper shall be connected to the terminal on the circulating pump motor that is intended for this purpose. The bonding jumper shall not be required to be connected to a double insulated circulating pump motor. The 8 AWG or larger solid copper bonding jumper shall be required for equipotential bonding in the area of the hydromassage bathtub and shall not be required to be extended or attached to any remote panelboard, service equipment, or any electrode. Where a double-insulated circulating pump motor is used, the 8 AWG or larger solid copper bonding jumper shall be long enough to terminate on a replacement nondouble-insulated pump motor and shall be terminated to the equipment grounding conductor of the branch circuit for the motor. (680.74)

CHAPTER 43
CLASS 2 REMOTE-CONTROL,
SIGNALING AND POWER-LIMITED CIRCUITS

RESERVED

SECTIONE4301
GENERAL

E4301.1Scope.

This chapter contains requirements for power supplies and wiring methods associated with Class 2 remote-control, signaling, and power-limited circuits that are not an integral part of a device or appliance. Other classes of remote-control, signaling and power-limited conductors shall comply with Article 725 of NFPA 70. (725.1)

E4301.2Definitions.

CLASS 2 CIRCUIT. That portion of the wiring system between the load side of a Class 2 power source and the connected equipment. Due to its power limitations, a Class 2 circuit considers safety from a fire initiation standpoint and provides acceptable protection from electric shock. (725.2)

REMOTE-CONTROL CIRCUIT. Any electrical circuit that controls any other circuit through a relay or an equivalent device. (Article 100)

SIGNALING CIRCUIT. Any electrical circuit that energizes signaling equipment. (Article 100)

SECTIONE4302
POWER SOURCES

E4302.1Power sources for Class 2 circuits.

The power source for a Class 2 circuit shall be one of the following:

1. 1.A listed Class 2 transformer.
2. 2.A listed Class 2 power supply.
3. 3.Other listed equipment marked to identify the Class 2 power source.
4. 4.Listed information technology (computer) equipment limited power circuits.
5. 5.A dry-cell battery provided that the voltage is 30 volts or less and the capacity is equal to or less than that available from series connected No. 6 carbon zinc cells. [725.121(A)]

E4302.2Interconnection of power sources.

A Class 2 power source shall not have its output connections paralleled or otherwise interconnected with another Class 2 power source except where listed for such interconnection. [725.121(B)]

SECTIONE4303
WIRING METHODS

E4303.1Wiring methods on supply side of Class 2 power source.

Conductors and equipment on the supply side of the power source shall be installed in accordance with the appropriate requirements of Chapters 34 through 41. Transformers or other devices supplied from electric light or power circuits shall be protected by an over-current device rated at not over 20 amperes. The input leads of a transformer or other power source supplying Class 2 circuits shall be permitted to be smaller than 14 AWG, if not over 12 inches (305 mm) long and if the conductor insulation is rated at not less than 600 volts. In no case shall such leads be smaller than 18 AWG. (725.127 and 725.127 Exception)

E4303.2Wiring methods and materials on load side of the Class 2 power source.

Class 2 cables installed as wiring within buildings shall be listed as being resistant to the spread of fire and listed as meeting the criteria specified in Sections E4303.2.1 through E4303.2.3. Cables shall be marked in accordance with Section E4303.2.4. Cable substitutions as described in Table E4303.2 and wiring methods covered in Chapter 38 shall also be permitted. (725.130 (B); 725.135 (A), (C), (G) and (M); 725.154; Table 725.154; Figure 725.154 (A); and 725.179)

TABLE E4303.2

CABLE USES AND PERMITTED SUBSTITUTIONS [Figure 725.154(A)]

CABLE	USE	PERMITTED SUBSTITUTIONS[a]

~~TYPE~~

~~CL2P~~	~~Class 2 Plenum Cable~~	~~CMP, CL3P~~
~~CL2R~~	~~Class 2 Plenum Cable~~	~~CMP, CL3P, CL2P, CMR, CL3R~~
~~CL2~~	~~Class 2 Cable~~	~~CMP, CL3P, CL2P, CMR, CL3R, CL2R CMG, CM, CL3~~
~~CL2X~~	~~Class 2 Cable, Limited Use~~	~~CMP, CL3P CL2P, CMR, CL3R, CL2R, CMG, CM, CL3, CL2, CMX, CL3X~~

~~6.—a.For identification of cables other than Class 2 cables, see NFPA 70.~~

~~E4303.2.1Type CL2P cables.~~

~~Cables installed in ducts, plenums and other spaces used to convey environmental air shall be Type CL2P cables listed as being suitable for the use and listed as having adequate fire-resistant and low smoke-producing characteristics. [725.179(A)]~~

~~E4303.2.2Type CL2 cables.~~

~~Cables for general-purpose use, shall be listed as being resistant to the spread of fire and listed for the use. [725.179 (C)]~~

~~E4303.2.3Type CL2X cables.~~

~~Type CL2X limited-use cable shall be listed as being suitable for use in dwellings and for the use and in raceways and shall also be listed as being flame retardant. Cables with a diameter of less than $^1/_4$ inch (6.4 mm) shall be permitted to be installed without a raceway. [725.179 (D)]~~

~~E4303.2.4Type CL2R cables.~~

~~Cables installed in a vertical run in a shaft or installed from floor to floor shall be listed as suitable for use in a vertical run in a shaft or from floor to floor and shall also be listed as having fire-resistant characteristics capable of preventing fire from being conveyed from floor to floor. [725.179(B)]~~

~~**Exception:** CL2X and CL3X cables with a diameter of less than $^1/_4$ inch (6.4 mm) and CL2 and CL3 cables shall be permitted in risers in one- and two-family dwelling units. [725.154 (G)]~~

~~E4303.2.5Marking.~~

~~Cables shall be marked in accordance with Table E4303.2.5. Voltage ratings shall not be marked on cables.~~

~~Table E4303.2.5 [Table 725.179(K)]~~

~~CABLE MARKING~~

~~**CABLE MARKING**~~	~~**TYPE**~~
~~CL2P~~	~~Class 2 plenum cable~~
~~CL2R~~	~~Class 2 riser cable~~
~~CL2~~	~~Class 2 cable~~
~~CL2X~~	~~Class 2 cable, limited use~~

~~**SECTION**E4304~~
~~INSTALLATION REQUIREMENTS~~

~~E4304.1Separation from other conductors.~~

~~In cables, compartments, enclosures, outlet boxes, device boxes, and raceways, conductors of Class 2 circuits shall not be placed in any cable, compartment, enclosure, outlet box, device box, raceway, or similar fitting with conductors of electric light, power, Class 1 and nonpower-limited fire alarm circuits. (725.136)~~

~~**Exceptions:**~~

7. ~~1.Where the conductors of the electric light, power, Class 1 and nonpower-limited fire alarm circuits are separated by a barrier from the Class 2 circuits. In enclosures, Class 2 circuits shall be permitted to be installed in a raceway within the enclosure to separate them from Class 1, electric light, power and nonpower-limited fire alarm circuits. [725.136(B)]~~

8. ~~2.Class 2 conductors in compartments, enclosures, device boxes, outlet boxes and similar fittings where electric light, power, Class 1 or nonpower-limited fire alarm circuit conductors are introduced solely to connect to the equipment connected to the Class 2 circuits. The electric light, power, Class 1 and nonpower-limited fire alarm circuit conductors shall be routed to maintain a minimum of $^1/_4$-inch (6.4 mm) separation from the conductors and cables of the Class 2 circuits; or the electric light power, Class 1 and nonpower-limited fire alarm circuit conductors operate at 150 volts or less to ground and the Class 2 circuits are installed using Types CL3, CL3R, or CL3P or permitted substitute cables, and provided that these Class 3 cable conductors extending beyond their jacket are separated by a minimum of $^1/_4$-inch (6.4 mm) or by a nonconductive sleeve or nonconductive barrier from all other conductors. [725.136(D)]~~

~~E4304.2Other applications.~~

~~Conductors of Class 2 circuits shall be separated by not less than 2 inches (51 mm) from conductors of any electric light, power, Class 1 or nonpowerlimited fire alarm circuits except where one of the following conditions is met:~~

~~9. 1.All of the electric light, power, Class 1 and nonpowerlimited fire alarm circuit conductors are in raceways or in metal-sheathed, metal-clad, nonmetallic-sheathed or Type UF cables.~~

~~10. 2.All of the Class 2 circuit conductors are in raceways or in metal-sheathed, metal-clad, nonmetallic-sheathed or Type UF cables. [725.136(I)]~~

~~E4304.3Class 2 circuits with communications circuits.~~

~~Where Class 2 circuit conductors are in the same cable as communications circuits, the Class 2 circuits shall be classified as communications circuits and shall meet the requirements of Article 800 of NFPA 70. The cables shall be listed as communications cables or multipurpose cables.~~

~~Cables constructed of individually listed Class 2 and communications cables under a common jacket shall be permitted to be classified as communications cables. The fire-resistance rating of the composite cable shall be determined by the performance of the composite cable. [725.139(D)]~~

~~E4304.4Class 2 cables with other circuit cables.~~

~~Jacketed cables of Class 2 circuits shall be permitted in the same enclosure or raceway with jacketed cables of any of the following:~~

~~11. 1.Power-limited fire alarm systems in compliance with Article 760 of NFPA 70.~~

~~12. 2.Nonconductive and conductive optical fiber cables in compliance with Article 770 of NFPA 70.~~

~~13. 3.Communications circuits in compliance with Article 800 of NFPA 70.~~

~~14. 4.Community antenna television and radio distribution systems in compliance with Article 820 of NFPA 70.~~

~~15. 5.Low-power, network-powered broadband communications in compliance with Article 830 of NFPA 70. [725.139(E)]~~

~~E4304.5Installation of conductors and cables.~~

~~Cables and conductors installed exposed on the surface of ceilings and sidewalls shall be supported by the building structure in such a manner that they will not be damaged by normal building use. Such cables shall be supported by straps, staples, hangers, cable ties or similar fittings designed so as to not damage the cable. Nonmetallic cable ties and other nonmetallic accessories used to secure and support cables located in stud cavity and joist space plenums shall be listed as having low smoke and heat release properties. The installation shall comply with Table E3802.1 regarding cables run parallel with~~

~~framing members and furring strips. The installation of wires and cables shall not prevent access to equipment nor prevent removal of panels, including suspended ceiling panels. Raceways shall not be used as a means of support for Class 2 circuit conductors, except where the supporting raceway contains conductors supplying power to the functionally associated equipment controlled by the Class 2 conductors. [300.22 (C) (1) and 725.24]~~

E7215

Date Submitted	11/8/2018	**Section**	3702.13	**Proponent**	John Hall
Chapter	37	**Affects HVHZ**	No	**Attachments**	Yes
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **Yes** **Alternate Language** **No**

Related Modifications

No related modifications have been identified.

Summary of Modification

The modification provides for infrastructure to accomodate future electric vehicle charging equipment in one- and two-family dwellings and townhouses with garages.

Rationale

Florida consistently ranks in the top three states for electric vehicle sales. The Florida legislature cited the importance and benefit of electric vehicles in FS 718.113(8). The ability for property owners to install EV charging equipment without destructive measures will faciltate the adoption of this technology, protecting the environment and providing an economic benefit to the state.

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

There will be no cost impact relative to enforcement of the code due to this proposed modification. The inspection activity will be performed during already required inspections that are regularly scheduled.

Impact to building and property owners relative to cost of compliance with code

The cost impact to building and property owners for compliance with the proposed modification will be negligible. The modification seeks only the provision of a raceway and space in the electrical panel to facilitate the installation of EV charging equipment at a future date.

Impact to industry relative to the cost of compliance with code

The cost impact to industry will likewise be negligible due to the limited scope of the proposed modification. No installation of equipment, wiring, or outlet is required by the modification. Only an empty raceway and space in the electrical panel for the future circuit breaker is envisioned.

Impact to small business relative to the cost of compliance with code

There will be no cost impact to small business. The scope of the proposed modification is limited to one- and two-family dwellings and townhouses.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

The proposed modification has connection with the health, safety, and welfare of the general public through reduction of emissions from the use of fossil fuels and the economic savings of operating an electric vehicle versus the cost of operating fossil fuel powered vehicles.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

The proposed modification improves the code by making provision for the implementation of better products and methods of powering transportation. Electrical vehicle use is increasing annually and these systems are crucial to further adoption of the technology.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

The proposed modification does not discriminate against any materials, products, methods, or systems of construction as none are specified. The modification simply provides for the easier implementation of the technology with no destructive effect to the structure.

Does not degrade the effectiveness of the code

The proposed modification does not degrade the effectiveness of the code. The implementation of the code is enhanced through the provision of simplified means of compliance for property owners desiring to operate electric vehicles.

1st Comment Period History

E7215-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I support the proposed modification as it will ensure the FBC includes the most current requirements for electrical installations that provide for the health, safety and general welfare of the public.

CHAPTER 37
BRANCH CIRCUIT AND FEEDER REQUIREMENTS

SECTION E3702
BRANCH CIRCUIT RATINGS

E3702.1 Branch-circuit voltage limitations.

The voltage ratings of branch circuits that supply luminaires or receptacles for cord-and-plug-connected loads of up to 1,400 volt-amperes or of less than 1/4 horsepower (0.186 kW) shall be limited to a maximum rating of 120 volts, nominal, between conductors.

Branch circuits that supply cord-and-plug-connected or permanently connected utilization equipment and appliances rated at over 1,440 volt-amperes or 1/4 horsepower (0.186 kW) and greater shall be rated at 120 volts or 240 volts, nominal. [210.6(A), (B), and (C)]

E3702.2 Branch-circuit ampere rating.

Branch circuits shall be rated in accordance with the maximum allowable ampere rating or setting of the overcurrent protection device. The rating for other than individual branch circuits shall be 15, 20, 30, 40 and 50 amperes. Where conductors of higher ampacity are used, the ampere rating or setting of the specified over-current device shall determine the circuit rating. (210.3)

E3702.3 Fifteen- and 20-ampere branch circuits.

A 15- or 20-ampere branch circuit shall be permitted to supply lighting units, or other utilization equipment, or a combination of both. The rating of any one cord-and-plug-connected utilization equipment not fastened in place shall not exceed 80 percent of the branch-circuit ampere rating. The total rating of utilization equipment fastened in place, other than luminaires, shall not exceed 50 percent of the branch-circuit ampere rating where lighting units, cord-and-plug-connected utilization equipment not fastened in place, or both, are also supplied. [210.23(A)(1) and (2)]

E3702.4 Thirty-ampere branch circuits.

A 30-ampere branch circuit shall be permitted to supply fixed utilization equipment. A rating of any one cord-and-plug-connected utilization equipment shall not exceed 80 percent of the branch circuit ampere rating. [210.23(B)]

E3702.5 Branch circuits serving multiple loads or outlets.

General-purpose branch circuits shall supply lighting outlets, appliances, equipment or receptacle outlets, and combinations of such. Multioutlet branch circuits serving lighting or receptacles shall be limited to a maximum branch-circuit rating of 20 amperes. [210.23(A), (B), and (C)]

E3702.6 Branch circuits serving a single motor.

Branch-circuit conductors supplying a single motor shall have an ampacity not less than 125 percent of the motor full-load current rating. [430.22(A)]

E3702.7 Branch circuits serving motor-operated and combination loads.

For circuits supplying loads consisting of motor-operated utilization equipment that is fastened in place and that has a motor larger than 1/8 horsepower (0.093 kW) in combination with other loads, the total calculated load shall be based on 125 percent of the largest motor load plus the sum of the other loads. [220.18(A)]

E3702.8 Branch-circuit inductive and LED lighting loads.

For circuits supplying luminaires having ballasts or LED drivers, the calculated load shall be based on the total ampere ratings of such units and not on the total watts of the lamps. [220.18(B)]

E3702.9 Branch-circuit load for ranges and cooking appliances.

It shall be permissible to calculate the branch-circuit load for one range in accordance with Table E3704.2(2). The branch-circuit load for one wall-mounted oven or one counter-mounted cooking unit shall be the nameplate rating of the appliance. The branch-circuit load for a counter-mounted cooking unit and not more than two wall-mounted ovens all supplied from a single branch circuit and located in the same room shall be calculated by adding the nameplate ratings of the individual appliances and treating the total as equivalent to one range. (220.55 Note 4)

E3702.9.1 Minimum branch circuit for ranges.

Ranges with a rating of 8.75 kVA or more shall be supplied by a branch circuit having a minimum rating of 40 amperes. [210.19(A)(3)]

E3702.10 Branch circuits serving heating loads.

Electric space-heating and water-heating appliances shall be considered to be continuous loads. Branch circuits supplying two or more outlets for fixed electric space-heating equipment shall be rated 15, 20, 25 or 30 amperes. [424.3(A)]

E3702.11 Branch circuits for air-conditioning and heat pump equipment.

The ampacity of the conductors supplying multimotor and combination load equipment shall be not less than the minimum circuit ampacity marked on the equipment. The branch-circuit overcurrent device rating shall be the size and type marked on the appliance. [440.4(B), 440.35, 440.62(A)]

E3702.12 Branch circuits serving room air conditioners.

A room air conditioner shall be considered as a single motor unit in determining its branch-circuit requirements where all the following conditions are met:

1. It is cord- and attachment plug-connected.
2. The rating is not more than 40 amperes and 250 volts; single phase.
3. Total rated-load current is shown on the room air-conditioner nameplate rather than individual motor currents.
4. The rating of the branch-circuit short-circuit and ground-fault protective device does not exceed the ampacity of the branch-circuit conductors, or the rating of the branch-circuit conductors, or the rating of the receptacle, whichever is less. [440.62(A)]

E3702.12.1 Where no other loads are supplied.
The total marked rating of a cord- and attachment plug-connected room air conditioner shall not exceed 80 percent of the rating of a branch circuit where no other appliances are also supplied. [440.62(B)]

E3702.12.2 Where lighting units or other appliances are also supplied.
The total marked rating of a cord- and attachment plug-connected room air conditioner shall not exceed 50 percent of the rating of a branch circuit where lighting or other appliances are also supplied. Where the circuitry is interlocked to prevent simultaneous operation of the room air conditioner and energization of other outlets on the same branch circuit, a cord- and attachment-plug-connected room air conditioner shall not exceed 80 percent of the branch-circuit rating. [440.62(C)]

E3702.13 Electric vehicle branch circuit.

Outlets installed for the purpose of charging electric vehicles shall be supplied by an individual branch circuit. Each circuit shall not supply other outlets. (625.40)

E3702.13.1 Electric vehicle (EV) charging for new construction.
New construction shall comply with this Section to facilitate future installation of *electric vehicle supply equipment.*

E3702.13.2 New one- and two-family dwellings and *townhouses* with attached or detached private garages.

For each dwelling unit with an attached or detached garage shall be designed with provision for future installation of *electric vehicle supply equipment* in accordance with Section E3702.13 through E3702.13.3.2.

E3702.13.3 Raceway.

A listed raceway of minimum trade size 1 shall be installed to accommodate a branch circuit for *electric vehicle supply equipment.*

The raceway shall originate at the main electrical panel or a properly rated sub-panel, and terminate in a listed box or enclosure in close proximity to the proposed location of the *electric vehicle supply equipment.*

The raceway shall be continuous from the point of origin to the termination at the proposed location of the *electric vehicle supply equipment.*

The enclosure provided for future *electric vehicle supply equipment* shall be labeled “EV CAPABLE”. The label shall comply with NFPA 70 Section 110.21(B).

E3702.13.3.4 Service Capacity.

The electrical service shall be sized to accommodate a 40-ampere 240-volt branch circuit for *electric vehicle supply equipment.*

E3702.13.3.5 Electrical panel capacity.

The electrical panel from which the electric vehicle supply equipment branch circuit originates shall be rated for, and be provided with open space for installation of a two-pole 40-ampere overcurrent protective device. The provided overcurrent device space(s) shall be identified in the panel circuit directory as "EV CAPABLE".

E3702.14 Branch-circuit requirement—summary.

The requirements for circuits having two or more outlets, or receptacles, other than the receptacle circuits of Sections E3703.2, E3703.3 and E3703.4, are summarized in Table E3702.14. Branch circuits in dwelling units shall supply only loads within that dwelling unit or loads associated only with that dwelling unit. Branch circuits installed for the purpose of lighting, central alarm, signal, communications or other purposes for public or common areas of a two-family dwelling shall not be supplied from equipment that supplies an individual dwelling unit. (210.24 and 210.25)

Plug In America. We drive electric. You can too.

Electric Vehicles in Florida

Plug-in electric vehicles (PEVs) are fun to drive and provide significant benefits to the American economy not just through the domestic manufacturing of the vehicles, but also through additional jobs in the electric power industry for the energy to operate them.[1,2] The increased use of domestic electricity in the transportation sector promotes national security by reducing our dependence on imported oil. These vehicles keep the U.S. competitive with China and the Europe Union, which are both movingly aggressively towards full deployment of the vehicles and nationwide charging systems.

There are currently over 23,376 PEVs on Florida roads today, with the market ready to expand as new vehicle makes and models become available in Florida.[3] As these vehicles are a win-win for Florida, it's no surprise that consumers want more of these vehicles today.

Policies in Florida for PEVs

Policy support at the federal, state and local levels is needed as the PEV market continues to develop and grow. Below is the most current list of PEV policies in Florida:

Vehicle Purchase Incentive: Jacksonville Electric Authority (JEA) offers a rebate up to $1,000 for the purchase or lease of a qualified PEV.[4]

Charging Station Incentive: The Orlando Utilities Commission (OUC) offers a rebate of $200 per station for businesses to install workplace charging stations. Local governments may also offer funding to property owners within their jurisdiction to help with EVSE financing.[5]

West Palm Beach, Florida National Drive Electric Week 2016

HOV Lane Access Policy: PHEVs are eligible for the HOV lane after applying for the Florida HOV decal. [6]

Parking Policy for PEVs: Some commercial and public buildings may offer parking for PEV customers only.

Other: FL Insurance companies may offer discounts on PEVs.

Fun Facts for PEVs in Florida

- Florida is second to California in number of EVs registered in the state. Florida even beats out New York, Texas, Washington and Georgia, all large car markets.
- With a cleaner electricity grid and improved efficiency of electric vehicles, greenhouse gas emissions and air quality from charging an electric vehicle on the grid improved in 76% of the regions sampled from 2012 to 2015.[7]

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[1] Currently, the U.S. manufactures PEVs and other advanced technology vehicles and components in at least 20 states, creating thousands of new, good jobs. Furthermore, the auto industry has distribution centers, sales offices and operational facilities in all 50 states; the PEV industry is a part of the same distribution, sales and operational network and is difficult to separate from the main auto industry. More at: http://sierraclub.typepad.com/compass/2012/06/fuel-economy-jobs.html

[2] PEVs include battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). The BEVs are charged by electricity from the local grid, while PHEVs drive on electricity from the local grid first, then on gasoline for longer trips

[3] https://autoalliance.org/in-your-state/FL/

[4] https://www.jea.com/Ways_to_Save/Go_Green/Plug-in_Electric_Vehicles/Electric_Vehicle_Incentives/

[55] http://www.ouc.com/business/business-rebates-programs/business-ev-charging-stations

[6] https://www.flhsmv.gov/motor-vehicles-tags-titles/high-occupancy-vehicle-decal/

[7] http://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf

Plug In America

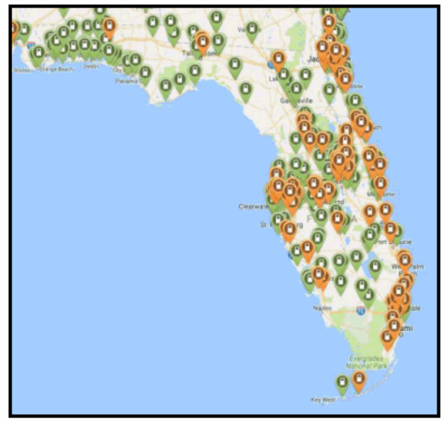
We drive electric. You can too.

- In 2016, the US sold over 159,000 EVs, which is a 38% increase over 2015.[8]
- In 2015, the Tesla Model S, Chevrolet Volt, and Nissan Leaf (all mass marketed EVs) ranked first, second and third for most satisfying commuter car.[9]

Benefits for Every Driver in Florida

The benefits of PEVs accrue to all residents in Florida, regardless if the driver is in an urban or metro area. Top benefits include:

1. **PEVs put money back in the pockets of consumers.** On average, fueling a car with electricity is roughly the same as gas at $1 per gallon, thanks to a PEV's performance efficiency and the lower cost of electricity.[10] Maintenance costs are also significantly reduced.
2. **All drivers in Florida have the ability to charge.** PEVs can be charged on a standard 120V wall outlet, also called Level 1 charging.[11] Faster charging can be achieved at the home or workplace with Level 2 charging.[12] The map at the right shows the public charging stations that are currently available to all Florida drivers.[13] The orange icons are DC Fast charging stations, and the green icons represent public Level 2 charging stations. It is possible to get nearly anywhere in the state with a PEV, proving that these vehicles can work for all Florida drivers.



Current public charging stations available to all Florida drivers.

3. **PEVs are significantly better for the local economy**. PEVs are fueled from electricity from the local grid, which is cheaper for all consumers. Money not spent on gas or on maintenance can be invested back into the local economy.
4. **PEVs improve air quality and reduce health care costs.** Poor air quality is still a problem for many U.S. states.[14] PEVs produce far fewer tailpipe emissions than a standard gasoline-powered vehicle, therefore significantly reducing dangerous air pollution. With more PEVs on the roads, public and private health care costs can be greatly reduced.

About Plug In America

Plug In America is the nation's leading independent consumer voice for accelerating the use of plug-in electric vehicles in the United States to consumers, policymakers, auto manufacturers and others. Formed as a non-profit in 2008, Plug In America provides practical, objective information collected from our coalition of plug-in vehicle drivers, through public outreach and education, policy work and a range of technical advisory services. Our expertise represents the world's deepest pool of experience of driving and living with plug-in vehicles. The organization conceived National Drive Electric Week and has advanced workplace charging by pioneering ride-and-drive events at such leading corporations as Google, Mattel and Paramount Pictures. We drive electric. You can too. www.pluginamerica.org

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[8] http://www.fleetcarma.com/ev-sales-usa-2016-final/
[9] http://www.consumerreports.org/cars-the-most-satisfying-cars-for-commuting/
[10] http://energy.gov/eere/eveverywhere/ev-everywhere-saving-fuel-and-vehicle-costs
[11] Level 1 is AC charging at 120V, the level of power that is supplied by a normal household outlet. This will supply up to 40 miles of range for an 8-hour connection during a typical work day. That's enough to replenish the charge for the majority of Florida drivers.
[12] Level 2 is AC charging at a power level similar to what is supplied by an outlet for an electric dryer, typically 240V.
[13] Zooming in further shows even more charging stations available. PlugShare is one platform that tracks charging station locations, prices and types of charging at each location. Drivers can download the PlugShare app to a mobile phone for free.
[14] http://www.lung.org/our-initiatives/healthy-air/sota/key-findings/

E8149

Date Submitted	12/14/2018	**Section**	3902.16	**Proponent**	STEVE ROOD
Chapter	39	**Affects HVHZ**	No	**Attachments**	Yes
TAC Recommendation	Pending Review				
Commission Action	Pending Review				

Comments

General Comments **Yes** | **Alternate Language** **No**

Related Modifications

Summary of Modification

This proposal recommends deletion of kitchens and laundry areas from the list of locations within dwelling units where AFCI protection is required.

Rationale

Please see two uploaded support files:

- One summarizes lack of substantiation of fires specifically located in kitchens or laundry areas from the fire data used to justify expansion to those areas, along with information on the nuisance tripping problem that is increasing along with expanded use of AFCI.

- The second is a two-page summary of an NFPA-funded Fire Protection Research Foundation report that advised “the most significant problem with residential electrical fire data is that nearly all of the currently available public data is lacking in quality and accuracy, and is relatively unusable for data analytics in its current state.” As such,” the existing residential electrical data is generally unrefined and provides limited value to the analysis of determining the effectiveness of electrical branch circuit protection devices.”

Fiscal Impact Statement

Impact to local entity relative to enforcement of code

No known impact; no known or obvious incremental added enforcement expense to the deletion of these requirements, as the enforcement activity is ongoing and required as is currently the case (a "roll back" vs. an added requirement is proposed).

Impact to building and property owners relative to cost of compliance with code

FISCAL IMPACT: Estimated electrical installer savings: $180 - $192 per home. Please see attached support file for fiscal input assumptions.

Impact to industry relative to the cost of compliance with code

No known impact; no known or obvious incremental cost of compliance to industry, as the recommendation is for a "roll back" as opposed to an added requirement.

Impact to small business relative to the cost of compliance with code

FISCAL IMPACT: Estimated electrical installer savings: $180 - $192 per home. Please see attached support file for fiscal input assumptions.

Requirements

Has a reasonable and substantial connection with the health, safety, and welfare of the general public

Mandated AFCI protection in kitchen and laundry areas can compromise electrical safety for home dwellers. Please see uploaded support file that reviews these points.

Strengthens or improves the code, and provides equivalent or better products, methods, or systems of construction

Strengthens the code with respect to incrementally reducing AFCI requirements where increased safety that is purported to be provided by its implementation in the kitchen and laundry areas cannot be quantified or confirmed due to the lack of verifiable data as the FPRF report points out.

Does not discriminate against materials, products, methods, or systems of construction of demonstrated capabilities

No known discrimination of this sort; assists with reductions of installer call backs due to nuisance tripping, which enhances productivity of builders, contractors and similar installer firms.

Does not degrade the effectiveness of the code

No known degradation to the effectiveness of the code; many other states and municipalities have approved and implemented amendments and exceptions to AFCI protection for the same reasons as detailed in this proposal. Please see uploaded support file of 15 states and 3 municipalities.

1st Comment Period History

E8149-G1

Proponent Vincent Della Croce **Submitted** 1/8/2019 **Attachments** No

Comment:

I strongly oppose this proposal as it reduces the effectiveness and safety of the code requirements related to life and property safety.

1st Comment Period History

E8149-G2

Proponent Si Farvardin **Submitted** 2/5/2019 **Attachments** Yes

Comment:

Dear TAC members,

The Insurance Institute for Business & Home Safety (IBHS) is a nonprofit organization supported by the property insurance industry. Our mission is to identify and promote effective ways to strengthen homes and businesses against natural hazards and other causes of loss. We do this by conducting research and testing, and advocating adoption of building and safety codes, and improved construction, maintenance and preparedness practices.

Among IBHS's highest priorities are the adoption and enforcement of building and safety codes without any weakening amendments. Accordingly, IBHS respectfully requests the Florida Electrical TAC to reject Modification E8149, which proposes to eliminate the arc fault circuit interrupters (AFCIs) in kitchen and laundry circuits of residential dwellings. The AFCIs required by the National Electrical Code® (NEC) are proven to be quite effective in residential wiring systems by detecting and isolating problems that could lead to electrical fires. Elimination of this important code requirement and life-saving technology—from kitchen and laundry circuits—will seriously reduce the electrical safety of new residential dwelling construction throughout the state of Florida.

IBHS urges the TAC members to continue to protect the safety and welfare of the state residents and retain the recommended requirement for arc fault circuit interrupters in kitchen and laundry circuits to be adopted as part of the 2017 NEC.
We thank you for the opportunity to comment.

Sincerely,

Si Farvardin
Manager of Codes and Standards
Insurance Institute for Business & Home Safety

1st Comment Period History

E8149-G3

Proponent Bryan Holland **Submitted** 2/6/2019 **Attachments** Yes

Comment:

NEMA strongly opposes this proposed modification that would reduce electrical safety by increasing the risk of fire in a home.
Please see the attached support files.

1st Comment Period History

E8149-G4

Proponent Jeff Terrey **Submitted** 2/15/2019 **Attachments** Yes

Comment:

Please see attached.

1st Comment Period History

E8149-G5

Proponent Jeff Terrey **Submitted** 2/15/2019 **Attachments** Yes

Comment:

Please see attached.

1st Comment Period History

E8149-G6

Proponent Johnson Steve **Submitted** 2/15/2019 **Attachments** No

Comment:

Dear Committee members,

My name is Steve Johnson and I'm a professional firefighter in Marion County. My wife is a burn survivor from an electrical fire started by an arc in a circuit. Together, we offer unique perspectives on why you should not approve a proposal that would prevent our state from having the strongest electrical building codes at 2017 levels. This proposal would scale back arc fault circuit interrupter requirements to 2011 levels – exposing all new residential construction to potential electrical fires in kitchens and laundry areas. Why would you do that?

As a career firefighter, I respond to numerous house fires, most of which are determined to be caused by an electrical malfunction and many of which originate in these areas of the home. These areas need this additional protection with the use of added electrical devices, power cords, and appliances. Do we need these devices to detect the dangerous arcing that can prevent these fires from ever starting? Of course, we do. We need them as badly as we need smoke detectors, sprinklers, fire ladders, carbon monoxide detectors, and fire resistant construction materials that also help prevent the spread of fires. Everything working together helps prevent and warn us of house fires that risk not only the occupant's lives, but mine as a firefighter as well.

I've seen firsthand how devastating electrical fires can be to buildings and families. Estimates are in the millions of dollars when it comes to structural damage, and more importantly, consider the emotional toll deaths and injuries bring to people nationwide.

You are the experts on this issue on the front end, but from someone who is out in the trenches, I beg of you – please protect the safety of every man, woman and child and those protecting our communities in the fire services. Approve of technologies like AFCIs that save lives and prevent electrical fires. Please oppose this bad idea to scale back those requirements.

Steve Johnson

1st Comment Period History

E8149-G7

Proponent David Hewitt **Submitted** 2/18/2019 **Attachments** Yes

Comment:

Siemens strongly opposes this proposed modification in that it would reduce electrical safety by increasing the risk of fire in a home. Removing AFCI protection raises concerns with respect to the protection of life and property.

Branch circuits that supply 120-volt, single-phase, 15- and 20-ampere outlets installed in ~~kitchens~~, family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreations rooms, closets, hallways, ~~laundry areas~~ and similar rooms or areas shall be protected by any of the following: [210.12(A)]

Insurance Institute for Business & Home Safety®

February 4, 2019

Florida Electrical TAC

Re: —Opposition to Modification E8149

Dear TAC members,

The Insurance Institute for Business & Home Safety (IBHS) is a nonprofit organization supported by the property insurance industry. Our mission is to identify and promote effective ways to strengthen homes and businesses against natural hazards and other causes of loss. We do this by conducting research and testing, and advocating adoption of building and safety codes, and improved construction, maintenance and preparedness practices.

Among IBHS's highest priorities are the adoption and enforcement of building and safety codes without any weakening amendments. Accordingly, IBHS respectfully requests the Florida Electrical TAC to reject Modification E8149, which proposes to eliminate the arc fault circuit interrupters (AFCIs) in kitchen and laundry circuits of residential dwellings. The AFCIs required by the *National Electrical Code®* (NEC) are proven to be quite effective in residential wiring systems by detecting and isolating problems that could lead to electrical fires. Elimination of this important code requirement and life-saving technology—from kitchen and laundry circuits—will seriously reduce the electrical safety of new residential dwelling construction throughout the state of Florida.

IBHS urges the TAC members to continue to protect the safety and welfare of the state residents and retain the recommended requirement for arc fault circuit interrupters in kitchen and laundry circuits to be adopted as part of the 2017 NEC.
We thank you for the opportunity to comment.

Sincerely,

Si Farvardin
Manager of Codes and Standards
Insurance Institute for Business & Home Safety

Where building safety research leads to real-world solutions.

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2 of 2

Circuit Breaker AFCIs | Advanced Technology for the Modern Home

Applying technology to improve the electrical safety of the modern home is a wise investment for both the homeowner and the community at large. Circuit breaker arc-fault circuit interrupters, or AFCIs, can provide enhanced protection from fires resulting from damaged or unsafe home wiring conditions. Typical household fuses and standard circuit breakers do not respond to early arcing and sparking conditions in home wiring. By the time a fuse or standard circuit breaker opens a circuit to defuse these conditions, a fire may already have begun.

AFCI circuit breakers represent the latest technological advancement for home electrical systems.

According to the National Fire Protection Association, fire safety officials recommend the use of AFCIs in all dwellings.

Effective

AFCI circuit breakers are **intelligent devices** containing advanced technology that will detect an arc fault in home wiring and automatically shut down the electricity when it senses a hazard.

The National Fire Prevention Association publishes the National Electrical Code® (NEC) to protect people and property from electrical hazards. The NEC has required AFCI protection for bedroom wiring since 2002 and has since expanded to require AFCI protection for the wiring of living, dining, and family rooms as well as kitchens, laundry, hallways, and closets.

Available

Several companies manufacture AFCI circuit breakers for consumers to choose from. AFCI circuit breakers can be purchased at **electrical supply houses, home improvement stores**, and **online**.

National Averages

Kitchen remodel	$22,134
Bathroom remodel	$9,700
Cabinets	$3,500
Granite countertops	$2,500
Garage door	$1,200
AFCI protection	$300

Source: HomeAdvisor.com

AFCI circuit breakers should be installed by a person trained and qualified in electrical wiring methods.

Affordable

The average cost for an AFCI circuit breaker is **$38***, and the average lifetime cost to protect a new 2,000 square-foot, four-bedroom home is **$300**.

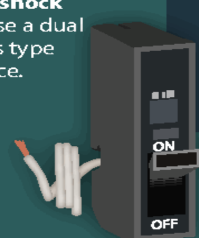
Compatible

AFCI circuit breakers work extremely well with **new appliances** that meet U.S. product safety standards.

AFCI vs GFCI

AFCIs and GFCIs provide different but **critically important protection**. AFCI circuit breakers address fire hazards whereas GFCIs address **electric shock hazards**. A common way to provide both types of protection is to use a dual function breaker that combines Class A 5mA GFCI and combinations type AFCI protection against both arc faults and ground fault in one device.

According to the Consumer Product Safety Commission, both AFCI and GFCI circuit breakers are important safety devices.



For more information go to **www.afcisafety.org**

**NEMA blind survey for 2017 HUD Manufactured Housing Construction Standards.*

NEMA National Electrical Manufacturers Association

National Electrical Manufacturers Association

The association of electrical equipment and medical imaging manufacturers
www.nema.org

Circuit Breaker Arc-Fault Circuit Interrupters (AFCIs) – Myth vs. Fact

Cost

Myth: AFCI circuit breakers required in new home construction can cost $3,000+ per home, making them unaffordable.

Fact: The average cost for an AFCI circuit breaker is $38 (according to a NEMA blind survey for 2017 HUD Manufactured Housing Construction Safety Standards), or approx. $300 to protect a new 2,000-square-foot, four-bedroom home from electrical fires caused by electrical arcing. That's about 83 cents per month to protect a family from electrical fires over a 30-year mortgage. In contrast, material and hefty labor costs associated with installing a home builder upgrade like granite countertops averages around $4,500, or $12.50 per month over the same period. The National League of Cities recently indicated home builder "labor and land costs are by far the biggest construction expenses nationwide," resulting in rapidly rising home prices.

Appliance Compatibility

Myth: AFCI circuit breakers are not compatible with common household appliances.

Fact: AFCI circuit breakers work extremely well with new appliances that meet U.S. product safety standards. Some older appliances may incorporate components that predate current product safety standards or have operational characteristics that are not compatible with AFCI protection. Counterfeit appliances or those not certified by a Nationally Recognized Testing Laboratory (NRTL) may also be incompatible with AFCI circuit breakers.

AFCI/GFCI Compatibility

Myth: AFCI circuit breaker and Ground Fault Circuit Interrupters (GFCIs) won't work together.

Fact: AFCI circuit breakers and GFCIs complement and function well together in providing electrical safety and fire protection throughout a home. Both devices are required by the 2017 National Electrical Code® because they provide different, but critically important, protection. AFCI circuit breakers detect dangerous arcing in a home's wiring and stop electrical fires before they can start. GFCIs are required in rooms like kitchens, bathrooms and laundry rooms where water is present and help prevent possible shock and electrocution. There are dual function AFCI/GFCI circuit breakers on the market today that provide both types of protection in one device.

Product Availability

Myth: AFCI circuit breakers are hard to find.

Fact: Several companies manufacture AFCI circuit breakers for consumers to choose from. AFCI circuit breakers can be purchased at electrical supply houses, home improvement stores, and online.

AFCI Lifespan

Myth: AFCI circuit breakers only last one year or need frequent replacement.

Fact: AFCI circuit breakers are tested and certified to extremely rigorous U.S. product safety standards. When installed correctly, AFCI circuit breakers are expected to last the life of a standard circuit breaker under normal operating conditions. AFCI circuit breakers also carry a manufacturer's warranty.

1300 17th St N, Suite 900 — Arlington, VA 22209 — 703.841.3200

NEMA

ISSUE BRIEF

The Association of Electrical Equipment and Medical Imaging Manufacturers | nema.org/policy-briefs

Circuit Breaker Arc-Fault Circuit Interrupters (AFCI)

Smoke alarms, fire extinguishers and escape ladders are all examples of emergency equipment used in homes to take action when a fire occurs. A circuit breaker arc-fault circuit interrupter (AFCI) is a product designed to detect a wide range of arcing electrical faults to help reduce the electrical system from being an ignition source of a fire. Unlike a standard circuit breaker detecting overloads and short circuits, an AFCI utilizes advanced electronic technology to "sense" the different arcing conditions that may be occur on a circuit. While there are different techniques employed to detect arcs by the various AFCI circuit breaker manufacturers, the end result is the same: detection of arcing conditions on the branch-circuit wiring, plugged-in electrical cords, and within appliances and other utilization equipment.

Importance

AFCI circuit breakers were created as a direct response to a U.S. Consumer Product Safety Commission report conducted by Underwriters Laboratories (UL) that identified an electrical problem in residential wiring systems causing numerous residential fires. In 1999, AFCI protection became a requirement in the National Electrical Code®. According to a 2017 National Fire Protection Association report, between 2010 and 2014, U.S. municipal fire departments responded to an estimated annual average of 45,210 home structure fires involving electrical failure or malfunction. These fires caused annual averages of 420 civilian deaths, 1,370 civilian injuries, and $1.4 billion in direct property damage.

Affordability

The average cost for an AFCI circuit breaker is $38, according to a NEMA blind survey for 2017 HUD Manufactured Housing Construction Safety Standards, or $300 to protect a new 2,000-square-foot, four-bedroom home from electrical fires caused by electrical arcing. That equates to 83 cents per month to protect a family from electrical fires over a 30-year mortgage. When installed correctly, AFCI circuit breakers are expected to last the life of a standard circuit breaker under normal operating conditions. AFCI circuit breakers can be purchased at electrical supply houses, home improvement stores, and online. Several companies manufacture AFCI circuit breakers for consumers to choose from.

Compatibility

AFCI circuit breakers work extremely well with appliances and devices that meet U.S. product safety standards. AFCI circuit breakers also compliment ground-fault circuit interrupters (GFCIs) and function well together to provide electrical safety and fire protection throughout a home. Both devices are required by the National Electrical Code® because they provide different but critically important protection. AFCIs detect dangerous arcing in a home's wiring and stop electrical fires before they can start whereas GFCIs help to prevent possible shock and electrocution where these hazards to a person are present.

NEMA Position

The National Electrical Manufacturers Association actively supports and promotes the installation and use of AFCI technology in residential and commercial buildings as an important electrical safety device to protect persons and property.

The National Electrical Manufacturers Association (NEMA) represents nearly 350 electrical equipment and medical imaging manufacturers that make safe, reliable, and efficient products and systems. Our combined industries account for 360,000 American jobs in more than 7,000 facilities covering every state. Our industry produces $106 billion shipments of electrical equipment and medical imaging technologies per year with $36 billion exports.

arc fault circuit interrupters using advanced technology to reduce electrical fires

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

INTRODUCTION

Arc fault circuit interrupters (AFCIs) are required by the National Electrical Code® (NEC) for certain electrical circuits in the home. Questions have been raised regarding their application and even the need for them. Various technical "opinions," organizational "marketing pitches," and misinformation are being distributed about AFCIs that further mislead the public about the purpose of the device as a part of overall electrical safety for the public.

This brochure is intended to address the various aspects of AFCIs and dispell the misinformation circulating in the industry.

WHY DO WE REALLY NEED AFCIs?

Smoke alarms, fire extinguishers and escape ladders are all examples of emergency equipment used in homes to take action when a fire occurs. An AFCI is a product that is designed to detect a wide range of arcing electrical faults to help prevent the electrical system from being an ignition source of a fire. Conventional overcurrent protective devices do not detect low level hazardous arcing currents that have the potential to initiate electrical fires. It is well known that electrical fires do exist and take many lives and damage or destroy significant amounts of property. Electrical fires can be a silent killer occurring in areas of the home that are hidden from view and early detection. The objective is to protect the circuit in a manner that will reduce its chances of being a source of an electrical fire.

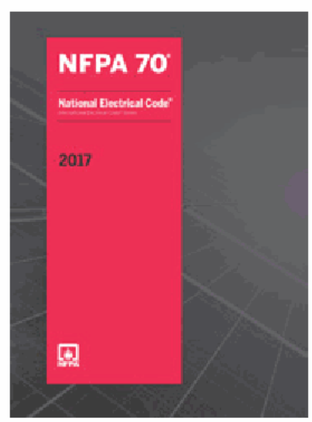
THE JOURNEY TO DEVELOP DETECTION TECHNOLOGY

Research in the arc fault area began in the late 1980s and early 1990s when the U.S. Consumer Product Safety Commission (CPSC) identified a concern with the residential fires of electrical origin. A large number of these fires were estimated to be in branch circuit wiring systems.

The concept of AFCIs gained more momentum when code proposals were made to the 1993 NEC to change the instantaneous trip levels of 15A and 20A circuit breakers. The Electronic Industries Association (EIA) had studied the issue of electrical fires and determined that additional protection against arcing faults were an area that needed to be addressed by electrical protection. This proposal first attempted to do this by requiring that instantaneous trip levels of a circuit breaker be reduced from a range of 120 to 150 amperes down to 85 amperes. However, it became clear that the lowering of those levels below some of the minimums already available on the market would result in significant unwanted tripping due to normal inrush currents.

It was these early studies and code efforts that led to the first proposals requiring AFCIs, which were made during the development of the 1999 NEC. NEC Code-Making Panel 2 (CMP2) reviewed many proposals ranging from protecting the entire residence to the protection of living and sleeping areas. In addition, the panel heard numerous presentations on both sides of the issue. After much data analysis and discussion, the CMP2 concluded that AFCI protection should be required for branch circuits that supply receptacle outlets in bedrooms.

Subsequent editions of the NEC further upgraded the requirements to include all 120-volt, single-phase, 15- and 20-ampere branch circuits supplying outlets or devices installed in dwelling unit kitchens, family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets, hallways, laundry areas, and similar rooms or areas, along with other enhancements.



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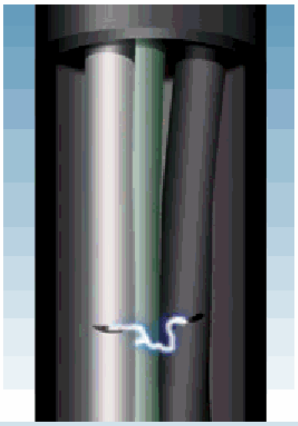
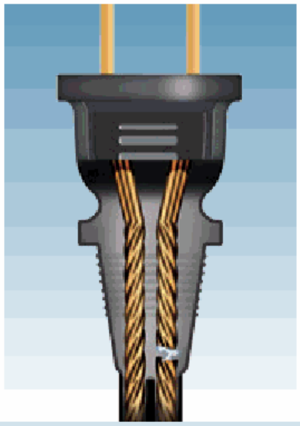

Parallel Arc


Series Arc

WHAT ARE ARC FAULTS?

The UL Standard for AFCIs (UL 1699) defines an arc fault as an unintentional arcing condition in a circuit. Arcing creates high intensity heating at the point of the arc, resulting in burning particles that may over time ignite surrounding material, such as wood framing or insulation.

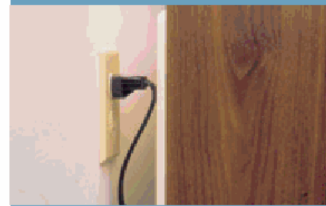
The temperatures of these arcs can exceed 10,000 degrees Fahrenheit. Repeated arcing can create carbon paths that are the foundation for continued arcing, generating even higher temperatures.

typical causes of arc faults

Example conditions where arc faults may start include:

- Damaged wires
- Worn electrical insulation
- Wires or cords in contact with vibrating metal
- Overheated or stressed electrical cords and wires
- Misapplied or damaged electrical appliances

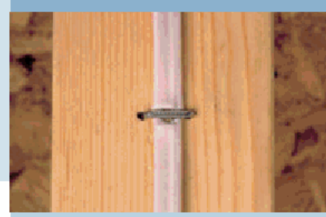
Furniture pushed against or resting on electrical cords can damage the wire insulation. Damaged cords can become a potential condition for arcing.



Extension or appliance cords that are damaged or have worn or cracked insulation can contribute to electrical arcing.

Cord insulation can be deteriorated by heat generated by hot air ducts or sunlight.

Cables that are improperly nailed or stapled too tightly against a wall stud can sever insulation and cause arcing.



Wires located behind walls can be accidentally punctured by a screw or drill bit damaging the insulation of the wiring.

Nails carelessly driven into walls can break wire insulation and cause arcing.

Nonmetallic sheathed cable damaged by gusset plate while being pulled through attic.

FIRE DATA ANALYSIS

The Federal Government, the National Fire Protection Association, and US fire departments track the incidence of electrical fires across the United States and categorize those fires based on their causes. In reviewing statistics from 2003 to 2014, fires in home electrical systems averaged 25,366 annually and resulted in 378 civilian deaths, 1,290 civilian injuries and $1.4 billion in direct property damage.* The NFPA Home Electrical Fires Fact Sheet indicates that wiring and related equipment were involved in 63% of these fires and half of the associated deaths in 2007-2011.

The U.S. Department of Housing and Urban Development (HUD) recommendation is to promote AFCIs as one of the many devices that can be used to prevent burns and fire related injuries. In addition, it cites a 1999 CPSC Report recommending the use of AFCIs to "prohibit or reduce potential electrical fires from happening."**

As you can see from the data above, fires of electrical origin are a significant issue that must be addressed. Frequently, it is argued that fires only occur in older homes. However, it should be recognized that new homes become older homes. It is critical to install the AFCIs in the beginning so that they can perform their protection function from the start. Seldom are devices such as AFCIs added to homes after they are constructed and occupied.

*Home Electrical Fires Fact Sheet, National Fire Protection Association

**Healthy Homes Issues: Injury Hazards, U.S. Department of Housing and Urban Development, Version 3, March 2006

HOW IS AN ARC FAULT DETECTED?

An AFCI device uses advanced electronic technology to "sense" the different arcing conditions. While there are different technologies employed to measure arcs by the various AFCI manufacturers, the end result is the same, detecting parallel arcs (line to line, line to neutral and line to ground) and/or series arcs (arcing in series with one of the conductors).

How does arc fault detection work? In essence, the detection is accomplished by the use of advanced electronic technology to monitor the circuit for the presence of "normal" and "dangerous" arcing conditions. Some equipment in the home, such as a motor driven vacuum cleaner or furnace motor, naturally create arcs. This is considered to be a normal arcing condition. Another normal arcing condition that can sometimes be seen is when a light switch is turned off and the opening of the contacts creates an arc.

A dangerous arc, as mentioned earlier, occurs for many reasons, including damage of the electrical conductor insulation. When arcing occurs, the AFCI analyzes the characteristics of the event and determines if it is a hazardous event. AFCI manufacturers test for the hundreds of possible operating conditions and then program their devices to monitor constantly for the normal and dangerous arcing conditions.

THE NEC AND UL STANDARD

National Electrical Code

The National Electrical Code specifically defines and mandates the installation of AFCIs. The areas in homes where AFCI protection is required have gradually expanded, and as of the 2014 edition include kitchens, family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets, hallways, laundry areas, and similar rooms or areas.

UL Standard

Product standards to cover AFCIs began to be developed in the mid-1990s. Underwriters Laboratories published UL 1699 Standard for Safety for AFCIs in 1999 to cover a wide variety of conditions to evaluate an AFCI. The standard includes requirements for the following conditions:

- Humidity conditioning
- Leakage current
- Voltage surge
- Environmental evaluation
- Dielectric voltage
- Arc-fault detection
- Unwanted tripping
- Operation inhibition
- Resistance to environmental noise
- Abnormal operation

One of the most frequent questions about AFCIs is related to resistance to unwanted tripping. There are four varieties of tests related to its ability to resist unwanted tripping:

- Inrush current: High-current-draw devices such as tungsten filament lamps and capacitor start motors.
- Normal arcing: Brush motors, thermostatic contacts, wall switch and appliance plugs.
- Non-sinusoidal waveforms: Examples of devices creating these electrical waveforms include electronic lamp dimmers, computer switching-mode power supplies and fluorescent lamps.
- Cross talk: This test measures trip avoidance for an AFCI when an arc is detected in an adjacent circuit. Only the circuit with the arc should cause the breaker to trip, not another circuit.

Through the use of the NEC requirement and extensive UL testing, manufacturers' AFCI products provide superior protection against arcing faults.

CONTRASTING AFCIs AND GFCIs

There is a major difference between the functioning of an AFCI as compared to a GFCI (ground fault circuit interrupter). The function of the GFCI is to protect people from the deadly effects of electric shock that could occur if parts of an electrical appliance or tool become energized due to a ground fault. The function of the AFCI is to protect the branch circuit wiring and electrical cords connected to it from dangerous arcing faults that could initiate an electrical fire.

AFCI and GFCI technologies can co-exist with each other and are a great complement for the most complete protection that can be provided on a circuit.

WHAT ARE THE VARIOUS SAFETY AND GOVERNMENTAL AGENCIES SAYING ABOUT AFCI?

"The National Association of State Fire Marshals (NASFM) strongly supports the broad adoption of AFCI technology through national, state, and local building codes. AFCIs are the most welcome addition to fire prevention in decades. AFCIs promise to save hundreds of lives every year."

— John C. Bean, President, NASFM

"The National Association of Home Inspectors (NAHI) strongly encourages its members to educate all of their clients about the life and property saving benefits of AFCI technology, especially those clients considering the purchase of a home more than 20 years old."

— Mallory Anderson, Executive Director

"The National Electrical Contractors Association (NECA) submitted comments to legislative committees in Michigan and South Carolina, urging them to retain requirements for AFCI protection of bedroom receptacles in their state electrical codes. Cost-cutting pressure from homebuilders' associations in both states led to code proposals to delete AFCI protection required by the National Electrical Code, when constructing new homes."

— NECA Contractor Code Letter

"CPSC has identified arc fault circuit interrupter (AFCI) technology as an effective means of preventing fires caused by electrical wiring faults in homes."

— U.S. Fire Administration

"The Electrical Safety Foundation International (ESFI) urges that arc fault circuit interrupter (AFCI) technology be installed in all new and existing housing to protect homes and families from fires caused by electrical arcing."

— Brett Brenner, President, ESFI

TYPES OF ARC FAULT CIRCUIT INTERRUPTERS

AFCI and GFCI Protection

An AFCI can be used in conjunction with GFCI protection to provide both arcing fault protection as well as 5mA ground fault (people) protection. A way to provide both types of protection is to use an AFCI circuit breaker and a GFCI receptacle. Another way is to install a dual function device that provides both AFCI and GFCI protection.

defining the arc fault risk to people and property

WIRING AND INSTALLATION GUIDELINES

There are no special requirements for an AFCI circuit other than proper installation and wiring practices. There are various special considerations that must be given to certain circuits that vary from the norm, such as shared neutral applications, but in general the application of an AFCI is as simple as following the installation instructions that come from the manufacturer.

As with any change in the required protection for the electrical system, there have been many discussions and deliberations both for and against arc fault protection being a part of the NEC. Some have argued that the cost of installing AFCIs is higher than the cost of installing standard devices and, as such, it costs too much to provide the increased protection. Others have argued that since it is a relatively new type of protection, it does not have the history on which to base a decision as to whether to support or not.

These issues have been debated thoroughly and completely. It is important to keep a few critical facts in mind.

- The cost to install AFCI circuit breakers in the home is insignificant when compared to the number of lives and property the device helps protect.
- The additional cost to install AFCIs is insignificant compared to the total cost of a new home, typically less than 0.1%.
- The Consumer Product Safety Commission staff report on Estimated Residential Structure Fires on Selected Electrical Equipment (October 2006) from 1999-2003 reported that 142,300 electrical distribution fires occurred on all distribution components. Installed wiring fires were estimated to have occurred in 50,200 instances.
- Using the same report, the CPSC projected that there were 910 deaths attributed to electrical distribution equipment during that five-year period. Installed wiring led to approximately 210 deaths as a part of that total.

Applying technology to improve the electrical safety of the home is a wise investment for both the homeowner and the community at large. Reducing fires of electrical origin and saving lives is an important responsibility of the entire construction and regulatory community. Taking these CPSC statistics into account, one has to ask, if a portion of the 50,200 fires could have been prevented, would the increase in cost have been worth the added protection AFCIs provide the homeowner?

what is the price of new safety technology worth?

When GFCIs were introduced in the 1970s, similar discussions took place regarding the cost/benefit to the consumer, homebuilder and others. GFCIs have been a standard requirement in homes for over 30 years with additional locations and circuits being added over time as well. GFCI also has a statistical track record over time as to the reduction of electrocutions. On an annual basis, in 1983, there were almost 900 electrocutions total per year with approximately 400 being consumer product related. Ten years later, the total was reduced to 650 annually and slightly over 200 consumer product electrocutions annually.

With over 20 years of history, statistically based analysis of GFCIs was built on a solid foundation of data. AFCIs are relatively new and have only been installed in a small fraction of the total number of circuits in U.S. homes. As with all products, given time, they too will be able to provide a solid statistical base of measure.

Some have argued that it should be shown how many times an AFCI has "prevented" a fire from occurring. Of course, this is not a feasible request. The AFCI disconnects the power when an arc fault occurs, therefore no incidence of fire or arc is reported to authorities. The same can be true when a smoke alarm siren alerts the homeowner and the small smoking event is extinguished without incident. Is that statistic reported to the federal government or local fire department? Of course not. Safety prevention is just that: prevention. The only statistics that are reported are those that have resulted in a fire or a response of a fire department. Many safety protection actions go unreported.

If we are to offer consumers a safer home, then the appropriate technology should be put into place.

Removing AFCI as a local or state code requirement is reducing safety requirements. These rules are established by a national body of experts that have heard testimony from many sources as well as reviewed a significant amount of data to make their recommendation. Shouldn't we trust the safety experts that develop our safety procedures?

NEMA AND ELECTRICAL SAFETY

For more than 80 years, manufacturers of low-voltage distribution equipment have been working to ensure public safety through standards writing efforts and the dissemination of important industry information through the National Electrical Manufacturers Association (NEMA), one of the most respected standards development organizations in the world. Headquartered in Rosslyn, Virginia, NEMA has approximately 350 electroindustry member companies, including large, medium and small businesses. To learn more about NEMA visit **www.nema.org**.

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

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www.nema.org

NEMA Objections to Proposed Modification E8149:

1. NEC CMP-2 has rejected similar proposals that have attempted to reduce or remove AFCI requirements from the code. In fact, the proponent of this proposal submitted a similar public input to the 2020 NEC (PI-3813) which was overwhelmingly rejected. His second attempt to remove kitchens and laundry areas during the comment phase (PC-1432) was again soundly rejected by the committee. The Electrical TAC should not support a fire-safety "roll back" and should never approve a below-code amendment to a national consensus standard that provides the minimum provisions considered necessary for safety.

2. The substantiation being provided by the submitter is not accurate and not applicable to AFCI protection. The NFPA studies being cited have nothing to do with the effectiveness of AFCI devices. The findings of the reports do not focus on a specific reason home fires continue to be a problem. The total number of home fires in any given year is not a proper metric for determining the efficacy or merits of AFCI protection or any other electrical/fire safety product. Home fires that have not started as a result of AFCI protection are not reported or tracked. There is currently no way to document the reduction of fires as a result of AFCI protection. More importantly, nothing in the reports indicate that AFCIs are not preventing fires from occurring. In fact, there is currently no evidence in any published report that a fire has occurred in a home where AFCI protection has been installed. The removal or reduction of AFCI protection for kitchens and laundry areas is not supported by the findings of any NFPA report.

3. The wiring methods and materials supplying kitchens and laundry areas along with receptacle use in these rooms are identical to those in the other rooms and spaces of a dwelling. There is no technical basis for not including the branch circuits that supply these areas within a dwelling while supporting continued protection of the other branch circuits in the rooms and spaces named in the code.

4. Approval of this proposal would discriminate against 1&2 family dwelling owners as it would only apply to those buildings under the scope of the FBC-R. All other dwellings under the scope of the FBC-B have to comply with the 2017 NEC as published. The Florida codes should not discriminate against one class of citizen.

5. AFCI devices tested and certified to the UL 1699 Standard have been shown to effectively prevent the ignition of combustible materials where an arcing event occurs on the premises wiring system. AFCI devices undergo not less than (50) performance tests to ensure safe and proper operation. These findings have been reported to the US Consumer Product Safety Commission whom support and endorse AFCI protection as an effective means to prevent electric fires from occurring.

6. The UL 1699 Standard includes not less than six performance tests related to unwanted tripping. AFCI devices certified to UL 1699 will not trip due to inrush currents, normal operation arcing, non-sinusoidal waveforms, branch-circuit cross talk, multiple loads, and environmental noise (EM/RF). NEMA and the Association of Home Appliance Manufacturers (AHAM) have assembled a Task Force to address the remaining incompatibility issues that may exist between the UL 1699 Standard and the various appliance product Standards. Where unwanted AFCI tripping is encountered in the field, the NEMA Low Voltage Distribution Equipment section has developed an online unwanted tripping reporting tool at www.afcisafety.org. Additional guidance and support for Outlet Branch Circuit (OBC) AFCI Devices as an alternative solution to AFCI Circuit Breakers can be found at www.afcisafetyreceptacles.org.

SCANDAGLIA RYAN LLP

February 15, 2019

Thomas Campbell Executive Director Florida Building Commission 2601 Blair Stone Road Tallahassee FL 32399	James Schock Vice Chairman Florida Building Commission 2601 Blair Stone Road Tallahassee FL 32399

Re: Legrand Proposal E8149

Dear Director Campbell and Vice Chairman Schock:

I represent the Arc Fault Circuit Interrupter Wiring Device Joint Research and Development Consortium ("the AFCI Consortium" or "the Consortium"). The AFCI Consortium is comprised of manufacturers of outlet branch circuit AFCI receptacles. Its members are: Hubbell Inc. (Delaware) Wiring Device Division ("Hubbell"), Legrand/Pass & Seymour ("LPS"), and Leviton Manufacturing Co. ("Leviton"). Please accept this letter as the AFCI Consortium's formal support of LPS's E8149 proposal to the Florida electrical code seeking deletion of kitchen and laundry areas from the list of locations within the dwelling unit where AFCI protection is required.

As an industry stakeholder, the AFCI Consortium supports E8149 because it seeks to pause further expansion of AFCI throughout the dwelling unit. The AFCI Consortium is concerned about a lack of technical substantiation and data to justify the proliferation of AFCI technology throughout the entire dwelling. As such, the Consortium questions whether continued AFCI expansion actually correlates with improved fire safety. On this front, the NFPA recently published a report saying that there was a lack of data to connect expanded AFCI with a decrease in fires. *See* V. Hutchison, "*Residential Electrical Fire Problem: The Data Landscape*," NFPA FIRE PROTECTION RESEARCH FOUNDATION pages 3-4 (Oct. 2018). This same report stated that since 2002, there has been an increase in residential fires despite the increase in AFCI technology during roughly the same time period. E8149 represents a much needed "pause" in the continued proliferation of AFCI technology throughout the dwelling unit pending the collection of technical data and substantiation that actually supports an increase in fire safety outcomes with expanded use of AFCI.

The AFCI Consortium supports E8149 for the additional and related reason that a "pause" in AFCI expansion is necessary until the problematic issue of "nuisance tripping" is better understood. A "nuisance trip" is an unwarranted or false trip of an AFCI or GFCI breaker or receptacle. For example, an AFCI breaker or receptacle may act as if there is an arc fault and "trip" (cut power to the circuit) when an arc fault does not exist. Concerns can arise from false trips due to home appliances. For example, unwarranted false trips can lead to increased safety risks within dwellings, driven significantly by homeowners seeking to correct a wide range of power outage situations on their own by "workarounds" that may cause inadvertent removal of *both* AFCI and GFCI protection. Reports of nuisance tripping involving refrigerators, dishwashers, and

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microwave ovens, among other appliances, are continuing to be accumulated. However, the data on nuisance tripping in AFCI and GFCI embodiments is incomplete. Still and all, nuisance tripping is the cited reason many States have exempted the AFCI requirements when determining the scope of local NEC adoptions. The AFCI Consortium believes that E8149 represents a necessary "pause" of continued AFCI expansion in the dwelling unit until a full and thorough accounting and consideration of relevant nuisance trip data is collected and analyzed.

Thank you for your consideration.

Counsel for the AFCI Consortium

By: ________________________

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SCANDAGLIA RYAN LLP

February 15, 2019

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Dear Director Campbell and Vice Chairman Schock:

I represent the Arc Fault Circuit Interrupter Wiring Device Joint Research and Development Consortium ("the AFCI Consortium" or "the Consortium"). The AFCI Consortium is comprised of manufacturers of outlet branch circuit AFCI receptacles. Its members are: Hubbell Inc. (Delaware) Wiring Device Division ("Hubbell"), Legrand/Pass & Seymour ("LPS"), and Leviton Manufacturing Co. ("Leviton"). Please accept this letter as the AFCI Consortium's formal support of LPS's E8149 proposal to the Florida electrical code seeking deletion of kitchen and laundry areas from the list of locations within the dwelling unit where AFCI protection is required.

As an industry stakeholder, the AFCI Consortium supports E8149 because it seeks to pause further expansion of AFCI throughout the dwelling unit. The AFCI Consortium is concerned about a lack of technical substantiation and data to justify the proliferation of AFCI technology throughout the entire dwelling. As such, the Consortium questions whether continued AFCI expansion actually correlates with improved fire safety. On this front, the NFPA recently published a report saying that there was a lack of data to connect expanded AFCI with a decrease in fires. *See* V. Hutchison, "*Residential Electrical Fire Problem: The Data Landscape*," NFPA FIRE PROTECTION RESEARCH FOUNDATION pages 3-4 (Oct. 2018). This same report stated that since 2002, there has been an increase in residential fires despite the increase in AFCI technology during roughly the same time period. E8149 represents a much needed "pause" in the continued proliferation of AFCI technology throughout the dwelling unit pending the collection of technical data and substantiation that actually supports an increase in fire safety outcomes with expanded use of AFCI.

The AFCI Consortium supports E8149 for the additional and related reason that a "pause" in AFCI expansion is necessary until the problematic issue of "nuisance tripping" is better understood. A "nuisance trip" is an unwarranted or false trip of an AFCI or GFCI breaker or receptacle. For example, an AFCI breaker or receptacle may act as if there is an arc fault and "trip" (cut power to the circuit) when an arc fault does not exist. Concerns can arise from false trips due to home appliances. For example, unwarranted false trips can lead to increased safety risks within dwellings, driven significantly by homeowners seeking to correct a wide range of power outage situations on their own by "workarounds" that may cause inadvertent removal of *both* AFCI and GFCI protection. Reports of nuisance tripping involving refrigerators, dishwashers, and

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microwave ovens, among other appliances, are continuing to be accumulated. However, the data on nuisance tripping in AFCI and GFCI embodiments is incomplete. Still and all, nuisance tripping is the cited reason many States have exempted the AFCI requirements when determining the scope of local NEC adoptions. The AFCI Consortium believes that E8149 represents a necessary "pause" of continued AFCI expansion in the dwelling unit until a full and thorough accounting and consideration of relevant nuisance trip data is collected and analyzed.

Thank you for your consideration.

Counsel for the AFCI Consortium

By: ______________________________

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The US Consumer Product Safety Commission (CPSC), in Publication 5133 R042012, supports and endorses AFCI protection as an enhanced means of protection from electric fires resulting from unsafe home wiring conditions.

The NEC, in CMP2, has supported this position not only by requiring the use of AFCI protection since 1999 but had further expanded the requirements for their use throughout homes in each of the following code cycles. This proposed modification flies in the face of reason by reducing the required level of protection.

AFCIs are designed specifically to protect electrical circuits by detecting when an arcing event occurs, arcing events that cause fires, destroy homes and irrevocably change lives. Arcing can occur on any circuit including those removed though this proposal.

It has been rumored that installing AFCI protection is too costly for home owners. The truth is homeowners insurance premiums may increase due to lower ISO Building Code Effectiveness Grading Schedule rating. Additionally, lowering this score also decreases the amount of federal funding provided after natural disasters such as hurricane Wilma and Irma. Amending the code to remove AFCI protection weakens the mitigation intent of the code.

Do not support Proposed Code Modification E8149.

FISCAL IMPACT: Estimated electrical installer savings: $180 - $192 per home. Assumptions: Installation of 5 Kitchen plus 1 Laundry circuits = 6 total circuits to be installed. AFCI breaker per ACBMA = estimated unit cost of $35 each. Standard listed branch-circuit overcurrent protective device (i.e. – standard overcurrent circuit breaker) estimated unit cost of $3 to $5 each.

Range of added costs avoided = $180 to $192 per home based upon savings of $30 to $32 for each of the six breakers that would not need to be AFCI protected. No additional savings for labor expense associated with avoidance of AFCI breaker installation vs. standard breaker installation was calculated for this example, although there may be an associated labor expense savings.

Residential Electrical Fire Problem: The Data Landscape

NFPA Research Foundation

October 2018

Summary

The Fire Protection Research Foundation (an affiliate of NFPA) was initially asked by leadership of NEC Code Making Panel (CMP) #2 to collect data to assist Panel members with determining the best methods of protecting branch circuit wiring in dwelling units against electric arcing. Upon closer consideration, the Foundation realized that there are inherent challenges and barriers to the effective identification and collection of applicable data, which must be resolved before recommendations or conclusions can be made towards degree of effectiveness of applied methods, such as AFCI.

The Foundation acknowledged that ***"data and data analytics is lacking to guide the optimum approaches to minimize residential electrical fires and related hazards."*** After identification and consideration of the numerous relevant (but unknown) factors, the goal of this project became an effort to summarize the landscape of residential electrical fire incident data to address the ***"problem and the impact of the NEC's regulatory changes regarding AFCIs from being precisely defined."*** The report summarizes the data landscape for residential electrical systems and related fires, identifies gaps in the available data, and makes recommendations to address the lack of data. It observes that "while proving the effectiveness of preventative measures (e.g. AFCI's) is a challenging task, the significant limitations associated with the existing traditional data sources presents serious concerns."

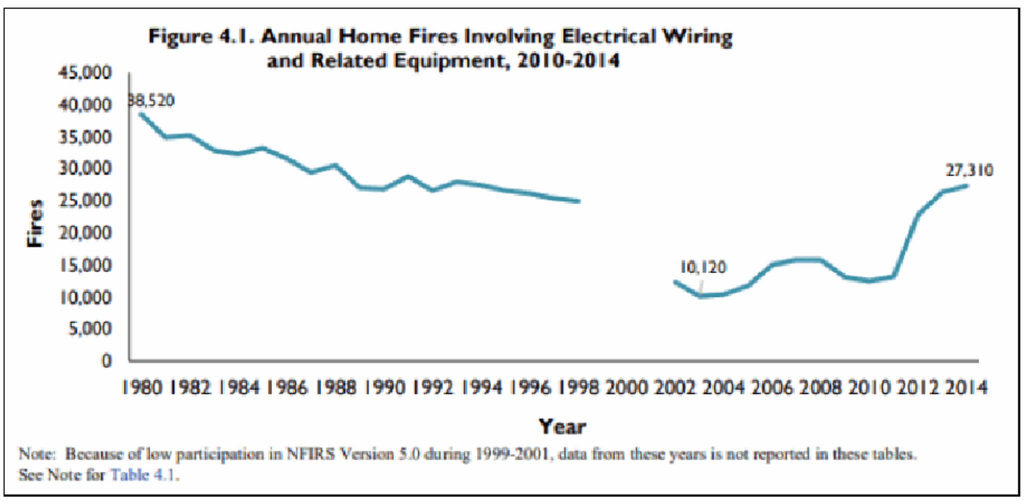

Figure 2 Annual Home Fires Involving Electrical Wiring (Image retrieved from Campbell, 2017)

The report highlights that, despite the general downward trend of electrical fires since 1980, "home fires involving electrical wiring and related equipment have generally been on the rise since 2002." In addition, a very significant increase in residential electrical fires was recorded from 2012 to 2014, of which 49% were said to be "related to some form of arcing in the electrical wiring." Accordingly, the report states that ***"there is uncertainty regarding the residential electrical fire problem and the effectiveness of branch circuit protection devices, such as AFCI's."***

Identification and Analysis of the Existing Data Sources

The report identified and analyzed existing data sources, along with the positive and negative characteristics of each in understanding electrical fires. Included in the analysis of identified current data sources was the following:

1) NFIRS: does not include the year a structure was built, the type of branch circuit protection or the type of wiring. This "lack of granular detail in an NFIRS report hinders a detailed analysis of residential fires due to

electrical failures." Also, it is common to have misclassified cause of electrical fires, best evidenced by 51% of electrical fires from 2010 to 2014 being identified as "unclassified electrical failure or malfunction".

2) Fire Incident Data Organization (FIDO), an NFPA-owned database of fire incident data; this is a voluntary system (typically handwritten), "so the number of incidents in the database is somewhat sparse and is currently a relatively small sample of incidents." In addition, FIDO has extremely limited relevance towards solving the residential electrical fire problem, as "residential electrical fires have not been a targeted incident category".
3) Fire Investigation Reports: this is a small sample size, usually of large-loss fires. "The relatively small sample size of investigated residential electrical fires could be a limiting factor for this analysis." The reports are extremely detailed but are therefore very time consuming to develop and analyze. Most significantly, the data is not in a format that can lead to data analytics.

Summary Observations

The report finds that ***"the most significant problem with residential electrical fire data is that nearly all of the currently available public data is lacking in quality and accuracy, and is relatively unusable for data analytics in its current state."*** As such," the existing residential electrical data is generally unrefined and provides limited value to the analysis of determining the effectiveness of electrical branch circuit protection devices."

1) Good and accurate data is needed: "If the goal is to utilize data to evaluate the effectiveness of branch circuit protection devices, it is imperative that we collect better data. Without better data, we cannot prove the effectiveness of these devices or evaluate the optimal means of protecting branch circuits against electrical arcing."
2) A lot of good data is needed: "The primary issue with getting good data within the existing infrastructure is the frequent misclassification of electrical fire incidents, which limits the quantity of good, available data."
3) Data analytics is extremely challenging to perform on existing post-incident data: "The quality and quantity of currently available residential electrical fire incident data is inadequate."
4) The data needs to be compatible, unified and scalable.
5) The greatest challenge lies with the non-technical issues: there are political, social and economic issues that can impact data collection.
6) All data collected, despite the source, needs to be technically validated prior to use.

"Before conclusions can be drawn regarding the effectiveness of electrical protection devices, the summary observations listed above should be addressed with respect to residential electrical data."

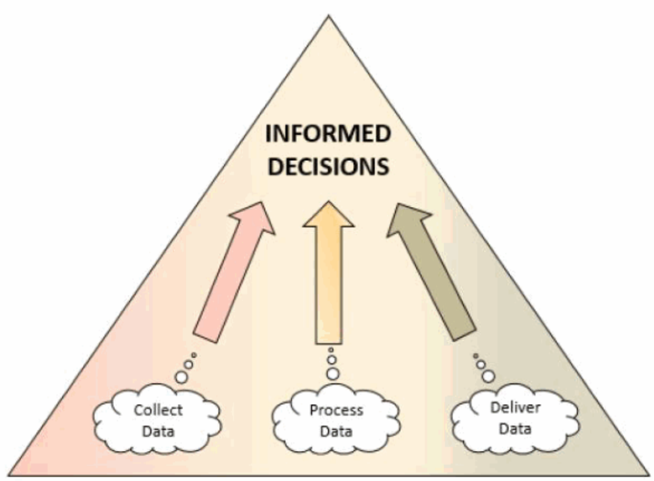

Figure 3 Core Principles of Data Collection and Analytics

Review of the previous expansion proposals to add kitchens and laundry areas and their ballot comments noted that National Electrical Code Panel 2 did not have clear substantiation of fires specifically located in kitchens or laundry areas from the fire data used to justify that expansion. This lack of technical substantiation was noted in several comments for the 2014 NEC cycle, but was rejected by Panel 2.

Although we recognize the problem with residential fires due to electrical systems, there remains no independently verifiable measurement method to determine the performance of solutions. The data available presently does not serve to reflect the efficacy of any implemented solution. NEC Panel 2 has no independently verifiable tool to measure the veracity of AFCI protection.

In response to this lack of data, a project sponsored by NFPA was conducted by the Fire Protection Research Foundation. This project entitled "Residential Electrical Fire Problem: The Data Landscape" was initiated to "...summarize the landscape of residential electrical fire incident data and provide recommendations for future efforts to precisely define the residential electrical fire problem and the impact of the NECs regulatory changes (e.g. - AFCIs)." A link to the report on the NFPA site is provided here https://www.nfpa.org/News-and-Research/Data-research-and-tools/Electrical/Residential-Electrical-Fire-Problem-The-Data-Landscape, while a two-page summary is provided as an uploaded support file.

This completed NFPA-funded FPRF project concludes that, if the previous positions of NEC Panel 2 regarding the initial acceptance and subsequent expansions of AFCI requirements were and are justified based upon reductions in residential electrical fires delivered by increased AFCI protection, evidence-based substantiation data to support this claim does not exist and cannot be made.

Nuisance Tripping Problem Increased with Expanded AFCI Use: reports of nuisance trip incidents involving refrigerators, dishwashers and microwave ovens among other appliances are continuing to be accumulated. The impacts of the nuisance trips are multi-fold, including but not limited to:

- Removal of AFCI and GFCI protection by replacing a dual function AFCI/GFCI circuit breaker with a standard thermal-magnetic circuit breaker
- Unpaid call-backs for contractors
- Homeowner inconvenience
- Power loss resulting in property loss or injury
- Untested workarounds such EMI filters
- Unsafe workarounds such as extension cords

Mandated AFCI protection in kitchen and laundry areas can compromise electrical safety for home dwellers. If GFCI protection is inadvertently removed and not replaced with a suitable GFCI device (which has been stated as happening in actual practice) to resolve an AFCI/GFCI nuisance trip, then the safety provided by the GFCI that has been historically present in these locations is lost. This is true because installers are not (and are not doing so) obligated to install GFCI protection at the point of use to comply with the code. All protection is being placed within the breaker panel in the form of a dual-function breaker; in these examples cited, the long-standing GFCI protection is now non-existent. Although the requirement is to ensure that GFCI protection remains in place, home dwellers often will come up with their own "work-arounds" to independently solve a dual-function breaker nuisance trip issue, compromising safety in the process due to no initial need for GFCI protection to be installed at the point of use.

AFCI expansion is resulting in fewer GFCIs located at the point of use. In view of the issues with nuisance tripping of AFCI or dual function AFCI/GFCI devices, accessibility for required monthly testing and to reset now becomes a very important safety factor to assure continued personnel protection. As such, this proposal respectfully requests for consideration and accounting for those with special needs (elderly, infirm, physically challenged and similar) to retain point of use capability to manage these requirements necessary to preserve safety in the home. Since the element of accessibility for all affected parties is not considered in the national minimal standard context of the NEC, the appeal here is to address it with this local amendment. The needs of dwelling occupants are addressed with this proposal to remove AFCI from kitchen and laundry areas; retention of AFCI in these areas can compromise the safety of those who are most affected by and due to their mobility challenges.

State-by-State NEC Adoption – as of August 29, 2018

Overview of NEC adopted versions:

- 2017 NEC – 22 States
- 2014 NEC – 14 States
- 2011 NEC – 0 States
- 2008 NEC – 4 States
- Local Adoption – 5 States
    - Alabama, Arizona, Mississippi, Missouri and Nevada.
- AFCI Requirements Controlled by International Residential Code – 5 States

Overview of AFCI Requirements:

15 states and 3 major municipalities have made amendments to reduce the AFCI requirements. Below is summary of the changes that have been made:

- Arkansas (2017 NEC) – AFCI's are not required in kitchens and laundry areas.
- Delaware (2014 NEC) – Smoke alarms shall not be placed on branch circuits protected by AFCI's.
- Idaho (2017 NEC) – AFCI protection is only required in bedrooms.
- Iowa (2017 NEC) – AFCI requirements for branch circuit extensions or modifications in dwelling or dormitory units were deleted.
- Michigan (2018 IRC) – AFCI requirements were deleted.
- New Hampshire (2017 NEC) – AFCI requirements for dormitory unit devices and bathrooms, guest rooms and guest suites, and branch circuit extensions or modifications for dormitory units were deleted.
- New Jersey (2014 NEC) – AFCI requirements for kitchens and laundry areas, as well as for branch circuit extensions or modifications, were deleted.
- North Carolina (2017 NEC) – AFCI requirements for kitchens and laundry areas were deleted, as well as those for dormitory unit bathrooms guest room and guest suites, and extensions or modifications.
- Oregon (2017 NEC) – AFCI requirements deleted from branch circuits that supply hallways, kitchen or laundry areas, as well as GFCI protected receptacles installed in dining rooms. AFCI protection shall not be required for optional, dedicated outlets that supply equipment known to cause unwanted tripping of AFCI devices and for branch circuits that serve an appliance that is not easily moved or that is fastened in place.
- South Carolina (2018 IRC) – AFCIs will not be required in kitchens and laundry areas.*
- Tennessee (2008 NEC) – The 2017 NEC will become effective in the state on October 1, 2018 and states that AFCIs shall be optional for bathrooms, laundry areas, garages, unfinished basements, work or similar area, and for branch circuits dedicated to supplying refrigeration equipment.
- Utah (2015 IRC) – AFCI requirements were deleted.
- Vermont (2017 NEC) – AFCI requirements for branch circuit extensions or modifications were deleted where the extension of the existing conductors is used solely to hardwire single station smoke and or CO alarms in an existing dwelling or dormitory unit.
- Virginia (2014 NEC) – AFCI's only required in bedrooms.
- Wisconsin (2017 NEC) – AFCI requirements do not apply to kitchens.
- Mobile, AL (2014 NEC) – AFCI's requirements were deleted for family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets and hallways
- Kansas City and Springfield, MO (2011 NEC) – AFCI's only required in bedrooms.

*Adoption of 2018 IRC was approved by Building Codes Council and is pending legislative review.