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Technical Report

Photovoltaic and Solar-Thermal Technologies in Residential Building Codes

Tackling Building Code Requirements to Overcome the Impediments to Applying New Technologies

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Linda Echo-Hawk

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Prepared from a longer report for the National Renewable Energy Laboratory, entitled "Renewable Energy and Energy Efficiency Technologies in Residential Building Codes," by David Wortman and Linda Echo-Hawk (September 20, 1998).

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Executive Summary

This report describes the building code requirements and impediments to applying photovoltaic and solar-thermal technologies in residential buildings. The goal is to include all relevant issues raised in the codes. However, due to the complex and often confusing language in the codes, this report is not necessarily comprehensive.

This report reviews six modern model building codes that represent the codes to be adopted by most locations in the coming years:

- International Residential Code, First Draft, April 1998 (IRC)[1]
- International Energy Conservation Code, 1998 (IECC)[2]
- International Mechanical Code, 1998 (IMC)[3]
- International Plumbing Code, 1997 (IPC)[4]
- International Fuel Gas Code, 1997 (IFGC)[5]
- National Electrical Code, 1996 (NEC)[6]

The IRC may become the basis for many of the building codes in the United States after it is released in 2000, and it references the other codes that will also likely become applicable at that time. These codes are selected because they represent the latest generation of available model building codes, and the international codes listed are the only model codes that will be updated continuously after 1999. (note: Model codes have no legal authority in a jurisdiction until they are put into force through enabling legislation.)

These codes are reviewed as they apply to the technologies described below:

- *Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems*—Photovoltaic systems can be stand-alone, hybrid, or utility-connected. They can be mounted on building roofs or walls, integrated as roof or wall components, or ground-mounted. The relevant codes include the NEC, the structural sections of the IRC, and the renewable-energy sections of the IECC.
- *Active-Solar Domestic Hot-Water and Space-Heating Systems*—Active-solar hot-water systems can be roof-, wall-, or ground-mounted. The relevant codes include the IPC, the

Footnotes

1. International Code Council, Inc. April, 1998. International Residential Code for One- and Two-Family Dwellings, First Draft. International Code Council, Inc.
2. International Code Council, Inc. March, 1998. International Energy Conservation Code, 1998. International Code Council, Inc.
3. International Code Council, Inc. January, 1998. International Mechanical Code, 1998. International Code Council, Inc.
4. International Code Council, Inc. April, 1998. International Plumbing Code, 1997. International Code Council, Inc.
5. International Code Council, Inc. November, 1997. International Fuel Gas Code, 1997. International Code Council, Inc.
6. National Fire Protection Association. 1995. National Electrical Code. National Fire Protection Association.

solar systems and structural sections of the IRC, the solar systems section of the IMC, and the control-signal and circuit language in the NEC.

This report covers the application of the codes listed above to residential buildings that are one- or two-family dwellings. Although some of the discussion may apply to other building types and other renewable energy and energy conservation technologies, these are not specifically addressed here.

The first discussion is on general code issues that impact the above technologies—for example, solar access and sustainability. Then, secondly, the discussion investigates the relationship of the technologies to the codes, providing examples, while keeping two major issues in mind:

- How do the codes treat these technologies as *building components*? This includes both the obvious code sections, as well as those that are more obscure. An example of the "obvious" type is that the electrical components of photovoltaic systems must be designed and installed to comply with the requirements of the NEC. An example of the "obscure" type is that roof-mounted photovoltaic systems can also be considered roof structural components and roof coverings, and must therefore comply with the structural sections of the IRC.
- Do the IECC and other codes allow *reasonable credit for the energy impacts* of the technologies? This issue concerns two points: Is credit allowed?, and Are the methods used to quantify the energy savings in the codes practical to apply, as well as reasonable and fair to the technologies?

The codes almost entirely ignore the economic issues related to the building technologies. Investments in energy-related technologies are reasonably based on economic criteria. Detailed economic discussions are outside the scope of this report.

The codes can impact the implementation of the above technologies in several ways:

- The technology is not mentioned in the codes. It may be an obstacle to implementing the technology, and the solution is to develop appropriate explicit sections or language in the codes.
- The technology is discussed by the codes, but the language is confusing or ambiguous. The solution is to clarify the language.
- The technology is discussed in the codes, but the discussion is spread over several sections or different codes. Practitioners may not easily find all of the relevant material that should be considered. The solution is to put all relevant information in one section or to more clearly reference relevant sections.
- The technology is prohibited by the code. Examples of this situation were not found. However, energy credit for some technologies cannot be achieved with the requirements of these codes.

Finally, four types of future action are recommended to make the codes reviewed in this report more accommodating to renewable energy technologies:

- *Include suggested language additions and changes*, listed in Appendix C of this report, in the codes.

- *Create new code sections* that place all of the requirements for a technology in one section of an appropriate code. This would include language specific to technology, as well as references to other applicable code sections. (Two proposed code sections are reviewed: Article 690 of the National Electrical Code, 1999: Solar Photovoltaic Systems,[7] which is intended to be included in the 1999 NEC; and the Solar Rating and Certification Corporation [SRCC] Document OG-300: Solar Water Heating Systems.[8])
- *Apply existing standards*, as appropriate, to innovative renewable energy and energy conservation technologies. An obvious example is the application of existing standards for asphalt shingles to photovoltaic shingle products. If the existing standards are applicable, code language should be amended to specifically refer the standard to the technology.
- *Develop new standards*, as necessary, to ease code compliance. Again, code language would need to be amended to specifically refer the new standard to the technology.

A synergy may be possible in developing suitable code language changes for both photovoltaic and solar hot-water systems. The installation of rooftop photovoltaic panels and solar hot-water collectors involves many overlapping issues. Roof loading, weather tightness, mounting systems, roof penetrations, and similar concerns are identical for both technologies. If such work can be coordinated, organizations supporting both technologies could work together to implement the appropriate revisions and additions to the codes.

7. Unpublished draft of Article 690 of the National Electrical Code, 1999: Solar Photovoltaic Systems.
8. Solar Rating and Certification Corporation. April, 1997. SRCC Document OG-300 Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems: An Optional Solar Water Heating System Certification and Rating Program. Solar Rating and Certification Corporation.

Notes and Acknowledgments

Specific code sections that impact the technologies are footnoted in the following discussion of each technology. To shorten this report, the various codes used in the footnotes are generally abbreviated. The full references are available under References in Appendix F.

Note that the information in the shaded sidebars in Sections 1 through 4 is *also* included within the text on the pages. The purpose of the sidebars is to highlight particularly important points.

The authors—David Wortman and Linda Echo-Hawk—are generalists in these technology fields and may not have the in-depth knowledge and practical experience of the reviewers in specific technologies. Therefore, this report was reviewed by experts from the National Renewable Energy Laboratory who specialize in many of the technologies, with the goal of filling in these areas. Sheila Hayter and Ron Judkoff provided funding and general guidance for the project, and they reviewed the entire draft report. Jay Burch provided input on active-solar domestic hot-water and space-heating systems. And Dick DeBlasio provided guidance and reviewed the material on photovoltaic systems in buildings and building-integrated photovoltaic systems. All opinions in this report are those of the authors.

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Section 1

Introduction

Widespread acceptance and market penetration of renewable energy and energy efficiency technologies in buildings depends on compliance with existing and proposed building codes. Practitioners must understand the opportunities and constraints provided by the codes before they can legally install these technologies. The codes generally apply to both new construction and modifications to existing buildings.

The various building codes were developed to safeguard the public, not to promote energy efficiency. Industry, research, standards, and other interested organizations participated in their development. An example is the "International Residential Code for One- and Two-Family Dwellings" or IRC.[1] Publication of the IRC in final form is planned for 2000 and is designed to be the basis, potentially, for many of the legally acceptable building codes in the United States. The IRC references other codes, such as the "International Energy Conservation Code" (IECC),[2] the International Mechanical Code (IMC),[3] and so forth, for rules regarding special technical areas. The purpose of the IRC is to "provide minimum requirements to safeguard life or limb, health and public welfare, and affordability."[4]

Although the IRC purpose statement includes "affordability," this is not an evident priority in most of the various codes. Indeed, only the IECC has any reference to energy efficiency in its intent or purpose section. Reinforcing the main goal of building codes is the reminder that the IECC "is not intended to abridge safety, health or environmental requirements under other applicable codes or ordinances."[5] There is no explicit discussion in the IECC or any other code as to "affordability" or economic feasibility in their application.

Building codes have been in use for a long time. However, the "energy crises" of the 1970s produced a flood of new building-related energy efficiency and renewable energy technologies, equipment, and construction techniques. The development of many of these

- The various building codes were developed to safeguard the public, not to promote energy efficiency.
- There is no explicit discussion in the IECC or any other code as to "affordability" or economic feasibility in their application.

Footnotes

1. International Code Council, Inc. April, 1998. International Residential Code for One- and Two-Family Dwellings, First Draft. International Code Council, Inc.
2. International Code Council, Inc. March, 1998. International Energy Conservation Code, 1998. International Code Council, Inc.
3. International Code Council, Inc. January, 1998. International Mechanical Code, 1998. International Code Council, Inc.
4. IRC, 101.3 Purpose.
5. IECC, 101.2 Intent.

- To make a major impact on energy use in this country, renewable energy and energy efficiency technologies need to be accepted by all the different interest groups involved in the construction process.
- The code officials are less likely to approve unconventional approaches if they cannot rely on generally recognized codes or standards.

innovations came from outside the traditional construction industry and without the normal scrutiny of applicable standards organizations. The installation of many such systems did not meet the requirements of the existing building codes. A large number of these systems, particularly active-solar heating and domestic hot-water systems, produced disappointing performance and reliability, as well as other problems.

Research and product development on renewable energy (RE) and energy efficiency (EE) technologies has progressed in the two decades since the energy crises of the 1970s. Sophisticated technologies have been developed through the application of many innovative ideas, the pursuit of economically optimized designs, and the weeding out of weaker concepts. The RE and EE technologies often rival or exceed the sophistication of more traditional technologies. Some of these innovative technologies are cost-effective today. Many more would become instantly cost-effective if a 1970s-style increase in energy prices and the uncertain availability of energy supplies should revisit this country. However, even under those circumstances, compliance to building codes can present a major obstacle to significant market penetration.

To make a major impact on energy use in this country, RE and EE technologies need to be accepted by all the different interest groups involved in the construction process. Financial interests will not likely finance what they perceive as risky technologies because of code compliance issues. Construction companies will not likely train workers for what they perceive as markets that are limited by the building codes. Moreover, in a chicken-and-egg fashion, manufacturers of these technologies often do not have a large enough market to justify the expense of Underwriters Laboratories (UL) or other standards-type testing required for compliance.

Local code officials are ultimately responsible for the safety and reliability of the buildings in their jurisdiction.[6] They can approve non-standard equipment, designs, materials, and so forth that are outside the explicit scope of existing building codes. However, acceptance must satisfy typical building-code language, such as "the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this Code."[7] Further, if the technologies do not meet the existing approvals, "the Code official shall have the authority to require tests as evidence of compliance... Test methods shall be as specified in this Code or by other recognized test standards." [8] The code officials are less likely to

6. IRC 104.1 "The code official is hereby authorized and directed to enforce the provisions of this code."
7. IRC, 104.11 Alternative materials, design and methods of construction and equipment. Equivalent language is in all of the various codes.
8. IRC, 104.11.1 Tests.

approve unconventional approaches if they cannot rely on generally recognized codes or standards. This represents a significant obstacle to their acceptance of these technologies.

A path around this obstacle is to include language in the codes that specifically addresses the issues involved with RE and EE technologies. In lieu of this, documentation, including standards-based testing, of how interpretations of the existing codes allow the application of these technologies, can also be used to convince local officials of their acceptability. Inserting appropriate language in the codes and standards and providing this documentation must necessarily be an activity of the RE and EE industry and supporting research organizations. The ready acceptance of these technologies by local officials will ease their acceptance by the other interest groups needed for their widespread implementation.

This report reviews various codes, with reference to their impacts on photovoltaic and solar-thermal technologies. The report also notes and discusses the barriers to implementing these technologies. Finally, alternative Code language, necessary testing, documentation, and other strategies for acceptance are presented.

- Inserting appropriate language in the codes and standards and providing this documentation must necessarily be an activity of the RE and EE industry and supporting research organizations.

Section 2

Renewable Energy and Energy Efficiency Technologies: General Issues of Code Impacts

In this section, some 11 topics (A through K) are discussed that relate to two issues: sections of the various codes that apply to many of the technologies, and areas of concern that are not addressed by any of the codes.

A. Alternatives to Materials, Design, Methods of Construction, and Equipment

Language in all of the codes allows alternatives that are not explicitly covered by the letter of the codes. The intent is to allow practitioners the flexibility to introduce new approaches to solving the classic problem of designing and building safe, comfortable buildings. For example, a section of the IRC states, "The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code..."[1] However, these alternatives shall only "be approved where the code official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code."[2] If there is insufficient information for the code official to determine if the proposed complies with the intent of the codes, then "the code official shall have the authority to require tests as evidence of compliance to be made at no expense to the jurisdiction. Test methods shall be as specified in this code or by other recognized test standards."[3]

This test requirement represents opportunities for both the introduction of innovative building technologies and an economic obstacle to their market penetration. On the one hand, any innovative technology could be legally used in a building if a local code official allows it. However, convincing individual code officials of the acceptability of a technology is likely an expensive and slow process, making it an impractical approach to the widespread implementation of the technology in many localities. The remedy to this problem is to conclusively show compliance with the existing

- Convincing individual code officials of the acceptability of a technology is likely an expensive and slow process, making it an impractical approach to the widespread implementation of the technology in many localities.

Footnotes

1. IRC 104.11
2. Ibid.
3. IRC 104.11.1

- Language should be added to the IECC to account for the potential impact of solar access from shading objects or trees located on other properties and from permanent or future objects, including trees, on the subject property.

codes, if possible. To show compliance, pertinent sections of the codes must be examined and, if necessary, the new technology tested to the relevant standards. If the existing standards are not appropriate for the new technology, then the practitioner, supplier, trade organization or other entity should be prepared to provide for the development of such standards. If the existing codes are not appropriate for showing compliance for new technologies, then these same entities should be prepared to develop and implement appropriate sections of future versions of the codes that address the new technologies. These are likely to be slow and expensive processes. Included in this report are suggested code-language changes and standards needed to ease the compliance for both technologies.

B. Solar Access

Solar access is the ability of a solar energy system to "see" the sun. The codes reviewed for this report did not address solar access issues. It is likely outside the scope of the codes to regulate activities on adjacent properties or public areas that impact the solar access for a solar energy system. However, it seems appropriate to include language to require that these should be considered at the time of the installation. Shading from structures, topography, trees, and so forth need to be considered in the energy analysis sections of the IECC. Shading from objects on the same property where the solar system is installed also needs to be addressed. Although it is unlikely that they can control activities on other properties that could shade the solar system, local officials likely have the jurisdiction to prevent the system owner from construction or planting activities that limit the system's solar access.

Language should be added to the IECC to account for the potential impact of solar access from shading objects or trees located on other properties and from permanent or future objects, including trees, on the subject property. It is reasonable to expect energy contributions of the solar system to be calculated under the worst-case solar-access conditions. Sample language could be included in IECC 402.1.3.11, a subsection of "Input values for residential buildings."

> **402.1.3.11 Solar access.** Any existing permanent objects that will reduce the solar gains on any window surfaces or other solar-energy collection devices must be accounted for in the energy analysis.

Similar language should also be included in code sections on active solar systems and photovoltaic solar systems.

C. Sustainability

Sustainability encompasses the concepts of energy conservation, renewable energy utilization, minimal use of other resources, and minimal or positive environmental impacts. Generally, the issues of "minimal use of other resources, and minimal or positive environmental impacts" are ignored in the various codes. One aspect of the sustainable building industry is to use recycled materials. This is explicitly covered in IRC section 104.9.1: "Used materials, equipment and devices shall not be reused unless approved by the code official." Recycled materials should not be used unless the code officials are previously informed of their use and have agreed to it.

Environmental impacts, including air pollution from on-site fuel burning and off-site electric generation and greenhouse-gas production, are not discussed in the codes. These concerns are not considered by code officials in dealing with EE and RE technologies.

D. Climate Criteria

Design weather conditions and appropriate long-term climate data are controversial and dynamic. The choice of these data impacts both the design criteria for building-component and heating, ventilation, and air-conditioning (HVAC) equipment, as well as annual energy analysis. The Typical Meteorological Year (TMY)[4] hourly weather data sets are widely used to drive building energy simulation programs. The original TMY data set presents an annual data set designed to represent typical weather and is derived from data collected from 1951 through 1990. Recently, the TMY data sets were updated with the release of the TMY2[5] data sets. These are derived using measured weather data from 1961 through 1990. The intent is to account for climate changes between the two time periods.

The performance path through the IRC is the required compliance method for all RE technologies and is the likely method used for innovative EE technologies.[6] This chapter requires the use of an hourly building energy simulation tool.[7] The requirements for climate data used to drive this tool is "coincident hourly data for temperatures, solar radiation, wind and humidity of typical days in the year representing seasonal variation."[8]

There is no specification on the source or validity of this data. A more constraining specification would increase the consistency of the performance path results, and likely increase the accuracy of these results. However, it is not always possible to obtain such data for all locations. Therefore, the best available and appropriate credible weather data source should be used for the performance path analysis.

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4. Hall, I. et al. 1979. Generation of typical meteorological years for 26 SOLMET stations. SAND-78-1601.

5. Marion, W. and K. Urban. 1995. User's Manual for TMY2s, typical meteorological years, derived from the 1961-1990 national solar radiation data base. NREL/SP-463-7668. E95004064. National Renewable Energy Laboratory, Golden, CO.
6. IRC Chapter 4.
7. IRC 402.3.2.
8. IRC 402.4.2 Climate data.

E. Energy Compliance Paths

Compliance with the IECC and similar energy codes is designed to ensure that buildings do not exceed a maximum permitted level of annual energy use. These codes have two general types of approaches to determine compliance. The prescriptive path defines minimum energy related requirements on a component by component basis. These can be opaque or glazed surfaces, air sealing packages, portions of mechanical systems, and similar components that affect the energy usage. The codes generally allow trade-offs that let one component fall short of compliance if another compensates for it by exceeding the minimum requirements. The advantage of the prescriptive path is that it is easy to understand, and inexpensive and simple to apply. Its disadvantages include the inability to account for a range of technologies. The prescriptive path to compliance is generally accurately applicable to:

- Some low-energy designs
- Most innovative roof/attic, wall, floor, and foundation systems
- Most innovative fenestration systems or products
- Some innovative HVAC systems.

The alternative to the prescriptive path is the *performance* path. This requires modeling the building and its mechanical systems to determine the annual energy usage. Two buildings are modeled: a standard design that meets the minimum prescriptive path requirements, and the proposed building design. The codes specify the allowed differences between the two designs. The advantage of this path is that accurate models can provide a more accurate evaluation of the proposed design than the prescriptive requirements. In addition, sufficiently detailed simulation models can analyze almost any type of EE and RE technology. However, such analysis can be very expensive, particularly if done correctly. This can be a major obstacle to pursuing this compliance path, which is a deterrent to code compliance of the technologies that require it. The performance path is generally required to accurately analyze the following technologies:

- Photovoltaic systems in buildings and building-integrated photovoltaic systems
- Active-solar domestic hot-water and space-heating systems
- Some passive-solar and low-energy designs
- Some innovative HVAC systems
- Electrical lighting, daylighting, and associated controls
- Innovative thermal-storage systems
- Buildings requiring no heating/ cooling equipment
- Buildings requiring no conventional air distribution (duct) systems
- Solar-assisted ventilation systems
- Desiccant dehumidification systems.

F. Inappropriate Prescriptive Requirements in the IRC Performance Path

The scope statement of the IRC performance path states that, "This chapter establishes design criteria in terms of total energy use by a residential building, including all of its systems."[9] Language in the chapter contradicts this statement by requiring specific design features without considering their energy impacts. Such requirements may be appropriate for prescriptive path compliance, but they should be eliminated from the IECC performance path. These requirements include:

- "Passive solar building designs shall provide documentation, acceptable to the building official, that fixed external or other acceptable shading is provided to limit excessive summer cooling energy gains to the building interior."[10] This both contradicts the scope statement and is too loosely worded to be consistently interpreted or enforced. There is no explicit definition of "passive solar" in any of the reviewed codes, so it is not clear to which designs to apply this requirement. There is also no definition for "excessive summer cooling energy gains." Because the goal of the performance path is to limit total annual energy use, this requirement for shading—which reduces cooling loads, but likely increases heating loads—necessarily restricts potential designs.

- "Passive solar buildings shall utilize at least 45 Btu/ºF of additional thermal mass, per square foot of added glass area, when added south-facing glass area exceeds 33 percent of the total glass area in walls."[11] This prescriptive requirement also unnecessarily restricts potential designs.

- The maximum number of zones that are allowed for the performance-path analysis is two.[12] One method of reducing the energy use in buildings is to include an HVAC system that can heat and/or cool multiple building zones simultaneously. This permits separate zones to be conditioned with a minimum amount of energy and prevents HVAC over-heating or over-cooling of different building areas. Zones that are used for only portions of the day can then have different setpoints and setpoint schedules. This prescriptive language in the IECC prevents designers from taking credit for these types of systems and strategies. Other requirements in this section of

9. IRC 401.1 General.
10. 402.1.3.2 Passive solar.
11. 402.1.3.3 Heat storage (thermal mass).
12. IECC 402.1.3.5 Heating and cooling controls.

code are similarly restrictive.[13] These limit the heating and cooling setpoints, and the maximum setback/set-up temperature differences, duration, and number per day.

G. Building Energy Analysis Methods

The requirements for the allowed simulation tools used to perform the analysis in the IECC Chapter 4 (the performance path) are specified in the IECC Section 402.3.2. It states, "The calculation procedure used to simulate the operation of the building and its service systems through a full-year operating period shall be detailed to permit the evaluation of the effect of system design, climatic factors, operational characteristics, and mechanical equipment on annual energy usage. Manufacturer's data or comparable field test data shall be used when available in the simulation of systems and equipment. The calculation procedure shall be based upon 8,760 hours of operation of the building and its service systems and shall utilize the design methods specified in the ASHRAE [American Society of Heating, Refrigerating and Air-Conditioning Engineers] Handbook of Fundamentals..."

This language is ambiguous and does not necessarily require that a true hourly simulation program be used. There are, for example, bin-method simulation programs and "typical day" simulation programs that, although "based upon 8,760 hours of operation," do not capture the true thermal dynamics required to accurately analyze buildings with features like setback thermostats or significant levels of thermal mass. Both types of programs were developed when computing power was expensive and computers were relatively slow. Many design firms use these methods, possibly because they learned to use them a long time ago. However, these programs will produce inaccurate results for many types of building designs that incorporate RE or EE technologies.

Bin-method programs count the hours in each of a series of temperature bins, and then typically perform a steady-state heat loss/ gain calculation on each bin. The hourly loads are then multiplied by the number of hours in each bin, and these are summed over all the bins to produce annual results. This neglects the coincidence of solar radiation and ambient temperatures and is totally incapable of accounting for building thermal-mass effects or the impacts of setback thermostats or other non-linear control strategies.

The "typical day" approach creates typical days out of the annual weather data. The typical days might be weekdays and weekend days for each month. These days are simulated, but only 2 day's worth of run-time is needed to

13. IECC Table 402.1.3.5 Heating and cooling controls.

simulate each month. This saves a significant amount of computer run-time, but again neglects many of the thermal details that are of particular interest to the EE and RE design community. This approach misses the extreme weather conditions each month, and cannot account, for example, for the Tuesday morning start-up loads after a 3-day weekend. These nuances are not likely to be noticed by the typical local code official. Accordingly, language similar to the following should be included in the IECC.

> **IECC 402.3.2.1 Special requirements for appropriate energy analysis tools.** If the proposed design involves significant amounts of thermal mass or contains thermal control systems with non-linear control characteristics, then a true 8,760-hour annual simulation driven by appropriate weather data shall be used in the systems analysis.

> **IECC 402.3.2.2 Hourly simulation tools for photovoltaic system analysis.** If the proposed design involves a photovoltaic system to generate electricity, then a true 8,760-hour annual simulation driven by appropriate weather data shall be used in the systems analysis. This simulation shall be capable of analyzing the type of photovoltaic system specified in the design. This analysis shall use the hourly electrical loads from the building simulation as the basis for the analysis of the photovoltaic system.

In addition, an exception allows residential buildings with less than 5000 square feet of floor area from requiring the hourly simulation analysis. However, "comparison of energy consumption using correlation methods based on full-year hourly simulation analysis or other engineering methods that are capable of estimating the annual heating, cooling and hot water use between the proposed alternative design and the standard shall be provided."[14] The simplifying assumptions inherent in all correlation methods limit their accuracy and flexibility in analyzing real-world building designs. This is a trade-off between the cost of performing the energy analysis and the accuracy and applicability of the results.

H. UL or Comparable Listing of Electrical and Mechanical Components

Electrical "conductors and equipment required by this Code (the NEC) shall be acceptable only if approved."[15] "Approval" is defined as acceptable to the authority having jurisdiction.[16] Components of mechanical systems have similar requirements: "All

14. IECC 402.5 Documentation, Exception.
15. NEC 110-2 Approval.
16. NEC 100 – Definitions.

- Proponents of these technologies should develop prescriptive-path methods to help implement code compliance. It is easy to envision this approach for technologies such as some photovoltaic and active-solar domestic hot-water systems, where the renewable energy performance is relatively independent of the other building details.

appliances and equipment installed in mechanical systems covered by this code shall be listed and bear the label of an approved agency or shall be approved by the building officials for safe use."[17] In practice, these requirements are satisfied if the electrical and mechanical equipment has been tested and is labeled by Underwriters Laboratories or a similar testing organization. Local code officials are not likely to approve their use if such certification is missing.

I. Economic Realities

Economic conditions vary greatly at different locations. Electric utility rate structures, fuel costs, heating-fuel availability, utility and government incentive programs, and other factors can all have a primary impact on appropriate building design. Such considerations, as well as the cost of alternative energy design approaches, should be the driving factor in selecting envelope and mechanical systems, as well as RE and EE technologies. Many houses built in the 1970s have electric heating because no gas taps were available when they were built. It seems reasonable that electrically heated houses could be built to a higher level of envelope thermal performance than houses with much less expensive natural gas or other fuels. There is no consideration given to heating-fuel costs in any of the codes. An argument can be made that all economic conditions, including utility rate structures, will change in the future, particularly in light of potential utility deregulation. However, this does not appear to be a sufficient reason to ignore these issues in regard to compliance with the building codes.

J. Complication and Expense of the Performance Path as a Deterrent to Innovation

The engineering cost to perform the systems analysis of the IECC energy performance path is likely to be at least several thousand dollars for a typical dwelling. People building new houses, especially the custom houses likely to include the EE and RE technologies, will have higher priorities than spending this money on additional engineering and analysis. Proponents of these technologies should develop prescriptive-path methods to help implement code compliance. It is easy to envision this approach for technologies such as some photovoltaic and active-solar domestic hot-water systems, where the RE performance is relatively independent of the other building details. Available maps, tables, and simple algorithms could be used to show the annual energy performance for each of the various optional designs of such systems.

17. IRC 1302.1 Appliances.

K. Requirements for Renewable Energy Sources to Qualify as an Exclusion under the IECC Performance Path

"To qualify [as an exclusion]...such renewable energy must be derived from a specific collection, storage, and distribution system."[18] Not all renewable energy systems use all of these components. One example is a photovoltaic system with utility connection, but with no storage. A second example is a once-through active-solar hot-water system. This language should be removed from the IECC.

18. IECC 403.1.1 Solar energy exclusion, one.

Section 3

Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems: Code Impacts

In this section, three types of considerations are discussed that show compliance of photovoltaic (PV) systems with the codes.

- The electrical aspects of PV systems must comply with the appropriate sections of the National Electrical Code. The NEC is concerned mainly with safety issues, including electrical fires, electric shock, and other possible hazards.

- The PV systems must meet the structural and mechanical safety requirements of the IRC. These include weather tightness, fire resistance, wind loading, access, roof penetrations, and related issues.

- The energy analysis sections of the IECC are used to determine if proper energy load reductions are given to PV systems to help a building comply with the overall IECC requirements.

Presently, the relevant code language applicable to PV systems is spread throughout the various codes. The IRC should include a new chapter for photovoltaic systems. This allows practitioners in the PV field to easily locate all applicable code requirements. This new chapter should include references to the NEC Article 690, and other relevant language in the IRC, IMC, IPC, and IECC.

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A. Photovoltaic Systems and the National Electrical Code

The electrical safety-related aspects of PV systems are extensively covered in Article 690 of the NEC and other articles that it references. Note that this article references many other articles in the NEC, showing the range of knowledge that must be applied to install PV systems that comply with the code. The more relevant articles in the NEC that apply to PV systems are presented in Table 1. However, the information in the NEC applies only to the electrical and electrical safety aspects of PV system installations. There is no mention in the NEC or the other codes about the building-component aspects of PV systems.

A report from Sandia National Laboratories, entitled "Photovoltaic Power Systems and the National Electrical Code: Suggested

Table 1. Partial List of important Articles in the NEC for PV system installations.

Article #	Title
110	Requirements for Electrical Installation
200	Use and Identification of Grounded Conductors
210	Branch-Circuit Ratings
220	Branch-Circuit, Feeder and Service Calculations
240	Overcurrent Protection
250	Grounding
300	Wiring Methods
310	Conductors for General Wiring
339	Undergrund Feeder and Branch-Circuit Cable, Type UF
384	Switchboards and Circuit Boards
445	Generators
480	Storage Batteries
705	Interconnected Electric Power Production Sources
720	Circuits and Equipment Operating at less than 50 Volts

Practices,"[1] presents an excellent treatment of the real-world electrical safety problems addressed by the NEC and encountered in the field. A list of the more common code violations found in the field and listed in this report is presented below. Also included are the pertinent Articles in the NEC that address each problem and an explanation of how to correct the problem. Due to the complexity of the NEC, this list is not comprehensive and only highlights commonly found problems and their resolution within the NEC. Many of the problems presented do not strictly result from the difficulty of fitting PV technologies within the constraints of the NEC. Rather, they result from the lack of sophistication and formal electrical training of the installers and designers in the PV industry, the lack of experience that inspectors have with PV systems, and the small market related to lack of UL listings for PV system specific equipment.[2]

Improper ampacity of conductors. [690-8, 690-31]
A great deal of information is presented in the NEC on how to

Footnotes

1. Wiles, John. 1996. Photovoltaic Power Systems and The National Electrical Code: Suggested Practices. SAND96-2797. Sandia National Laboratories, Albuquerque, NM.

2. Ibid., page 19.

correctly size conductors and other equipment. Conductor sizes depend on the maximum possible current, or ampacity, of the cir- cuit. Wires between the modules and from the modules to their common connection point (the photovoltaic source-circuit) are sized at 125% of the parallel rated short-circuit current of the connected modules.[3] The extra 25% amperage is because the standard solar-insolation conditions for rating the panels can be exceeded by the insolation actually found in the field. The ampacity of the solar photovoltaic output circuit—the wiring that, for example, leads directly into an inverter or direct DC loads—is the sum of the parallel source-circuit maximum currents, as rated above. The ampacity of the inverter output-circuit between an inverter and the AC load center is the inverter maximum continuous output current rating. The ampacity of the inverter input circuit with no utility connection is the inverter continuous input current rating when the inverter is producing rated power at the lowest input voltage. The ampacity of conductors must also be derated if the conductors are exposed to temperatures above 30°C.[4] This can occur near modules. Temperatures of 60° to 70°C can reduce the ampacity by a factor of three.

Improper insulation on conductors. [690-31] This article specifies the wire types that must be used for the various connections in a PV system. It specifies, for example, that any wire exposed to the sun must be rated as sunlight-resistant. Flexible cords used to connect the moving parts of tracking PV modules must be identified as a hard service cord or portable power cable, shall be suitable for extra-hard usage, listed for outdoor use, and be water- and sunlight-resistant. Battery cables can be flexible cables, but they must be listed for hard-service use and moisture-resistant. Welding and automobile-battery cables are not permitted.[5] The standard wire color coding for conducting wires is also often not followed in PV systems.[6]

Unsafe wiring methods. [Many] The approved wiring methods described in various sections of Article 690 are often overlooked in the field. For example, 690-4(c) requires that the "removal of a module or panel from a photovoltaic source circuit does not interrupt a grounded conductor to another photovoltaic source circuit." This means that "daisy-chain" wiring is prohibited, and a more expensive bus-bar wiring scheme is required. Many more examples are presented in the Sandia report.[7]

3. NEC, proposed 690-8.
4. NEC Table 690-31(C).
5. Wiles, John. 1996. Photovoltaic Power Systems and The National Electrical Code: Suggested Practices. SAND96-2797. Sandia National Laboratories, Albuquerque, NM.
6. NEC 310-12. Conductor Identification.
7. Wiles, John. 1996. Photovoltaic Power Systems and The National Electrical Code: Suggested Practices. SAND96-2797. Sandia National Laboratories, Albuquerque, NM.

No overcurrent protection on many conductors. [690-9] Essentially all PV system circuits need overprotection devices, such as fuses and circuit breakers. This can be overlooked in hybrid systems with multiple potential electric power sources, such as a PV/diesel generator hybrid. To prevent nuisance tripping, the ampacity of overcurrent protection devices must be at least 125% of the ampacity of the protected circuit.[8] Overcurrent protection devices in DC circuits must be rated and listed for the appropriate DC voltage and current.[9]

Inadequate number and placement of disconnects. [690-13 through 690-18] Means need to be provided to disconnect all current-carrying PV power source conductors from all other conductors in a building. Means also need to be provided to disconnect all equipment, such as inverters, batteries, charge controllers, and so forth, from all ungrounded conductors of all sources.

Use of non-approved components when approved components are available. [Various] There are at least two factors that make it difficult for PV installers to always locate and use equipment and components that are listed for PV system applications. Much of the circuitry in PV systems is direct current (DC). DC-rated components are not always readily available or price competitive with comparable AC-rated components. The relatively small number of PV systems provides an obstacle to the expensive testing required for UL certification of PV-specific equipment and components. Local code officials are not likely to accept systems with inappropriate components.

Improper system grounding. [690-41 through 690-47] PV systems need to be correctly grounded to reduce safety problems and electrical surges from lightning and other sources. The grounding conductor needs to be properly sized and connected at the proper location. The use of more than one ground will produce problems, including potential ground-loop currents. Any exposed metal frames of module frames, equipment cases, junction boxes, and other conductor enclosures need to be grounded.

Unsafe use of batteries. [690-71] Batteries present several types of safety hazards. First, the types of batteries used in PV systems can store a very large amount of energy. This energy can be very quickly released if the battery terminals are shorted. For this reason, batteries in PV systems in dwelling units are generally limited to 50 volts and must have guarded terminals and other live parts. Second, storage batteries can produce potentially explosive amounts of hydrogen gas during charging. Therefore, batteries need to be located in a ventilated area to prevent

8. NEC 690-8. Circuit Sizing and Current.
9. NEC 690-9(d). DC Rating.

accumulation of an explosive mixture of hydrogen and air.[10] Batteries with vented cells need flame arresters. Sealed batteries need a pressure-release vent to prevent excessive accumulation of gas pressure.

B. Photovoltaic Systems and Structural and Mechanical Requirements

The PV industry and research communities developed and implemented Article 690 of the NEC to provide the compliance path for the electrical and electrical safety aspects of PV systems. No similar effort has been made for the structural and mechanical aspects of these systems. However, there are many sections scattered through the IRC and other codes that are relevant to these issues. These sections are described here, grouped into discussions on building structural loads, building weather tightness, access safety, and other related issues.

Building Loads

Dead Loads. A major purpose of the IRC is to present rules that ensure that building structures do not fail. "Buildings and...all parts thereof, shall be constructed to support safely all loads, including dead loads."[11] Dead loads are defined as the "actual weight of materials and construction."[12] The dead load for a roof includes all structural materials, weather-barrier layers, and any permanent, roof-mounted structures. "Dead loads shall not exceed 15 PSF (pounds per square foot) for roofs…in Seismic Zone 4, roof dead loads shall not exceed 9 PSF."[13] The weight for calculation of the dead load is defined, but the applicable roof area is not. Although not strictly defined in the IRC, the purpose is to prevent both local and general failures of roof structures. Consequently, the structural designs for any roof-mounted PV panels, support structures, batteries, or other auxiliary equipment should account for these requirements. Mounting frames and other structures should transfer dead loads directly to roof structural members. Any roof-mounted concentrated loads, such as batteries, should be designed on structures that distribute their weight over a large enough area to comply with these requirements. Engineering design of roof structures should include the loads from the weight of any PV system equipment. For example, for a wood truss roof, "No additional loading of any member (e.g., HVAC equipment, water heater) shall be permitted without such additional load being incorporated in the engineering design."[14]

Wind Loads and Snow Loads. PV modules, frames, and other structures on rooftops are subject to aerodynamic forces from high

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10. NEC 480-8. Battery Locations.
11. IRC 301.1 Design.
12. IRC 301.3 Dead Load.
13. IRC 301.2.3.4. Weights of Materials.
14. IRC 802.9.3. Alteration to trusses.

winds and the weight of accumulated snow. PV modules on roof-mounted frames can also act as a “snow fence” and increase the local accumulation of snow. The IRC contains several sections to ensure that these forces do not produce structural failure or glass breakage. Compliance requires sufficient structural design and material strength to prevent failure during extreme conditions.

Wind-loading requirements are based on the exposure, the maximum expected wind speed, and the building height. Exposure classifications are “A/B” for built-up and wooded areas, “C” for open terrain, and “D” for areas adjacent to large bodies of water. The design wind speeds are determined from a table in the IRC[15] or from locally derived information. Many areas, such as the Front Range of Colorado, are defined as “Speci al Wind Regions” because of high and variable maximum expected wind speeds. The design wind loads, in pounds per square foot of “uplift,” are found in IRC Table 301.2b, Design Wind Loads. There are no design implications for wind speeds less than 81 miles per hour in A/B, less than 71 miles per hour in C, and less than 70 miles per hour in D.

There is no specific mention of structural considerations for frame-mounted PV modules in the IRC. However, “Buildings...with unusual constructions or geometric shapes... shall be designed in accordance with the provisions of ASCE 7–88[16].”[17] In addition, “construction in regions where reference wind speeds equal or exceed 90 mph shall be designed in accordance with ASCE 7-88 or another standard.”[18] It is reasonable to expect that local building inspectors in areas where wind loading is a design consideration for typical roof construction will require additional engineering documentation to show the adequacy of any rooftop structures and connections to roof structural members. If PV system installations increase the uplift from wind loading over an entire roof, there may be additional structural requirements for the roof and other framing members. “Roof assemblies subject to wind uplift pressures of 20 pounds per square foot or greater, as established in Table 301.2b shall have rafter or truss ties provided at bearing locations in accordance with Table 802.10. A continuous load path shall be provided to transmit the uplift forces from the rafter or truss ties to the foundation.”[19] Areas with 20 pounds per square foot or more of wind-force uplift are the

15. IRC Fiure 301.2d. Basic Wind Speed Map.
16. American Society of Civil Engineers, ASCE 7: Minimum Design Loads for Buildings and Other Structures.
17. IRC Table 301.2b, Note 6.
18. AF&PA Wood Frame Construction Manual for One- and Two-Family Dwellings, or: SSTD 10 Standard for Hurricane Resistant Residential Construction.
19. IRC 802.10 Roof tie-down.

same areas discussed in the previous paragraph. These structural requirements are a function of the geometric design, module slope angle, and the maximum expected wind speed. Such information can be developed for each installation at a high engineering cost. Standard designs will need to be engineered for the most stringent conditions or they will not be applicable for all locations. If information on site-specific designs is readily available, it should be distributed to installers and other pertinent parties.

There are also wind-loading restrictions on glazing that code officials may decide to apply to PV panels, whose construction resembles a pane of glass. For glazing within 15 degrees of vertical, a formula is given that relates the length, width, thickness, and type of glass and how the glass is supported to the design wind loading.[20] Glass more than 15 degrees from vertical must be designed to also sustain snow loads, inward or outward wind loads, and the dead load of the weight of the PV panel.[21] The "allowable loads for glass thicker than ¼ inch shall be determined in accordance with ASTM E 1300." [22] Even if code officials do not require PV modules to meet the structural requirements for vertical or sloped glazing, it is in the best interest of the industry to prevent structural failures in the field. To help prevent these failures and to prevent code compliance problems, manufacturers could supply maximum sustainable wind and snow loads for each size and model of panel based on recognized testing standards.

Snow loading involves the downward force from the weight of snow. PV modules and support frames need to be built strong enough to support these loads. A map of design snow-load levels is presented in IRC Figure 301.2e, with a range from 0 to over 80 pounds per square foot. More-stringent local requirements can be determined by local code officials.[23]

Though not mentioned in the codes, the impact of roof-mounted PV systems on additional accumulation of snow should be considered. If the PV panels and frames tend to trap additional snow, then roof snow loads may be significantly higher than normal. The design of roof rafter systems depends on the maximum expected snow load. This snow load is "based on the higher of the ground snow load or the equivalent snow load converted from the wind speed."[24]

IRC Table 804.3.3b presents the information needed to convert the wind speed to an equivalent snow load. In this table, steeper-sloped

- Though not mentioned in the codes, the impact of roof-mounted PV systems on additional accumulation of snow should be considered.

20. IRC 308.5.1 Vertical glass. The data for these calculations are presented in Figures 308.5(1) through 308.5(5).
21. IRC 308.5.2 Sloped glazing.
22. ASTM E 1300 Standard Practice for Determining the Minimum Thickness and Type of Glass Required to Resist a Specified Load.
23. IRC 301.2 Climatic and geographic design criteria.
24. IRC 804.3.3 Allowable rafter spans.

roofs have a higher equivalent snow load than shallower ones with the same design wind speed and exposure. There are potential implications here for roof-mounted PV systems with steeper slopes than the supporting roof structure. The impact of increased effective snow loads is to decrease the allowable spans for a given rafter size and on center spacing.[25]

If installations of PV panels or products are similar to skylights or sloped glazing, then additional compliance constraints may also apply.[26] This could include PV-powered electrochromic windows. For an "installation of glass or other transparent or translucent glazing material installed at a slope of 15 degrees or more from vertical,"[27] only certain types of glazing materials may be used. These include "fully tempered glass, heat-strengthened glass, wired glass, and approved rigid plastics." There is no list of "approved rigid plastics."[28] However, in the IRC, approved "refers to approval by the code official as the result of investigation and tests conducted by him, or by reason of accepted principles or tests by nationally recognized organizations."[29] Rigid plastic materials in such PV applications would need to meet the testing standards for exterior glazing, such as CPSC 16 CFR 1202[30] or a similar standard. Additionally, IRC specifies "laminated glass with a minimum 0.015 inch polyvinyl butyral interlayer for glass panes 16 square feet or less in area: for larger sizes, the minimum interlayer thickness shall be 0.030 inch."[31] This is "safety glass," designed to break into small, rounded pieces upon shattering. The specific interlayer material requirements are quite constraining, as this material is not presently used in PV products. Language could be added to this section to read:

> **IRC 308.8.2 Permitted materials.** Laminated glass with a minimum 0.015-inch polyvinyl butyral interlayer for glass panes 16 square feet or less in area; for larger sizes, the minimum interlayer thickness shall be 0.030 inch. Alternate materials can be used for the interlayer if it provides comparable performance, as confirmed by testing under CPSC 16 CFR 1202 or a comparable standard.

Human Impact Loads. The IRC restricts glazing used in areas where there is increased chance of direct human contact resulting in glass breakage. A large number of rules and exceptions define the hazardous

25. IRC Table 804.3.3a Allowable Horizontal Rafter Spans. This refers to the horizontal projection of the spans.
26. IRC 308.6 Skylights and sloped glazing.
27. IRC 308.6.1 Definition of skylights and sloped glazing.
28. IRC 308.6.2 Permitted materials for skylights and sloped glazing.
29. IRC 202 General Building Definitions.
30. Consumer Product Safety Commission 16 CFR 1201 Safety Standard for Architectural Glazing.
31. IRC 308.6.2 Permitted materials for skylights and sloped glazing.

locations where these restrictions apply.[32] If any PV products are installed in these areas, they will need to comply with the test requirements of CPSC 16 CFR 1201.[33]

Weather Tightness

Attachments to the outside of buildings must prevent moisture from entering. Compliance with several sections of the IRC is relevant to these issues.

Roof penetrations. The IRC section on active-solar hot-water systems states that "Roof penetrations, including piping and electric wiring, need to be flashed and waterproofed in accordance with Chapter 9" of the IRC.[34] The purpose here is to prevent roof leaks. Applied to PV systems, this would logically pertain to the attachment points for the support frames, as well as to the electrical wiring penetrations. "Flashings shall be installed...around roof openings."[35] There are further requirements for flashing depending on the type of roof covering. For example, for asphalt shingles, "flashing shall be installed in accordance with manufacturer's installation instructions."[36]

32. IRC 308.4 Hazardous locations.
33. Consumer Product Safety Commission 16 CFR 1201 Safety Standard for Architectural Glazing.
34. IRC 2107.2.7 Roof penetrations.
35. IRC 903.2.1 Locations.
36. IRC 905.2.1 Base and cap flashing.

Penetrations between separate dwelling units. Although not concerned with weather tightness, there is a requirement in the IRC for wiring and piping penetrations between dwelling units in a multi-dwelling building. "Penetrations shall be fire resistant rated in accordance with sections 320.1 and 320.2. The through penetration firestop systems tested in accordance with ASTM E 814[37] with a minimum positive pressure differential of 0.01" of water. The firestop shall have an 'F' rating not less than required for the penetrated assembly." These requirements are to prevent the spread of fire from one dwelling unit to an adjacent unit.

Roof-covering materials. "Roof decks shall be covered with approved roof coverings secured to the building or structure..." [38] "Approved" is defined as approved "by the code official as the result of investigation and tests conducted by him, or by reason of accepted principles or tests by nationally recognized organizations."[39] At least two PV products—PV shingles and PV roof panels—are designed to replace traditional roofing materials, as well as to provide electric power. These products need to meet the code requirements for the types of roofing materials that they replace.

37. American Society for Testing and Material E 814 Test Methods for Fire Tests of Through Penetration Fire Stops.
38. IRC 903.11 Weather Protection, General.
39. IRC 202 General Building Definitions.

PV shingles are designed to replace flexible asphalt shingles. For these products, the requirements for asphalt shingles should reasonably apply.[40] Asphalt shingles shall only be used on roof slopes of 2 in 12 or greater.[41] They are not listed for roofs with lesser slopes.[42] If the shingles are appropriate for installation on roofs with lesser slopes, then additional language needs to be included in the IRC. This language should specify that PV shingles can be applied to roofs with slopes of less than 2 in 12, and should also describe any requirements that are specific to these applications. The following are some of the requirements for installing asphalt shingles that will apply to similar installations of PV shingles:

- "Asphalt shingles shall be fastened to solidly sheathed decks."[43]
- "For roof slopes from...2:12 to...4:12...double underlayment application is required..."[44]
- "Asphalt shingles shall have self-seal strips or be interlocking, and comply with ASTM D 225[45] or D 3462[46]."[47]

These standards apply to mineral-surfaced shingles, and a separate standard may need to be developed for the PV shingles. If a new standard is required, then language to include it in the IRC will also need to be developed.

The remaining sections on asphalt shingles cover the types and numbers of needed fasteners in typical and high-wind areas, how the underlayment is applied, protection against ice buildup, and the proper installation of flashings. Identical requirements may apply to PV shingles.[48] However, the different physical characteristics of PV and asphalt shingles may require changes in or additions to the requirements of IRC Section 905 when applied to PV shingles.

Roofing materials are also subject to additional requirements. "Roof coverings shall be applied in accordance with this chapter and the manufacturer's installation instructions."[49] "Roofs and roof coverings shall be of materials that are compatible with each other and with the building or structure to which the materials are applied."[50] There is no definition for "compatible" in the IRC, but this most likely means that materials

40. IRC 905.2 Asphalt shingles.
41. IRC 905.2.2 Slope.
42. IRC 906 Roof Coverings with Slopes Less than 2 to 12.
43. IRC 905.2.1 Deck requirements.
44. IRC 905.2.2 Slope.
45. American Society for Testing and Materials D 225 Asphalt Shingles Surfaced with Mineral Granules.
46. American Society for Testing and Materials D 3462 Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules.
47. IRC 905.2.5. Asphalt shingles.
48. IRC 905.2.3 Underlayment; IRC 905.2.6 Fasteners; IRC 905.2.7 Application; IRC 905.2.8 Underlayment application; IRC 905.2.8.2 Underlayment and high wind; IRC 905.2.9 Flashings.
49. IRC 904.1 Scope.
50. IRC 904.2 Compatibility of Materials.

will not cause corrosion or other degradation in other building materials. An additional requirement is that roofing "shall conform to UL 790 and shall be installed in areas designated by law as requiring their use..."[51] This refers to a testing standard for fire resistance. In the absence of applicable standards or where materials are of questionable suitability, testing by an approved testing agency shall be required by the code official to determine the character, quality and limitations of application of the materials."[52] Additionally, "roof covering materials shall be delivered in packages bearing the manufacturer's identifying marks and approved testing agency labels when required."[53]

PV roof panels are designed to replace metal roofing products. In the IRC, metal roof shingles[54] are approved for use on roofs with slopes more than 2 in 12, and metal roof panels[55] are approved on roofs with lesser slopes.

Requirements for metal roof shingles are similar to those for the asphalt shingles previously described. Specific requirements are that "metal roof shingle roof coverings of galvanized steel shall be 0.013 inch minimum thickness. Metal roof shingle roof coverings of aluminum shall be of 0.024 inch minimum thickness."[56]

Requirements for metal roof panels include:

- "Metal roof panel roof coverings shall be applied to a solid or space sheathing, except where the roof covering is specifically designed to be applied to space supports."[57]
- "The minimum slope for lapped, non-soldered seam metal roofs shall be … 3:12. The minimum slope for standing seam roof systems shall be … ¼:12."[58] This minimum requirement should be reviewed by manufacturers in regard to water collection, which may present possible electrical problems.
- "Metal-sheet roof covering systems that incorporate supporting structural members shall be designed in accordance with the IBC[59]."[60]
- "Metal-sheet roof coverings installed over structural decking shall comply with Table 906.4.3."[61] This table presents standards for various metal roofing materials. It should be referred to for specific PV roof panel materials.

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51. Underwriters Laboratories 790 Tests for Fire Resistance of Roof Covering.
52. IRC 904.3 Material specifications and physical characteristics.
53. IRC 904.4 Identification.
54. IRC 905.5 Metal roof shingles.
55. IRC 906.4 Metal roof panels.
56. IRC.5.4 Material standards.
57. IRC 906.4.1 Deck requirements.
58. IRC 906.4.2 Slope.
59. Change proposed to the IRC.
60. IRC 906.4.3 Material standards.
61. Ibid.

- Until the IRC includes specific requirements for PV shingles and PV roof panels, code officials can use the IRC to restrict their installation on buildings.

Until the IRC includes specific requirements for PV shingles and PV roof panels, code officials can use the IRC to restrict their installation on buildings.

Considerations for application to existing roofs. PV shingles cannot be applied to more than 25 percent of a roof with an existing roof covering, unless "the entire roof covering is made to conform to the requirements for a new roof."[62]

In a retrofit, the "structural roof components shall be capable of supporting the roof covering system and the material and equipment loads that will be encountered during installation of the roof covering system."[63]

Under certain circumstances, the existing roof coverings will need to be removed before a new roof covering is applied.[64] These circumstances include:

- "Where the existing roof or roof covering is water soaked or had deteriorated to the point that the existing roof or roof covering is not adequate as a base for additional roofing."
- "Where the existing roof covering is wood shake, slate, clay, cement or asbestos-cement tile."
- "Where the existing roof has two or more applications of any type of roof covering."
- "When the building is located in areas subject to hail damage according to Figure 909.3."

An exception is allowed if the new roof-covering system is designed to transmit structural loads directly to the building's structural system.

Access and Safety

There is concern within the renewable energy community that the codes may require expensive safety devices around roof-mounted PV arrays. There are no regulations in the codes reviewed for this report that directly require these devices. However, the IMC does require safety devices for roof-mounted "equipment and appliances."[65]
In the IMC, equipment is defined as everything "other than appliances which are permanently installed and integrated to provide control of environmental conditions for buildings."[66] Appliances are defined as "a device or apparatus that is manufactured and designed to utilize energy and for which this code provides specific requirements."[67] The scope statement for the IMC states that it regulates "mechanical systems that are permanently installed and utilized to provide control of environmental conditions and related processes within buildings. This code shall also regulate those mechanical systems, system components, equipment and

62. IRC 909.1 General.
63. IRC 909.2 Structural and construction loads.
64. IRC 909.3 Recovering vs. replacement.

65. IMC 304.8 Guards.
66. IMC 202 General Definitions.
67. Ibid.

appliances specifically addressed in this code."[68] There is no mention in the IMC of photovoltaic systems. There seems to be no requirements on access and safety in the IMC or other codes reviewed in this report that have jurisdiction over PV systems.

However, the final arbiter of code enforcement is the local code official. Because code officials may view roof-mounted PV equipment as similar to roof-mounted mechanical equipment, the PV community should be aware of possibly applicable sections of the codes.

Access. The NEC states that "sufficient access and working space shall be provided and maintained about all electric equipment to permit ready and safe operation and maintenance of such equipment."[69] Generally, the working space requires a minimum of 30 inches of free area.[70] This is directly applicable to PV systems. There are similar requirements in the IMC. Therefore, rooftop PV equipment must be installed to allow access to any part that may need future maintenance. This includes all wiring connections and other components. This NEC requirement could cause the local code officials to require compliance with the following to mitigate potential safety problems.

68. IMC 101.2 Scope.
69. NEC 110-16. Working Space About Electric Equipment (600 Volts, Nominal, or Less).
70. Ibid.

Guards. Guards need to be installed where mechanical equipment is within 10 feet of a roof edge or open side of a walking surface and the edge is more than 30 inches above grade.[71] There are specific requirements for the costruction of the guard rail.

Equipment and appliances on roofs or elevated structures. Mechanical equipment installed on roofs or elevated structures more than 16 feet above grade are required to have an approved, permanent means of access. This access allows no obstructions greater than 30 inches, or walking on roofs with a slope greater than 4 in 12.[72] If applied to PV systems, this could require ladders, roof hatches, and so forth.

Sloped roofs. Mechanical equipment installed on roofs with a slope greater than 3 in 12 and having an edge more than 30 inches above grade at the edge requires a level platform for each side of the equipment that requires access for service, repair, or maintenance. The platform needs to be at least 30 inches in any dimension. Guards need to be provided, as previously described.[73]

If enforced for PV systems, these requirements could provide a major economic and architectural obstacle to their widespread implementation. It must be remembered that these

71. IMC 304.8 Guards.
72. IMC 306.5 Equipment and appliances on roofs or elevated structures.
73. IMC 306.6 Sloped roofs.

requirements arose from real safety issues during the maintenance of mechanical systems. The problem for the PV industry is to include language in the codes that specifically exempt their systems from these requirements, or to otherwise provide data that will convince local code officials that these requirements are unnecessary.

Other Structural and Mechanical Issues

There are a number of other regulations in the codes that could be applied to rooftop PV systems.

Height limitations. Wood-framed buildings are generally limited to three stories above grade. Cold-formed, steel-frame buildings are limited to two stories. Buildings in Seismic Zone 4 are limited to two stories above grade.[74] There is no discussion in the codes as to the impact on these height limitations of additional roof-mounted structures. Many localities have height-limit regulations that may impact structures adding to the overall building height. This could impact roof-mounted PV systems and equipment.

Hazardous locations. Hazardous locations are defined in the NEC as "locations where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers..."[75] There are special and expensive requirements for wiring and components that help to eliminate the possible fire or explosion hazards in these locations.[76] It is not likely that rooftop PV equipment will be located near such hazards. However, batteries and other system components could be located in garages or other areas where these hazards could exist.

Rooftop structures: Towers, spires, dome and cupolas. These structures must be as fire-resistant as the building to which it is attached.[77] This could also apply to structures designed to architecturally integrate PV arrays into a building design.

C. Photovoltaic Systems and Systems Analysis of the IECC

In the IRC, credit for electric energy from photovoltaic systems is allowed. However, the steps necessary to calculate and document this energy credit are generally expensive and complex. It is in the interest of PV manufacturers and other interest groups to make compliance with the IECC an easier process.

In the IECC, renewable energy sources are defined as "sources of energy…derived from incoming solar radiation."[78] There is no

74. RC 301.2.2.5 Height Limitations.
75. NEC Article 500-1. Scope – Articles 500 Through 505.
76. NEC Article 500 - Hazardous (Classified) Locations.
77. IRC 908.2 Towers, spires, dome and cupolas.
78. IECC Section 201 General Definitions.

mention of renewable energy sources—including PV electricity—in the IECC prescriptive compliance path.[79]

The IECC performance path contains provisions to account for PV-generated electric power. "Renewable energy shall be permitted to be excluded from the total energy consumption allowed for the building..."[80] This energy must "be derived from a specific collection, storage, and distribution system."[81] Although not intended, this may exclude PV systems without storage, such as utility-connected systems, from energy credits in this analysis. A separate definition should be developed for PV systems, such as:

> **IECC 403.1.4 Photovoltaic energy exclusion.** Electrical energy from solar photovoltaic systems shall be permitted to be excluded from the total energy consumption allowed for the building. This electrical energy must be used in the building to displace purchased electrical energy.

An interesting question is if credit should be given for electrical energy from PV systems that is sold back or otherwise transferred to the utility grid. If the total annual production of the PV system is less than that required in the standard building design, it appears to be reasonable to allow credit for the entire amount produced. However, if the PV system produces more electrical energy than the house requires, the PV system then becomes an electrical generator and not just part of a house. It does not appear reasonable that this excess energy should be credited to the house design.

The IECC analysis procedures are designed to calculate envelope thermal loads and resulting HVAC equipment performance.[82] The referenced design methods likewise do not have provisions for the calculation of PV system performance, either in general or as applied to a specific building.[83]

There presently appears to be no method to legally allow credit from PV-generated electricity in either the prescriptive or performance paths in the IECC. This could be a major impediment to the implementation of this technology. Consequently, several activities could be undertaken to attack this problem.

- Analysis tools could be developed to allow, as appropriate, prescriptive-path compliance in the IECC. These tools could be implemented in maps or tables that relate annual PV production to collector performance parameters,

- There is no mention of renewable energy sources—including PV electricity—in the IECC prescriptive compliance path.

79. IECC Chapter 5 Residential Building Design by Component Performance Approach.
80. IECC 403.1 Renewagble Energy Source Analysis—General.
81. IECC 403.1.1 Solar energy exclusion, one.
82. IECC 403.2.3 Analysis procedure.
83. Ibid.

- Another issue with energy credits for PV systems involves the IECC requirement that electricity and other energy sources are treated equivalently. In general, energy in the form of electricity is more expensive than other types of energy. This puts PV and other alternative electricity sources at a disadvantage relative to energy credits in the IECC.

location, and collector orientation. A prescriptive-path analysis tool would likely be adequate for the majority of PV system installations. It is also likely that such a tool could be easily derived from existing research products from the U.S. Department of Energy, the PV industry, and similar sources.

- There is presently no widely used analysis program that integrates PV system performance with a detailed building simulation. This strategy could be implemented in the development of add-ons to appropriate building-energy analysis tools that add the simulation of PV system performance to these tools. It would also be necessary to develop standard profiles and area-based power densities for residential electric and thermal internal gains. For the IECC performance path, only a constant-value internal gain is specified, which presumably accounts for both electrical and thermal sources.[84] Such a program would allow the simultaneous analysis of a wide number of RE and EE technologies. This program would meet the analysis requirements of the IECC performance path. It would also allow the integration and design optimization of the wide range of these technologies.

84. IECC 402.1.3.6 Internal heat gains (constants).

- Language needs to be added to IECC Chapters 4 and 5 to allow credit for these proposed analysis methods.

There needs to be a report detailing the proposed design and analysis.[85] If RE is used, it needs to be separately identified from the overall building energy use. Supporting documentation needs to be submitted.

Another issue with energy credits for PV systems involves the IECC requirement that electricity and other energy sources are treated equivalently.[86] In general, energy in the form of electricity is more expensive than other types of energy. This puts PV and other alternative electricity sources at a disadvantage relative to energy credits in the IECC.

Finally, buildings less than 20,000 ft^2 that derive at least 30% of their annual energy from RE are exempt from a full-year energy system.[87] It is unclear what is meant by this confusing language. This represents a free bonus to some RE technology implementations, as it appears to exempt them from the detailed analysis required in the rest of Chapter 4. However, there is no discussion how this 30% figure is to be calculated, nor how compliance with this code language is to be established.

85. IECC 403.2 Documentation
86. IECC 402.2.3 Site energy.
87. IECC 403.2 Documentation, Exception.

D. Summary of Codes and Standards for PV Systems

The following table presents an overview of the sections of the reviewed codes and existing standards that apply to PV systems.

Note that blank cells in the table can represent areas where additional standards and code language may need to be developed.

Table 2. Summary of standards and reviewed code sections relevant to PV systems.

	Performance	Safety	Operation	Maintenance
Electrical Requirements				
PV module	IEEE 1262	UL 1703	NEC 690/IEEE 929	Manufacturer's Instructions
Inverter		UL 1741	NEC 690/IEEE 929	Manufacturer's Instructions
Other electrical components		UL (various)		Manufacturer's Instructions
PV system				
PV shingles	IEEE 1262	UL 1703	NEC 690/IEEE 929	Manufacturer's Instructions
PV roof panels	IEEE 1262	UL 1703	NEC 690/IEEE 929	Manufacturer's Instructions
Structural and Weather Sealing Requirement				
Weather sealing and penetrations	na	IRC Section 903	na	Manufacturer's Instructions
Racks	na		na	Manufacturer's Instructions
PV shingles	na	IRC Section 905.2	na	Manufacturer's Instructions
PV roof panels	na	IRC Section 905.4, 906.4	na	Manufacturer's Instructions

Section 4

Active-Solar Domestic Hot-Water and Space-Heating Systems: Code Impacts

There are four types of considerations for showing compliance of active-solar domestic hot-water and space-heating systems (SHW) with the codes. First, there are chapters on active solar systems in the IRC and the IMC. Second, the plumbing, mechanical, and electrical system aspects of SHW systems must comply with the appropriate sections of the IRC, IMC, IPC, and NEC not covered in the previous discussion. Third, SHW systems must meet the structural and mechanical safety requirements of the IRC. This includes weather tightness, fire resistance, wind loading, access, roof penetrations, and similar issues. Finally, the energy analysis sections of the IECC are used to determine if proper energy load reductions are given to SHW systems to help a building comply with the overall IECC requirements.

In the following section, these issues are discussed under the three headings of Access and Safety, Plumbing Requirements, and Active-Solar Hot-Water Systems and Systems Analysis of the IECC.

The code issues of SHW systems are also addressed in the SRCC Document OG-300.[1] This document is not part of the IRC or other codes referenced in this report. OG-300 will be discussed separately in Appendix A of this report. It is much wider in scope and brings together in one place many of the code issues relevant to SHW systems that are dispersed throughout the IRC and other referenced codes.

The requirements of the IRC Chapter 27 and the IMC Chapter 15 directly apply to active SHW systems. Topics from these chapters and other areas of the referenced codes are discussed.

Presently, the relevant code language applicable to SHW systems is spread throughout the various codes. The IRC chapter on solar systems[2] should include all of the information applicable to SHW applications. This allows practitioners in the SHW field to

Footnotes

1. Solar Rating and Certification Corporation Document OG-300: Operating Guidelines and Minimum Standards of Certifying Solar Water Heating Systems: An Optional Solar Heating System Certification and Rating Program, April 1997.
2. IRC 27 Solar Systems.

easily locate all applicable code requirements. This revised chapter should include references to the relevant language in the IRC, IMC, IPC, IECC, and NEC.

A. Access and Safety

There is concern within the renewable energy community that the codes may require expensive safety devices around roof-mounted SHW collectors. There are no regulations in the codes reviewed for this report that directly require these devices. However, the IMC does require safety devices for roof-mounted "equipment and appliances."[3] In the IMC, equipment is defined as everything "other than appliances which are permanently installed and integrated to provide control of environmental conditions for buildings."[4] Appliances are defined as "a device or apparatus that is manufactured and designed to utilize energy and for which this code provides specific requirements."[5] The scope statement for the IMC states that it regulates "mechanical systems that are permanently installed and utilized to provide control of environmental conditions and related processes within buildings. This code shall also regulate those mechanical systems, system components, equipment and appliances specifically addressed in this code."[6]

3. IMC 304.8 Guards.
4. IMC 202 General Definitions.
5. Ibid.
6. IMC 101.2 Scope.

The final arbiter of code enforcement is the local code official. Because code officials may view roof-mounted SHW equipment as similar to roof-mounted mechanical equipment, the SHW community should be aware of possibly applicable sections of the codes.

Access. Active solar system components "shall be accessible for inspection, maintenance, repair and replacement."[7] Accessible "signifies access that requires removal of an access panel or similar removable obstruction."[8] Readily accessible "signifies access without the necessity of removing a panel or similar obstruction."[9] The former is more restrictive. Therefore, active SHW system components must be accessible either with or without removal of a panel or similar obstruction. An exception is "live parts of electrical equipment operating at 50 volts or more shall be guarded against accidental contact by approved enclosures" or other means.[10] "Thirty inches of working space shall be provided in front of the control side to service an appliance."[11] An appliance is defined as a "device or apparatus that is manufactured and designed to utilize energy and for which this code [IRC] provides specific

7. IRC 2701.2.1 Access.
8. IRC 1202 General Mechanical Definitions.
9. Ibid.
10. NEC 110-17 Live Parts Guarded Against Accidental Contact.
11. IRC 1305.1 Appliance access for inspection service, repair and replacement.

requirements."[12] The terms "equipment" and "appliance" are used seemingly interchangeably in IRC section 1305. "Equipment" is defined as "materials, fittings, devices, appliances and apparatus used as part of or in connection with installations regulated by this code."[13] There are specific clearance requirements for equipment in rooms, including basements or similar spaces.[14] There must be an "opening or door and an unobstructed passageway measuring not less than 24 inches wide and large enough to allow removal of the largest appliance in the space." There are also specific requirements for access to equipment in attics that require access.[15] If equipment in the attic cannot be serviced "through the required opening," then a passageway with "solid continuous flooring...not less than 24 inches wide" is required for access. The equipment and appliances for which the IRC provides specific requirements include roof-mounted collectors, pressure and temperature relief valves, vacuum relief valves, freeze protection devices, expansion tanks, thermal storage units, and backflow protection devices. Presumably, local code officials would require adequate access and appropriate working space, as described above, for these and all other SHW components that may require maintenance, removal, or replacement. It would be useful if additional language describing all these requirements were included in the IRC and IMC solar system chapters.

12. IRC 1202 General Mechanical Definitions.
13. Ibid.
14. IRC 1305.1.2 Equipment in rooms.
15. IRC 1305.1.3 Equipment in attics.

Guards. Guards need to be installed where mechanical equipment is within 10 feet of a roof edge or open side of a walking surface and the edge is more than 30 inches above grade.[16] There are specific requirements for the construction of the guard rail.

Equipment and appliances on roofs or elevated structures. Mechanical equipment installed on roofs or elevated structures more than 16 feet above grade are required to have an approved, permanent means of access. This access allows no obstructions greater than 30 inches, or walking on roofs with a slope greater than 4 in 12.[17] If applied to SHW systems, this could require ladders, roof hatches, and so forth.

Sloped roofs. Mechanical equipment installed on roofs with a slope greater than 3 in 12 and having an edge more than 30 inches above grade at the edge require a level platform for each side of the equipment that requires access for service, repair, or maintenance. The platform needs to be at least 30 inches in any dimension. Guards need to be provided, as previously described.[18]

16. IMC 304.8 Guards.
17. IMC 306.5 Equipment and appliances on roofs or elevated structures.
18. IMC 306.6 Sloped roofs.

If enforced for SHW systems, these requirements could provide a major economic and architectural obstacle to their widespread implementation. It must be remembered that these requirements arose from real safety issues during the maintenance of mechanical systems. The problem for the SHW industry is to include language in the codes that specifically exempt their systems from these requirements, or to otherwise provide data that will convince local code officials that these requirements are unnecessary.

Roof-mounted collectors and roof structural loads. "The roof shall be constructed to support the loads imposed by the roof-mounted solar collectors."[19] Some designs of active SHW systems, such as those with a roof-located water storage tank, can produce highly concentrated roof loading. Higher weights are more likely to reach the roof dead-load limitations of 15 PSF (and 9 PSF in seismic areas). Although the maximum weight of these systems is relatively easy to determine, the applicable area is not. The roof structure needs to be designed and built to prevent both general and local failure. Loads over small areas need to be solidly supported, and the structure "shall transmit the resulting loads to its supporting structural elements."[20] If active SHW systems are installed on existing buildings, the roof structure may need to be evaluated to determine if excessive loading is a problem.

19. IRC 701.2.2 Roof mounted collectors.
20. IRC 801.2 Requirements of roof-ceiling construction.

Wind-loading requirements for SHW systems are specified in the IMC. "Mechanical equipment, appliances and supports that are exposed to wind shall be designed and installed to resist the wind pressures determined in accordance with the building code."[21]

Roof-mounted collectors as roof coverings. "Roof decks shall be covered with approved roof coverings secured to the building or structure..."[22] "Approved" is defined as approved "by the code official as the result of investigation and tests conducted by him, or by reason of accepted principles or tests by nationally recognized organizations."[23] If SHW collectors are designed to replace traditional roofing materials, they need to meet the code requirements for the types of roofing materials that they replace.

"Roof coverings shall be applied in accordance with this chapter and the manufacturer's installation instructions."[24] "Roofs and roof coverings shall be of materials that are compatible with each other and with the building or structure to which the materials are applied."[25]

21. IMC 301.12 Wind resistance.
22. IRC 903.11 Weather Protection, General.
23. IRC 202 General Building Definitions.
24. IRC 904.1 Scope.
25. IRC 904.2 Compatibility of Materials.

There is no definition for "compatible" in the IRC, but this most likely means that materials will not cause corrosion or other degradation in other building materials. An additional requirement is that roofing "shall conform to UL 790 and shall be installed in areas designated by l aw as requiring their use..."[26] This refers to a testing standard for fire resistance. In the absence of applicable standards or where materials are of questionable suitability, testing by an approved testing agency shall be required by the code official to determine the character, quality and limitations of application of the materials."[27] Additionally, "roof covering materials shall be delivered in packages bearing the manufacturer's identifying marks and approved testing agency labels when required."[28]

SHW collectors could be considered as roof panels designed to replace metal roofing products. In the IRC, metal roof shingles[29] are approved for use on roofs with slopes of more than 2 in 12, and metal roof panels[30] are approved on roofs with lesser slopes.

Specific requirements are that "metal roof shingle roof coverings of galvanized steel shall be 0.013 inch minimum thickness. Metal roof shingle roof coverings of aluminum shall be of 0.024 inch minimum thickness."[31]

26. Underwriters Laboratories 790 Tests for Fire Resistance of Roof Covering.
27. IRC 904.3 Material specifications and physical characteristics.
28. IRC 904.4 Identification.
29. IRC 905.5 Metal roof shingles.
30. IRC 906.4 Metal roof panels.

Requirements for metal roof panels include:

- "Metal roof panel roof coverings shall be applied to a solid or spaced sheathing, except where the roof covering is specifically designed to be applied to space supports." [32]
- "The minimum slope for lapped, non-soldered seam metal roofs shall be … 3:12. The minimum slope for standing seam roof systems shall be … ¼:12."[33] This minimum requirement should be reviewed by manufacturers in regard to water collection, which may present possible electrical problems.
- "Metal-sheet roof covering systems that incorporate supporting structural members shall be designed in accordance with the IBC."[34]
- "Metal-sheet roof coverings installed over structural decking shall comply with Table 906.4.3."[35] This table presents standards for various metal roofing materials. It should be referred to for specific roof panel materials.

31. IRC 905.5.4 Material standards.
32. IRC 906.4.1 Deck requirements.
33. IRC 906.4.2 Slope.
34. IRC 906.4.3 Material standards.
35. Ibid.

Until the IRC includes requirements specific to SHW roof systems, code officials can use the IRC to restrict their installation on buildings.

Considerations for application to existing roofs. New roof coverings cannot be applied to more than 25 percent of a roof with an existing roof covering, unless "the entire roof covering is made to conform to the requirements for a new roof."[36]

In a retrofit, the "structural roof components shall be capable of supporting the roof covering system and the material and equipment loads that will be encountered during installation of the roof covering system."[37]

Under certain circumstances, the existing roof coverings will need to be removed before a new roof covering is applied.[38] These circumstances include:

- "Where the existing roof or roof covering is water soaked or had deteriorated to the point that the existing roof or roof covering is not adequate as a base for additional roofing."
- "Where the existing roof covering is wood shake, slate, clay, cement or asbestos-cement tile."
- "Where the existing roof has two or more applications of any type of roof covering."
- "When the building is located in areas subject to hail damage according to Figure 909.3."

An exception is allowed if the new roof covering system is designed to transmit structural loads directly to the building's structural system.

Roof-mounted collectors and fire prevention. "When mounted on or above the roof coverings, the collectors and supporting structure shall be constructed of noncombustible materials or fire-retardant-treated wood equivalent to that required for the roof construction."[39] These materials must meet the requirements of UL 790.[40] Metal-framed collector panels with glass glazing will not create a fire hazard. However, flammable materials used for gaskets or other components may be a problem. There may be restrictions in the types of plastics that can be used for solar collectors. "The use of plastic solar collector covers shall be limited to those approved plastics meeting the requirement for plastic roof panels in the building code."[41] There is no information in the IRC on plastic roof panels. The IRC does have requirements for a variety of plastic and plastic-like materials. These include thermoset single-ply roof

36. IRC 909.1 General.
37. IRC 909.2 Structural and construction loads.
38. IRC 909.3 Recovering vs. replacement.
39. IRC 701.2.2 Roof-mounted collectors.
40. Underwriters Laboratories 790 Tests for Fire Resistance of Roof Covering.
41. IMC 502.3.1 Collectors mounted above the roof. Exception.

coverings,[42] thermoplastic single-ply roofing,[43] sprayed polyurethane foam roofing,[44] and foam plastics.[45] All of these materials are applied in monolithic layers on roofs. However, the fire resistance requirements in the referenced standards are likely similar to those needed for the materials found in plastic solar collectors. Because the requirements for the materials in plastic solar collectors are not in the IRC, the local code officials may need to be convinced that the fire resistance and other properties of these collectors are comparable to that of approved roof coverings. It will be easier to convince local code officials of the appropriateness of their products if the manufacturers and other constituents of these products develop an applicable standard and test their products to that standard.

B. Plumbing Requirements

Most of the components in active SHW systems are plumbing components, which come under the requirements of some sections of the IRC, IMC, and IPC. The plumbing components with code requirements in the Solar Systems sections of the IRC and IMC will be considered first.

Pressure and temperature relief. Fluid-containing components must be protected with pressure and temperature relief valves. The system must be designed to prevent the isolation of sections of the system from the relief devices.[46] The relief valves "shall bear the label of an approved testing agency and shall have a temperature setting of not more that 210°F and a pressure setting not exceeding the tank...working pressure or 150 psi, whichever is less. The relieving capacity of each pressure relief valve and each temperature relief valve shall equal or exceed the heat input to the water heater or storage tank."[47] Additional requirements apply to the size of the discharge pipe from the relief valve, where it goes, how to protect it from freezing, and other requirements.[48] Any pipe material listed as suitable for water-service pipe can be used for the discharge piping. There is no code language specifying that the discharge piping from each relief valve be separately piped to the outside or an appropriate drain. However, this may be an issue of concern to local code officials.

Vacuum relief. If any system components can experience sub-atmospheric pressures when in operation or shutdown, they must be protected with a vacuum relief valve.[49] There do not appear to be

- Because the requirements for the materials in plastic solar collectors are not in the IRC, the local code officials may need to be convinced that the fire resistance and other properties of these collectors are comparable to that of approved roof coverings.

42. IRC 906.6.2 Materials standards. These refer to the Rubber Manufacturer's Association standards RP-1, RP-2 and RP-3.
43. IRC 906.7.2
44. IRC 906.8.2
45. IRC 906.9.2
46. IRC 27.2.3 Pressure and temperature relief.
47. IPC 504.5 Relief valve approval.
48. IPC 504.7.1, 2 and 3 Relief outlet waste discharge, location and materials.
49. IPC 2701.2.4 Vacuum relief.

any additional requirements that specify the design or performance of relief valves. The IMC Solar Systems chapter requirement is similar, but states that such a system "shall be designed to withstand such vacuum or shall be protected with vacuum relief valves."[50] This allows more flexibility if other technical approaches are available.

Protection from freezing. Any system components subject to the freezing of heat-transfer fluids need to be protected from associated damage.[51] This language includes the use of low-freezing-temperature heat-transfer fluids for freeze protection. Reference is made that protection from freezing can be "by insulation or heat or both."[52] There is no direct reference to the emptying of piping and components with the approach of freezing temperatures, as is done with draining-type SHW systems. It would be useful to add language in the IRC Solar Systems chapter to more explicitly define the acceptable options.

> **IRC 2701.2.5.1 Acceptable freeze protection methods.** Freeze protection shall be provided by heating, insulation, suitable low-freezing-point fluids, draining of piping and other components, or an appropriate combination of these methods.

50. IMC 1502.4.2 Vacuum.
51. IRC 2701.2.5 Protection from freezing.
52. IPC 305.6 Freezing.

Expansion tanks. The IRC treats SHW systems as boilers in regard to expansion tanks.[53] Expansion tanks can be either non-pressurized or pressurized, depending on the system design. Both types must meet the minimum capacity requirements of IRC Table 2302.2.[54] Non-pressurized tanks are appropriate for draining systems that operate at atmospheric pressure. These are likely required even if the system is designed to accommodate the fluid expansion independent of an expansion tank. The IRC could be changed to provide for such systems.

> **IRC 2701.2.6.1 Exception.** Non-pressurized, draining solar hot-water systems do not need expansion tanks if the system is designed to accommodate the expansion volumes under "Nonpressurized Type" in IRC Table 2302.2.[55,56]

There are specific requirements for the location, structural support, and overflow discharge requirements of non-pressurized tanks.

Collectors. SHW collectors "shall be listed and labeled to show the manufacturer's name, model, serial number, collector weight, maximum allowable temperatures and pressures, and the type of heat transfer fluids allowed."[57] "Listed"

53. IRC 27.2.6 Expansion tanks. Refers to IRC section 2303.
54. IRC 2302.2 Minimum capacity.
55. IRC 2302.1 General.
56. IMC 1009.3 Open-type expansion tanks.
57. IRC 2701.3.1 Collectors.

refers to equipment that has been tested by an approved testing agency to meet nationally recognized standards.[58] At least one researcher claims that the type of heat-transfer fluids allowed should not be an issue with the collector or other components.[59] He states that this should be a system-level issue, and appropriate labels should be applied to the system drain and fill valves. It seems appropriate that any heat-transfer fluids that are not compatible with the collector materials, such as those that cause corrosion, should be labeled on the collector. Fluids that are not compatible with the piping and materials found in other SHW plumbing components, or prohibited heat-transfer materials could be labeled at the fill and drain valves.

The IRC and other referenced codes have no requirements to label collectors with results from standardized performance tests.

Thermal storage units.
"Pressurized thermal storage units shall be listed and labeled to show the manufacturer's name, model, serial number, maximum and minimum allowable operating temperatures and pressures, and the type of heat transfer fluids allowed."[60] The allowable fluids listing issue is the same as for collectors above. There are no requirements for non-pressurized thermal storage tanks, as would be used in some draining SHW systems.

The IPC has requirements for minimum insulation levels for water-heater storage tanks. They "shall be insulated so that heat l loss is limited to a maximum of 15 BTH/h/ft^2 of external tank surface area...the design ambient temperature shall not be higher than 65°F."[61] This equates to a water-to-air R-value of about 9.7. Additional requirements for water heater tanks are in the IECC, which may be applicable and more stringent than those in the IPC. [62] It would be useful to include this in the IRC Solar Systems chapter.

> **IRC 2701.3.2.1 Thermal storage unit insulation levels.** Thermal storage units shall be insulated so that heat loss is limited to a maximum of 15 BTH/h/ft^2 of external tank surface-area. For design purposes, the design ambient temperature shall not be higher than 65°F. This equates to a minimum water-to-air R-value of about 9.7.

Prohibited heat-transfer fluids.
Flammable gases and liquids cannot be used as heat-transfer fluids.[63] Flammable liquids are defined as having "a flash point below

- The IRC and other referenced codes have no requirements to label collectors with results from standardized performance tests.

58. IRC 202 General building definitions.
59. Jay Burch, NREL. Personal conversation.
60. IRC 2701.3.2 Thermal storage units.
61. IPC 505.1 Unfired vessel insulation.
62. IECC 504.2 Water heaters, storage tanks and boilers.
63. IRC 2701.4 Prohibited heat transfer fluids.

100°F."[64] The flash point is "the minimum temperature...at which the application of a test flame causes the vapors of a portion of the sample to ignite under 'standardized test conditions.' "[65] The flash point then is the minimum temperature at which the vapors from a liquid will ignite. The IMC allows liquids to be used with flash points above 100°F, as long as the flash-point temperature is less than the highest temperature conditions listed in the IMC.[66]

Backflow protection. The purpose of backflow prevention is that "potable water systems shall be protected against contamination in accordance with the plumbing code."[67] Potable water is defined as "water free from impurities present in amounts sufficient to cause disease or harmful physiological effects and conforming in...quality to the requirements of the...public health authorities having jurisdiction." [68] "The potable water supply to a solar system shall be equipped with a backflow preventer with intermediate atmospheric vent complying with ASSE/ANSI 1012[69] or a reduced pressure principle backflow preventer complying with ASSE/ANSI 1013.[70] Where chemicals are utilized, the potable water supply shall be protected by a reduced pressure principle backflow preventer."[71] "Heat exchangers utilizing an essentially toxic transfer fluid shall be separated from the potable water by double-wall construction. An air gap open to the atmosphere shall be provided between the two walls. Heat exchangers utilizing an essentially nontoxic transfer fluid shall be permitted to be of single-wall construction."[72]

This language is confusing, and the requirements may be excessive and redundant to other requirements for some SHW system designs. The definition of potable water can be interpreted in two ways. Does it refer to the potable water supply before it enters the house, or does it also include the potable water piping, both hot and cold, in the house? How this is interpreted affects system design choices and costs. The first would require an approved backflow preventer where the cold-water line enters the building if any SHW system is connected to the water lines in the building. Two types of SHW system designs will be considered.

Once-through systems. These systems can be used as pre-heaters for domestic water heaters. The cold, potable water runs through a pipe that enters and exits a solar

64. IMC 202 General definitions.
65. Ibid.
66. IMC 1503.1 Flash point.
67. IMC 1501.2 Potable water supply.
68. IPC 202 General definitions.
69. American Society of Sanitary Engineering 1012 Vacuum Breakers.
70. American Society of Sanitary Engineering 1013 Performance Requirements for Reduced Pressure Principle Backflow Preventers.
71. IRC 3402.4.3 Solar systems.
72. IPC 608.16.3 Heat exchangers.

collector. If the pipe meets the requirements for potable water piping in the IPC, there is no need for backflow protection to prevent contamination of the potable water supply. The existing code language is excessive. Such systems should be exempt from the backflow preventer requirements for solar systems.

Indirect systems with heat exchangers. These systems isolate the solar-loop fluid from the potable fluid with a heat exchanger. The solar-loop fluid can contain propylene glycol, a non-toxic antifreeze. The heat exchanger "utilizes an essentially nontoxic transfer fluid," and only a single-wall heat exchanger is required by IPC 608.16.3. This implies that leakage of the solar-loop fluid into the house potable water lines is permitted by the IMC. The addition of backflow preventers to isolate the potable water pipes is redundant and unnecessary. If the solar-loop fluid is not compatible with potable water, then a double-wall heat exchanger with an atmospheric air gap is required. This is sufficient to prevent contamination of the potable water, and additional backflow preventers should not be required. To quote a researcher in the active SHW system field, "an approved combination of heat exchangers and heat transfer fluids is sufficient to prevent contamination of potable water."[73]

There are other possible design features of SHW systems where contamination of the potable water is possible. One is a solid pipe connection where the potable water line refills the solar loop. This can be considered similar to the refill connection to a boiler, which does require a backflow preventer.[74]

A second design is where a loop of single-wall potable water pipe is used as a heat exchanger in a solar fluid storage tank. These systems would normally maintain a positive pressure differential between the potable water and the solar-loop fluid. Under improbable circumstances, the potable house water could be contaminated. It is not clear how backflow preventers would prevent this. If the potable water lines lost their positive pressure, and the pipe simultaneously developed a leak, solar-loop fluid could enter both legs of the potable water line. This requires the installation of a backflow preventer on both the inlet and outlet pipes of the heat exchange loop, which would prevent its normal operation.

The active SHW industry needs to determine under what types of system designs and conditions the contamination of potable water lines is possible. Suitable and effective designs of backflow prevention need to be developed, as necessary.

- The active SHW industry needs to determine under what types of system designs and conditions the contamination of potable water lines is possible. Suitable and effective designs of backflow prevention need to be developed, as necessary.

73. Jay Burch, NREL. Personal conversation.

74. IPC 608.16.2 Connections to boilers.

A change in the IRC language could read:

> **IRC 3402.4.3.1 Exceptions for solar systems that do not require backflow protection.** Solar systems that do not expose potable water to non-potable water are exempt from the requirements of 3402.4.3. This includes solar systems where the potable water acts as the solar-loop heat-transfer fluid, where the solar-loop fluid is essentially non-toxic, and where contamination of the potable water is not possible.

Backflow protection devices need to be installed so they are accessible for inspection and testing. "The frequency of testing shall be determined in accordance with t he manufacturer's installation instructions. Where the manufacturer...does not specify the frequency of testing, the assembly shall be tested at least annually."[75] Apparently, "the permit holder shall make the applicable tests..."[76]

There are several other areas of the codes that affect the plumbing aspects of a SHW system, but they are not specifically addressed in the chapters on solar systems. Significant code requirements are addressed here.

Water heater as space heater. "A water heater used as a part of a space heating system shall have a maximum outlet water temperature of 160ºF. The potability of the water shall be maintained throughout the system."[77] "When a combination water heater-space heating system requires water for space heating at temperatures higher than 140ºF, a means such as a mixing valve shall be installed to temper the water for domestic uses."[78]

Determining water-supply fixture units and estimating supply demand. The IRC presents a method for determining the maximum hot-water demand, based on the types and numbers of plumbing fixtures and appliances installed in a house.[79,80,] This information can be used to size the piping for the load side of a SHW system. It may also be useful in properly sizing the SHW system components.

Temperature controls. "All hot water supply systems shall be equipped with automatic temperature controls capable of adjustments from the lowest to the highest acceptable temperature settings for the intended temperature operating range."[81] On an active solar system, this will presumably be a tempering valve or similar device.

75. IPC 312.9 Inspection and testing of backflow prevention assemblies.
76. IPC 312.1 Required tests.
77. IPC 501.2 Water heater as space heater.
78. IRC 3302.2 Scald protection.
79. IRC 3403.5 Determining water-supply fixture units.
80. IRC 3403.6 Estimating supply demand.
81. IPC 501.8 Temperature controls.

Energy-cutoff device. "All automatically controlled water heaters shall be equipped with an energy cutoff device that will cut off the supply of heat energy to the water tank before the temperature in the tank exceeds 210ºF."[82] This type of control will eliminate the flow through SHW collectors when the temperature limit is reached. The 210ºF limit may be too high for high-elevation locations, where the boiling point of water is below 210ºF. Language could be added to the IRC to account for the reduction in boiling point due to increased elevation.

> **IRC 3301.7 Locations significantly above sea level.** The maximum temperature for the energy-cutoff device shall be 2ºF below the local boiling point of water.

Required pan. If leakage from water heaters or hot-water storage tanks can cause damage, the tank or water heater must be installed in a galvanized steel pan that meets the requirements in IRC 3301.5.1 and 3301.5.2.[83]

Piping support. The IPC contains the required piping supports that must be installed for all plumbing systems.[84] This includes the materials, support intervals, and other requirements. Additional requirements exist for supporting plumbing in seismic areas.

82. IRC 3301.7 Energy cutoff device.
83. IRC 3301.5 Required pan.
84. IPC 308 Piping support.

Protection of piping. Pipes and other plumbing system components must be installed to be protected against corrosion from contact with concrete materials,[85] breakage when passing through or under walls,[86] stress and strain from the expansion, contraction or settling of other building components,[87] and freezing from being located outside, in unconditioned spaces, or in outside walls.[88] SHW system piping, particularly in retrofits, may need to run through such spaces, particularly attics or unconditioned garages.

Penetrations between separate dwelling units. There is a requirement in the IRC for wiring and piping penetrations between dwelling units in a multi-dwelling building. "Penetrations shall be fire resistant, rated in accordance with sections 320.1 and 320.2. The through penetration firestop systems tested in accordance with ASTM E 814[89] with a minimum positive pressure differential of 0.01" of water. The firestop shall have an 'F' rating not less than required for the penetrated assembly." These requirements are to prevent the spread of fire from one dwelling unit to an adjacent unit.

85. IPC 305.1 Corrosion.
86. IPC 305.2 Breakage.
87. IPC 305.3 Stress and strain.
88. IPC 305 Protection of pipes and plumbing system components.
89. American Society for Testing and Materials E 814 Test Methods for Fire Tests of Through Penetration Fire Stops.

Rodent proofing. "In or on structures where openings have been made in walls, floors or ceilings, for the passage of pipes, such openings shall be closed and protected by the installation of approved metal collars that are securely fastened to the adjoining structure."[90]

Pipe insulation. There do not appear to be requirements in any of the reviewed codes for pipe insulation on systems that heat water for domestic use only. There are requirements for the minimum required pipe insulation for HVAC system piping,[91] which would apply to SHW space or space and domestic hot-water (DHW) heating systems.

Piping. The pipe and plumbing components associated with a SHW system that contains potable water shall meet the requirements of the IPC.[92] This pipe "shall conform to NSF 6.21[93] and shall conform to one of the standards listed in Table 605.5. All hot water distribution pipe and tubing shall have a minimum pressure rating of 100 psi at 180ºF."[94] The table presents ASTM standards for the following types of allowed pipe:

- Brass pipe
- Chlorinated polyvinyl chloride plastic pipe and tubing
- Copper or copper alloy pipe
- Copper or copper alloy tubing (Type K, WK,L, WL, M, or WM)
- Cross-linked polyethylene plastic tubing
- Cross-linked polyethylene/ aluminum/cross-linked polyethylene pipe
- Galvanized steel pipe
- Polybutylene pipe and tubing.

The listed pipe fittings for potable water include the following. These must also be approved for installation with the installed piping material[95] and must meet the appropriate standards listed in Table 605.6 of the IPC.

- Acrylonitrile butadiene styrene plastic
- Cast iron
- Chlorinated polyvinyl chloride plastic pipe and tubing
- Copper or copper alloy
- Cray iron and ductile iron
- Malleable iron
- Polyethylene plastic
- Polyvinyl chloride plastic
- Steel.

Non-potable piping in hydronic heating systems must meet the requirements of the IMC.[96] The piping standards are the same as for the water distribution piping listed above, except for the following additions and other changes:[97]

90. IPC 304.4 Rodent proofing.
91. IECC 503.3.3.1 Piping insulation.
92. IPC 605.5 Water distribution pipe.
93. National Sanitation Foundation 61 Drinking Water System Components – Health Effects.
94. Ibid.
95. IPC 605.6 Fittings.
96. IMC 1202.4 Piping materials standards.
97. IMC Table 1202.4 Hydronic Pipe.

- Acrylonitrile butadiene styrene plastic pipe
- Brass tubing
- Chlorinated polyvinyl chloride plastic pipe
- Copper or copper alloy tubing (Type K, L, or M)
- Cross-linked polyethylene/ aluminum/cross-linked polyethylene pressure pipe
- Lead pipe
- Polyvinyl chloride plastic pipe
- Steel pipe
- Steel tubing.

The materials and standards listed for pipe fittings in hydronic systems include:[98]

- Bronze
- Copper and copper alloy
- Gray iron
- Malleable iron
- Plastic
- Steel.

Solder types. "Soldered joints shall be made in accordance with the methods of ASTM B 828.[99]... The joint shall be soldered with a solder conforming to ASTM B 32."[100]

Disinfection of potable water system. "Water systems shall be purged of deleterious matter and disinfected prior to utilization."[101] The process includes flushing with clean, potable water and disinfecting with a minimum 50 ppm chlorine solution. Local jurisdictions may apply more stringent requirements.

Electrical requirements.

Electrical components of SHW systems must meet the minimum requirements of the NEC. Typical electrical components include sensors and associated circuits, pumps and their power circuits, and controllers and their power and sensor circuits. The electrical requirements for such components are typical of electrical work in buildings. Applicable NEC articles will be noted and briefly described.

Temperature limitation of conductors. The insulation on electrical wires and cables is temperature-rated. "No conductor shall be used in such a manner that its operating temperature will exceed that designated for the type of insulated conductor involved."[102] This may be a concern for wiring on or adjacent to SHW panels, piping, or storage tanks, where the temperatures can get quite high.

Signal-carrying, low-voltage circuits. These circuits must comply with the requirements of NEC Article 725 part C. Class 2 and Class 3 Circuits. The cable used for instrumentation signals in

98. IMC Table 1202.5 Hydronic Pipe Fittings.
99. American Society for Testing and Materials B 828 – 92 Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings.
100. American Society for Testing and Materials B 32 – 94 Specification for Solder Metal.
101. IPC 610 Disinfection of potable water system.
102. NEC 310-10. Temperature limitations of conductors.

dwellings must be rated Type CL2X or CL3X or better.[103] Cables in ducts delivering environmental air must be rated CL2P or CL3P or better.[104] Other permitted cable types are listed in Table 725-71 of the NEC. Instrumentation wire, Type ITC, is not approved for use in dwellings[105] because of concerns about the fire resistance of the cabling.

There are many requirements regarding the wiring methods used for the signal wiring. The signal-carrying cables cannot be in close contact with power-carrying wires, unless one of a number of specific isolation methods is used. These are described in NEC Article 725-54.

Pump motors. The fractional horsepower motors typically used in residential SHW systems are considered as "one horsepower or less, automatically started" by the NEC.[106] A motor is considered to be automatically started if its operation is controlled by an electronic controller, rather than manually. Protection against electric current overload—resulting from, for example, a locked pump rotor—must generally be provided by one of the following:

103. NEC 725-71(c) Types CL2X and CL3X.
104. NEC 725-61(a) Plenum.
105. NEC 727-2 Uses permitted.
106. NEC 430-32(c) Continuous-duty motors. One horsepower or less, automatically started.

- A separate overload device or circuit breaker, appropriately sized
- A thermal protection mechanism integral to the motor.

SHW system controllers. These units need to be listed and/or labeled as appropriate for use in the intended application.[107] This typically requires testing by Underwriters Laboratories or a similar organization to be acceptable to local code officials.

C. Active-Solar Hot-Water Systems and Systems Analysis of the IECC

In the IRC, credit for thermal energy from SHW systems is allowed. "Renewable energy shall be permitted to be excluded from the total energy consumption allowed for the building..."[108] This energy must "be derived from a specific collection, storage, and distribution system."[109] However, there is no mention of renewable energy sources, including heat from SHW systems, in the IECC prescriptive compliance path.[110] Unfortunately, the steps necessary to calculate and document the SHW

107. NEC 90-7 Examination of equipment for safety.
108. IECC 403.1 Renewable Energy Source Analysis – General.
109. IECC 403.1.1 Solar energy exclusion, one.
110. IECC Chapter 5 Residential Building Design by Component Performance Approach.

energy credit are generally expensive and complex. It is in the interest of SHW manufacturers and other interest groups to make compliance with the IECC an easier process.

The IECC performance path contains provisions to account for PV-generated electric power. “Renewable energy shall be permitted to be excluded from the total energy consumption allowed for the building...”[111] This energy must “be derived from a specific collection, storage, and distribution system.”[112] This may exclude SHW systems without storage, including once-through DHW pre-heating designs. A separate definition should be developed for SHW systems, such as:

> **IRC 403.1.5 Solar hot-water energy exclusion.** Thermal energy from solar hot-water systems shall be permitted to be excluded from the total energy consumption allowed for the building. This thermal energy must be used in the building to displace purchased electrical energy, fuel, or other thermal energy used for space heating of hot water.

The IECC analysis procedures are designed to calculate envelope thermal loads and resulting HVAC equipment performance.[113] The referenced design methods likewise do not have provisions for the calculation of SHW system performance, either in general or as applied to a specific building.[114] Building energy simulations like the DOE2 program[115] allow accurate calculation of time-varying DHW and space-heating hot-water loads. Such programs are not capable of modeling active solar systems. There are programs that allow the performance of active SHW systems to be analyzed,[116] but these are not tied into the calculation methods approved for the IECC analysis path. TRNSYS[117] is a program that does allow the simultaneous analysis of building thermal and hot-water loads, in conjunction with a coincident hourly analysis of the performance of an SHW system. Unfortunately, TRNSYS is designed as a research tool and is not appropriate or cost-effective for the analysis of each intended SHW installation.

As such, there presently appears to be no legal and practical method to allow credit from SHW derived thermal energy in either the prescriptive or performance paths in the IECC. This could be a major impediment to implementing this

- As such, there presently appears to be no legal and practical method to allow credit from SHW derived thermal energy in either the prescriptive or performance paths in the IECC.

111. IECC 403.1 Renewable Energy Source Analysis – General.
112. IECC 403.1.1 Solar energy exclusion, one.
113. IECC 403.2.3 Analysis procedure.
114. Ibid.
115. DOE2
116. Beckman, W. and Duffie, J. 1977. Solar heating design by the f-Chart method.
117. Klein, S., and Beckman, W. 1994. TRNSYS: A transient simulation program. Engineering Experiment Station Report 38-14. University of Wisconsin, Madison.

technology. Consequently, several activities could be undertaken to attack this problem.

- Analysis tools could be developed to allow, as appropriate, prescriptive path compliance in the IECC. These tools could be implemented in maps or tables that relate annual SHW energy performance to collector performance parameters, location, and collector orientation. A prescriptive-path analysis tool would likely be adequate for the majority of SHW system installations. It is also likely that such a tool could be easily derived from existing research products from DOE, the SHW industry, and similar sources.

- There is presently no widely used analysis program that integrates SHW system performance with a detailed building simulation. This capability used to be available in the DOE2[118] program and is presently being developed for the Energy-10[119] program. It would also be necessary to develop standard profiles and area-based DHW loads for residential buildings. For the IECC performance path, only a constant-value internal gain is specified, which presumably accounts for both electrical and thermal sources.[120] Such a program would allow the simultaneous analysis of a wide number of RE and EE technologies. This program would meet the analysis requirements of the IECC performance path. It would also allow the integration and design optimization of the wide range of these technologies.

- Language needs to be added to IECC Chapters 4 and 5 to allow credit for these proposed analysis methods.

There needs to be a report detailing the proposed design and analysis.[121] If RE is used, it needs to be separately identified from the overall building energy use. Supporting documentation needs to be submitted.

Finally, buildings less than 20,000 ft^2 that derive at least 30% of their annual energy from RE are exempt from a full-year energy system.[122] It is unclear what is meant by this confusing language. This represents a free bonus to some RE technology implementations, as it appears to exempt them from the detailed analysis required in the rest of IECC Chapter 4. However, there is no discussion of how this 30% figure is to be calculated, or how compliance with this code is to be established.

118. Lawrence Berkeley Laboratory. 1982. DOE2 Engineers Manual. Lawrence Berkeley Laboratory Report LBL-11353. National Technical Information Services, Springfield, VA.
119. Energy-10 reference.
120. IECC 402.1.3.6 Internal heat gains (constants).
121. IECC 403.2 Documentation.
122. IECC 403.2 Documentation, Exception.

Appendix A

Comparison of the SRCC Document OG-300 and the Reviewed Codes in Regard to Active-Solar Hot-Water Systems

The OG-300 document[1] (SRCC) describes a standard methodology for testing the performance parameters of active SHW systems as well as the building-code-related issues of these systems. Only the issues related to building codes are discussed here. SHW systems that pass the SRCC certification process will be labeled and listed for the purposes of the other codes reviewed in this document.

Certification under the SRCC does not overrule the requirements of the applicable building codes at the building location.[2] The SRCC also has many requirements for which there are no comparable requirements in the building codes. The remainder of this Appendix will list the building-code-related requirements in the SRCC and will discuss the comparable requirements between these codes and OG-300. SRCC requirements that are not discussed are either not related to, or have no comparable requirements in, the building codes. Most of the OG-300 requirements are more stringent than may be required by local code officials working under the other codes reviewed in this report.

6.1.1.3 Thermal Expansion and 6.1.3.4 Expansion Tanks. The SRCC states that the system "shall include adequate provisions for the thermal contraction and expansion of heat transfer fluids," and "Expansion tanks shall be sized in accordance with ASHRAE recommendations." The IRC requires expansion tanks and has specific requirements for the capacity of an expansion tank to handle thermal expansion.[3] The language in the SRCC could be interpreted to not require an expansion tank if other design features allow for the thermal expansion of the heat-transfer fluids.

6.1.1.4 Auxiliary Water-Heating Equipment. The SRCC states that "A backup system shall be provided such that the combined system will provide the same degree of reliability and performance as a conventional system." The IRC states that every "dwelling shall have an approved automatic water heater or other type domestic water-heating system sufficient to supply hot water to plumbing fixtures and appliances intended for [the typical uses.]"[4] The two requirements are functionally equivalent.

Footnotes

1. SRCC Document OG-300. Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems: An Optional Solar Water Heating System Certification and Rating Program, April 1997.
2. SRCC 3.0 Regulations.
3. IRC 2303 Expansion tanks.
4. IRC 3301.1 Required.

6.1.1.8 Vacuum-Induced Pressure Protection. The SRCC states that "All components of the solar energy system shall be protected against the maximum vacuum which could occur within the system." The IRC states that "System components that may be subjected to pressure drops below atmospheric pressure during operation or shutdown shall be protected by a vacuum-relief valve."[5] The language in the SRCC could be interpreted to not require vacuum relief valves if other design features allow for negative pressure in fluid loops.

6.1.1.10 Different Metallic Materials. The SRCC requires that "All metals used in the storage system which comes into contact with the heat transfer fluid shall be in accordance with...HUD Minimum Property Standard 4930.2." This reference has not been reviewed for this report. The IRC requires that "Joints between different piping materials shall be made with a mechanical joint of the compression or mechanical-sealing type...Connectors or adapters shall have an elastomeric seal conforming to ASTM D 1869[6] or ASTM F 477.[7]" The intent of both requirements is likely comparable.

6.1.2.2 Protection from Ultraviolet Radiation. The SRCC states, "Ultraviolet light shall not significantly alter the performance of any component or subcomponent of the system." The only reference in the other codes to this topic is the requirement in the NEC that cabling rated for outdoor use is to be used for module connections in a PV system.[8] The SRCC requirement covers all system components, and is more stringent.

6.1.3.1 Tank Design Requirements. The SRCC states that "Both pressurized and non-pressurized tanks shall meet the requirement set by a nationally accepted standard setting organization." The IRC requires pressurized thermal storage tanks to be listed and labeled,[9] but there are no requirements for non-pressurized storage tanks in any of the codes. However, the general requirement that all plumbing appliances and components be labeled by an approved agency[10] makes the two sets of requirements comparable.

6.1.3.2 Tank Insulation. The SRCC requires that "tank insulation shall have a minimum of R-12 ºF-ft^2-h/BTU. The IPC requires a water-to-air R-value of about R-9.7.[11] The SRCC requirements are more stringent.

6.1.5.3 Wiring Identification. The SRCC states that "Control circuit wiring and terminals shall be identified in accordance with Chapter 2 of the National Electrical Code." This is equivalent to the NEC requirements.

5. IRC 2701.2.4 Vacuum relief.
6. American Society for Testing and Materials D 869. Specification for Rubber Rings for Asbestos-Cement Pipe.
7. American Society for Testing and Materials F 477. Specification for Elastomeric Seals for Joining Plastic Pipe.
8. NEC 690-31 Methods permitted.
9. IRC 2701.3.2 Thermal storage units.
10. IPC 303.4 Labeled.
11. IPC 505.1 Unfired vessel insulation.

6.1.5.4 Temperature Rating. The SRCC states that "Wiring under insulation shall be rated for expected increased temperature conditions." The NEC requires that "No conductor shall be used in such a manner that its operating temperature will exceed that designated for the type of insulated conductor involved." Because high temperatures could be reached near collectors, but not necessarily under insulation, the NEC requirements are more restrictive.

6.1.5.5 Control Lines and Sensors. The SRCC states that all means of transmitting control or sensor signals "shall be sufficiently protected from degradation or from introducing false signals as a result of environmental or system operating conditions." Several sections of the NEC and other codes require protection from physical damage for wiring and similar components. However, nothing in these codes guarantees the integrity of the control or sensor signals. The SRCC requirements are more restrictive.

6.1.5.6 Temperature Control. The SRCC states that "The system shall be equipped with a means for automatically limiting the temperature of the hot water at the fixtures to a selectable temperature," and has further requirements for the temperature range. The IPC has similar language, but no specific temperature range is described. The SRCC is more restrictive.

6.1.6.3 Insulation. The SRCC states that "All interconnecting hot water piping and the final 5.0 feet of the cold water supply pipe leading to the system, or the length of piping which is accessible if less than 5.0 feet, shall be insulated with R-2.6 $^{o}F\text{-}ft^{2}\text{-}h/BTU$ or greater insulation." The other codes have pipe insulation requirements for hydronic systems, but not for hot-water heaters and similar installations. The SRCC requirements are more restrictive.

6.1.6.5 Water Shut-Off. The SRCC states that the solar "system shall be valved to provide for shut-off from the service water supply without interrupting normal cold water service to the residence." The IPC requires shut-off valves "On the water supply pipe to each appliance or mechanical equipment."[12] This may not be strictly equivalent, but would likely be interpreted as the same by local code officials.

6.2.5 Freeze Protection. The SRCC and the other codes have comparable general requirements for freeze protection. However, the SRCC has more-specific requirements.

6.2.6 Protection from Leaks. The SRCC requires both the potable and non-potable sections of a solar system to be free from leaks "when tested in accordance with the codes in force at the installation site." The IPC requires that the "system, or portion completed, shall be tested and proved tight under a water pressure not less than the working pressure of the systems..."[13] The latter may not strictly require the testing of the non-potable sections of an SHW system. However, these would both likely be interpreted as equivalent by local code officials.

6.3.2 Protection of Electrical Components. The SRCC states that for electrical components, "Overload and overcurrent protection...shall be consistent with the maximum current rating of

12. IPC 606.2 Location of shutoff valves.
13. IPC 312.5 Water supply system test.

the device and with the provisions of article 240, Chapter 2 of the National Electrical Code." This is equivalent to the requirements of the referenced NEC.

6.3.5 High-Temperature Control. The SRCC states "Means shall be provided to limit tank temperatures to a value not to exceed the tank supplier's specified high temperature limit. The pressure/temperature relief valve shall not be used for this purpose under normal operating conditions." The IRC requires that water heaters need to be equipped with an energy-cutoff device that limits tank temperatures to 210ºF, and that the device to implement this is in addition to the temperature and pressure relief valves. Because the maximum allowed tank temperature may be less than 210ºF, the SRCC requirements are more stringent.

6.3.8 Contamination of Potable Water. The SRCC requires that "Materials which come in direct contact with potable water shall not adversely affect the taste, odor or physical quality and appearance of the water..." The IPC requires that "A potable water supply system should be designed, installed and maintained in such a manner so as to prevent contamination..."[14] Contamination is defined as "an impairment of the quality of potable water that creates an actual hazard to the public health through poisoning or through the spread of disease..."[15] The SRCC requirements are more stringent.

6.3.10 Backflow. The SRCC states that "Means shall be provided to prevent backflow of nonpotable fluids into the potable water system." The IRC has more restrictive language, requiring an explicit backflow protection device for the potable water supply to a solar system.[16]

6.3.14 Liquid Flash-Point. The SRCC requires that "The flash point of a heat transfer fluid shall exceed by 50°F, or more, the design maximum no-flow temperature to be reached by the fluid in the collector." The IRC requirement prohibits flammable gases and liquids from use as an SHW system heat-transfer fluid. Flammable liquids are defined as having "a flash point below 100ºF."[17] The flash point is "the minimum temperature...at which the application of a test flame causes the vapors of a portion of the sample to ignite under 'standardized test conditions.' "[18] The flash point then is the minimum temperature at which the vapors from a liquid will ignite. Because the maximum temperature of the heat-transfer fluid in an SHW system is greater than 100ºF, the SRCC regulations are less strict than the IRC requirements.

6.3.16 Pressure Relief. The requirements for pressure relief valves in the SRCC and the other codes are comparable. The IMC further requires that the discharge piping "shall be of rigid pipe that is approved for the temperature of the system. The discharge pipe shall be the same diameter as the safety or relief valve outlet. Safety and relief valves shall not discharge so as to be a hazard, a potential cause of damage or otherwise a nuisance."[19]

14. IPC 608.1 General.
15. IPC 202 General definitions.
16. IRC 3402.4.3 Solar systems.
17. IMC 202 General definitions.
18. Ibid.
19. IMC 1006.6 Safety and relief valve discharge.

6.4.6 Maintenance and Servicing. The SRCC requires that system components "which may require...maintenance shall be easily and safely accessible by the owner and in accordance with the building codes in force at the installation site." This is equivalent to the requirements in several of the other codes. Local code officials could interpret the other codes to require ladders, platforms, and guard rails to facilitate safe access. This would be much more stringent than the requirements in the SRCC.

6.5.5 Building Penetrations. The SRCC states that "Penetrations of the building through which piping or wiring is passed shall not reduce or impair the function of the enclosure." This is comparable to various requirements in the other codes.

6.5.8 Structural Supports. The SRCC requires that "Neither wind loading (including uplift) nor the additional weight of filled collectors shall exceed the live or dead load ratings of the building, roof, roof anchorage, foundation or soil. Collector supports shall not impose undue stresses on the collectors. The design load shall be as specified by the codes in force at the installation site and shall include an additional load due to snow accumulation for applicable locations." The intent here is to be at least as stringent as the requirements in the other codes. The first sentence is comparable to the requirements in the other codes, except that it does not include the possible loads from other SHW system components, such as water storage tanks. There is also no discussion of the appropriate roof area to use when determining maximum allowable roof loads.

6.5.14 Pipe and Component Supports. The SRCC requirements for pipe hangers are comparable to the requirements of the other codes.

6.5.19 Penetrations through Fire-Rated Assemblies. The SRCC requirements for penetrations through fire-rated assemblies are comparable to the requirements of the other codes.

Appendix B

ASHRAE Standard 90.2 Energy-Efficient Design of New Low-Rise Residential Buildings and Energy Credit for Renewable Energy and Energy Efficient Technologies

The ASHRAE Standard 90.2 (denoted as 90.2) involves the same issues as the IECC. Like the IECC, 90.2 includes both prescriptive and performance compliance paths. The subject of this Appendix is the impact of the 90.2 performance path on the photovoltaic and solar thermal technologies discussed in the main body of this report.

A major difference between the IECC and 90.2 performance paths is that the latter is based on the cost of energy and not just on the energy involved.[1] This allows economically justifiable building design decisions to be supported by 90.2, rather than denied by the IECC compliance path.

Like the IECC, the 90.2 compliance path involves the analysis of a prescriptive design and a proposed design.[2] The prescriptive design must comply with the requirements of the 90.2 prescriptive path.[3] With some restrictions, the proposed design is modeled as it is to be built and operated.[4]

The impacts of the 90.2 performance-path requirements on each technology is now discussed. In this discussion, terms like "credit is allowed" means that the prescriptive path allows the energy savings from the technology to be included in the analysis.

The 90.2 performance path precludes credits for many technologies. "Annual energy cost compliance is applicable to energy for space conditioning only. Energy for other uses, such as domestic hot water, cooking, lighting, and appliances, is included for total energy cost estimates, but is not a variable between the proposed design and prescriptive design for compliance with this standard...Although space-conditioning, domestic hot water heating, and appliance energy costs are calculated together, no compliance trade-offs are allowed between them."[5] This language appears to preclude credit for renewable energy sources that service other than space-heating loads. However, "the analysis of the proposed design shall take into

Footnotes

1. 90.2 8.1 Purpose.
2. Ibid.
3. 90.2 Chapters 5, 6 and 7.
4. 90.2 8.4 General.
5. 90.2 Scope.

account all qualities, details and characteristics of the design that significantly affect energy use and cost. These may include construction, geometry, orientation, exposure, materials, equipment, and renewable energy sources."[6] A reasonable interpretation is that renewable energy sources can be credited toward the annual energy cost, but loads other than space conditioning cannot be changed between the prescriptive and proposed designs.

Credit for photovoltaic systems in buildings, building-integrated photovoltaic systems, and active-solar domestic hot-water and space-heating systems is allowed if it can be adequately modeled with the chosen analysis tool.

6. 90.2 8.6 Proposed.

Appendix C

Suggestions for Code Changes

This Appendix compiles a number of specific language changes for the various codes that could be made to allow fairer treatment of EE and RE technologies. There are other suggested code changes in the report that are not included here. These include, for example, the development of sections that accumulate all of the code requirements and references to other sections for a technology in one location.

IECC 402.1.3.11 Solar access. Any existing permanent objects that will reduce the solar gains on any window surfaces or other solar-energy collection devices must be accounted for in the energy analysis.

IECC 403.1.5 Solar hot-water energy exclusion. Thermal energy from solar hot-water systems shall be permitted to be excluded from the total energy consumption allowed for the building. This thermal energy must be used in the building to displace purchased electrical energy, fuel, or other thermal energy used for space heating of hot water.

IECC 402.3.2.1 Special requirements for appropriate energy analysis tools. If the proposed design involves significant amounts of thermal mass or contains thermal control systems with non-linear control characteristics, then a true 8,760-hour annual simulation driven by appropriate weather data shall be used in the systems analysis.

IECC 402.3.2.2 Hourly simulation tools for photovoltaic system analysis. If the proposed design involves a photovoltaic system to generate electricity, then a true 8,760-hour annual simulation driven by appropriate weather data shall be used in the systems analysis. This simulation shall be capable of analyzing the type of photovoltaic system specified in the design. This analysis shall use the hourly electrical loads from the building simulation as the basis for the analysis of the photovoltaic system.

IECC 403.1.4 Photovoltaic energy exclusion. Electrical energy from solar photovoltaic systems shall be permitted to be excluded from the total energy consumption allowed for the building. This electrical energy must be used in the building to displace purchased electrical energy.

IRC 308.8.2 Permitted materials. Laminated glass with a minimum 0.015-inch polyvinyl butyral interlayer for glass panes 16 square feet or less in area; for larger sizes, the minimum interlayer thickness shall be 0.030 inch. Alternate materials can be used for the interlayer if it provides comparable performance, as confirmed by testing under CPSC 16 CFR 1202 or a comparable standard.

IRC 2701.2.5.1 Acceptable freeze protection methods. Freeze protection shall be provided by heating, insulation, suitable low-freezing-point fluids, draining of piping and other components, or an appropriate combination of these methods.

IRC 2701.2.6.1 Exception. Non-pressurized, draining solar hot-water systems do not need expansion tanks if the system is designed to accommodate the expansion volumes under "Nonpressurized Type" in IRC Table 2302.2.

IRC 2701.3.2.1 Thermal storage unit insulation levels. Thermal storage units shall be insulated so that heat loss is limited to a maximum of 15 BTH/h/ft^2 of external tank surface-area. For design purposes, the design ambient temperature shall not be higher than 65°F. This equates to a minimum water-to-air R-value of about 9.7.

IRC 3301.7 Locations significantly above sea level. The maximum temperature for the energy-cutoff device shall be 2°F below the local boiling point of water.

IRC 3402.4.3.1 Exceptions for solar systems that do not require backflow protection. Solar systems that do not expose potable water to non-potable water are exempt from the requirements of 3402.4.3. This includes solar systems where the potable water acts as the solar-loop heat-transfer fluid, where the solar-loop fluid is essentially non-toxic, and where contamination of the potable water is not possible.

Presently, the relevant code language applicable to photovoltaic systems is spread throughout the various codes. The IRC should include a new chapter for photovoltaic systems. This will allow practitioners in the PV field to easily locate all applicable code requirements. This new chapter should include references to the NEC Article 690 and other relevant language in the IRC, IMC, NEC, and IECC.

Similarly, the relevant code language applicable to solar hot-water systems is spread throughout the various codes. The IRC should include a revised chapter for solar hot-water systems. This will allow practitioners in the SHW field to easily locate all applicable code requirements. This new chapter should include the present language in the IRC Chapter 27 and the IMC Chapter 15 and references to the other relevant language in the IRC, IMC, IPC, NEC, and IECC.

Appendix D

Suggestions for Potential Research Areas

Several potential research topics have been identified in this report and are presented here.

Wind loading of rooftop PV panels and SHW collectors. IRC Table 804.3.3b presents the information needed to convert the wind speed to an equivalent snow load. In this Table, steeper sloped roofs have a higher equivalent snow load than shallower ones with the same design wind speed and exposure. There are potential implications here for roof mounted systems with steeper slopes than the supporting roof structure. Guidelines need to be developed for appropriate roof rack structural loads and appropriate designs for different locations.

Structural requirements for PV shingles. Several sections on asphalt shingles cover the types and numbers of needed fasteners in typical and high wind areas, how the underlayment is applied, protection against ice buildup and the proper installation of flashings. Identical requirements may apply to PV shingles. However, the different physical characteristics of PV and asphalt shingles may require changes in or additions to the requirements of IRC Section 905 when applied to PV shingles.

Access and safety issues rooftop PV and SHW panels and other equipment. The enforcement of access and safety codes as applied to PV systems could provide major economic and architectural obstacles to the widespread implementation of this technology. Permanent ladders, railings, access space between panels and similar constraints could be imposed on rooftop mounted systems. It must be remembered that these requirements arose from real safety issues during the maintenance of mechanical systems. The problem for the PV industry is to include language in the codes which specifically exempt their systems from these requirements, or to otherwise provide data that will convince local code officials that these requirements are unnecessary.

Calculating proper roof dead loads for SHW systems. Some designs of active SHW systems, such as those with a roof-located water storage tank, can produce highly concentrated roof loading. Higher weights are more likely to reach the roof dead load limitations of 15 PSF (and 9 PSF in seismic areas). While calculation of the maximum weight of these systems is relatively easy to determine, the applicable area is not. The roof structure needs to be designed and built to prevent both general and local failure. Loads over small areas need to be solidly supported and the structure must transmit the resulting loads to its supporting structural elements. If active SHW systems are installed on existing or new buildings, the roof structure may need to be evaluated to determine if excessive loading is a problem. Guidelines for the proper approach to this issue may be an appropriate area for research.

Appendix E

Tables of Code References, Categorized by Renewable Energy and Energy Efficiency Technology

The following tables contain the references for each technology in the building codes reviewed for this report. These tables are not necessarily comprehensive.

Photovoltaic Systems in Buildings and Building-Integrated Photovoltaic Systems

Table 3. Code references for photovoltaic systems in buildings and building-integrated photovoltaic systems.

Code	Section	Reference No	Description
IECC	Materials and Equipment	103	**Alternate Materials-Method of Construction, Design of Insulating Systems**
IECC	Definitions	201	**General Definitions**
IECC	Residential Building Systems Analysis	402.1	**Energy analysis**
IECC	Residential Building Systems Analysis	402.1.1	**Standard design**
IECC	Residential Building Systems Analysis	402.1.2	**Proposed design**
IECC	Residential Building Systems Analysis	403	**Renewable Energy Source Analysis**
IECC	Residential Building Systems Analysis	403.1.1	**Solar energy exclusion, one**
IECC	Residential Building Systems Analysis	403.2	**Documentation**
IRC	Solar Systems	2701.2.2	**Roof mounted collectors**
IRC	Building Planning	301.1	**Design**

Code	Section	Reference No	Description
IRC	Building Planning	301.1	**Design**
IRC	Building Planning	301.2	**Climatic and geography design criteria**
IRC	Building Planning	301.2.1	**Wind Limitations**
IRC	Building Planning	301.2.1.1	**Design Criteria** for Wind
IRC	Building Planning	301.2.2.2	**Anchored Stone and Masonry Veneer**
IRC	Building Planning	301.2.2.4	**Weight of Materials**
IRC	Building Planning	301.2.2.5	**Height Limitations**
IRC	Building Planning	301.3	**Dead Load**
IRC	Building Planning	308.3	**Human impact loads** for glazing units
IRC	Building Planning	308.4	**Hazardous locations** for glazing units
IRC	Building Planning	308.5	**Wind, Snow and dead loads on glass**
IRC	Building Planning	308.5.1	**Vertical glass** loads
IRC	Building Planning	308.5.2	**Sloped glass** loads
IRC	Building Planning	308.6.2	Skylight **Permitted materials**
IRC	Building Planning	320.4	**Penetrations** between separate dwelling units
IRC	Energy Conservation	38	**Energy Conservation**
IRC	Electrical	39	**Reference to the 1998 International One and Two Family Dwelling Code.**
IRC	Wall Construction	610	**Windows**
IRC	Wall Covering	703.1	**General** Exterior Coverings
IRC	Wall Covering	703.2	**Weather-resistant sheathing paper**
IRC	Roof-Ceiling Construction	801.1	**Application** of Roof-Ceiling Construction
IRC	Roof-Ceiling Construction	801.2	**Requirements** for Roof-Ceiling Construction

Code	Section	Reference No	Description
IRC	Roof Assemblies and Rooftop Structures	902	**Roof covering materials**
IRC	Roof Assemblies and Rooftop Structures	904.3	**Material specifications and physical characteristics**
IRC	Roof Assemblies and Rooftop Structures	904.4	**Product identification**
IRC	Roof Assemblies and Rooftop Structures	905	**Roof coverings with slopes 2:12 or greater**
IRC	Roof Assemblies and Rooftop Structures	905.4	**Metal roof panels**
IRC	Roof Assemblies and Rooftop Structures	908.2	Rooftop structures: **Towers, spires, dome and cupolas**
NEC	Equipment for General Use	410-74	**Direct Current Equipment**
NEC	Equipment for General Use	411-2	**Lighting Systems Operating at 30 Volts or Less**
NEC	Equipment for General Use	411-3	Lighting Systems Operating at 30 Volts or Less: **Listing Requirement**
NEC	Equipment for General Use	411-4	Lighting Systems Operating at 30 Volts or Less: **Locations Not Permitted**
NEC	Equipment for General Use	411-7	Lighting Systems Operating at 30 Volts or Less: **Hazardous Locations**
NEC	Storage Batteries	480-8	Battery **Location**
NEC	Storage Batteries	480-9	Battery **Vents**
NEC	Interconnected Electric Power Production Sources	705	**General**
NEC	Interconnected Electric Power Production Sources	705.21	**Disconnecting Means, Equipment**

Code	Section	Reference No	Description
NEC	Interconnected Electric Power Production Sources	705.240	**Loss of Primary Source**
NEC	Circuits and Equipment Operating at Less Than 50 Volts	720	**General**
NEC 690		690-1	**Scope**
NEC 690		690-10	**Stand-Alone Systems**
NEC 690		690-13	**Disconnecting Means**
NEC 690		690-18	**Installation and Service of an Array**
NEC 690		690-3	**Other Articles**
NEC 690		690-31(b)	Wiring Methods: **Single Conductor Cable**
NEC 690		690-31(c)	Wiring Methods: **Flexible Cords and Cables**
NEC 690		690-31(d)	Wiring Methods: **Small Conductor Cables**
NEC 690		690-33	**Connectors**
NEC 690		690-4(a)	Installation of **Solar Photovoltaic Systems**
NEC 690		690-4(b)	**Conductors of Different Systems**
NEC 690		690-4(c)	**Module Connection Arrangement**
NEC 690		690-4(d)	**Equipment**
NEC 690		690-41	**Grounding**
NEC 690		690-5	**Ground Fault Protection**
NEC 690		690-6	**AC Modules**
NEC 690		690-7(a)	**Maximum Voltage**
NEC 690		690-7(b)	**Direct-Current Utilization Circuits**
NEC 690		690-7(c)	**Photovoltaic Source and Output Circuits**
NEC 690		690-7(d)	**Circuits Over 150 Volts to Ground**
NEC 690		690-8	**Circuit Sizing and Current**
NEC 690		690-8(a)(1)	Computation of Maximum **PV Source Circuit Current**

Code	Section	Reference No	Description
NEC 690		690-8(a)(2)	Computation of Maximum **PV Source Output Current**
NEC 690		690-8(a)(3)	**Inverter Output Circuit Current**
NEC 690		690-8(a)(4)	**Stand-Alone Input Circuit Current**
NEC 690		690-8(b)	**Ampacity and Overcurrent Devices**
NEC 690		690-8(c)	**Systems with Multiple DC Voltages**
NEC 690		690-9	**Overcurrent Protection**
IMC	General Regulations	304.8	**Guards**
IMC	General Regulations	306.5	**Equipment and appliances on roofs or elevated structures**
IMC	General Regulations	306.6	**Sloped roofs**

Active-Solar Domestic Hot-Water and Space-Heating Systems

Table 4. Code references for active-solar domestic hot-water and space-heating systems.

Code	Section	Reference No	Description
IECC	Materials and Equipment	103	**Alternate Materials-Method of Construction, Design of Insulating Systems**
IECC	Definitions	201	**General Definitions**
IECC	Residential Building Systems Analysis	402.1	**Energy analysis**
IECC	Residential Building Systems Analysis	402.1.1	**Standard design**
IECC	Residential Building Systems Analysis	402.1.2	**Proposed design**
IECC	Residential Building Systems Analysis	403	**Renewable Energy Source Analysis**

Code	Section	Reference No	Description
IECC	Residential Building Systems Analysis	403.1.1	**Solar energy exclusion, one**
IECC	Residential Building Systems Analysis	403.2	**Documentation**
IECC	Residential / Component Performance Approach	504.2	**Water heaters, storage tanks and boilers**
IECC	Residential / Component Performance Approach	504.2.2	**Combination service water-heating/space-heating boilers**
IMC	Administration	102.9	**Requirements not covered by code**
IMC	Solar Systems	15	**Solar Systems**
IMC	Solar Systems	1502.1	Solar Systems: **Access**
IMC	Solar Systems	1502.3	**Roof-mounted collectors**
IMC	Solar Systems	1502.3.1	**Collectors mounted above the roof**
IMC	Solar Systems	1502.3.5	**Filtering**
IMC	General Regulations	301.12	**Wind resistance**
IMC	General Regulations	301.14	**Seismic resistance**
IMC	General Regulations	301.7	**Electrical**
IMC	General Regulations	302.1	**Penetration of floor/ceiling assemblies and fire-resistance rated assemblies**
IMC	General Regulations	303.4	**Protection from damage**
IMC	General Regulations	303.6	**Outdoor locations**
IMC	General Regulations	304.8	**Guards**
IMC	General Regulations	306.5	**Equipment and appliances on roofs or elevated structures**

Code	Section	Reference No	Description
IMC	General Regulations	306.6	**Sloped roofs**
IPC	Administration	105.4	**Alternative engineered design**
IPC	General Regulations	305.1	**Corrosion**
IPC	General Regulations	305.2	**Breakage**
IPC	General Regulations	305.3	**Stress and strain**
IPC	General Regulations	305.6	**Freezing**
IPC	General Regulations	308	**Piping support**
IPC	General Regulations	312.9	**Inspection and testing of backflow prevention assemblies**
IPC	Fixtures, Faucets and Fixture Fittings	424.4	**Shower valves**
IPC	Water Heaters	501.2	**Water heater as space heater**
IPC	Water Heaters	501.6	**Water temperature control in piping from tankless heaters**
IPC	Water Heaters	501.7	**Pressure markings of storage tanks**
IPC	Water Heaters	501.8	**Temperature controls**
IPC	Water Heaters	504.3	**Energy cutoff device**
IPC	Water Supply and Distribution	601.2	**Solar energy utilization**
IPC	Water Supply and Distribution	602.3.4	**Disinfection of system**
IPC	Water Supply and Distribution	605.1	**Water compatibility**
IPC	Water Supply and Distribution	605.21	**Joints between different materials**
IPC	Water Supply and	606.5.10	**Pressure relief for tanks**

Code	Section	Reference No	Description
IPC	Water Supply and Distribution	606.5.9	**Pressure tanks, vacuum relief**
IPC	Water Supply and Distribution	608.13	**Backflow protection**
IPC	Water Supply and Distribution	608.16.3	**Heat Exchangers**
IPC	Water Supply and Distribution	610	**Disinfection of Potable Water System**
IRC	Heating and Cooling Equipment	1401.4	**Sizing**
IRC	Boilers/Water Heaters	2307	**Water Heaters**
IRC	Solar Systems	2701.2.1	**Access**
IRC	Solar Systems	2701.2.2	**Roof mounted collectors**
IRC	Solar Systems	2701.2.3	**Pressure and temperature relief**
IRC	Solar Systems	2701.2.4	**Vacuum relief**
IRC	Solar Systems	2701.2.5	**Protection from freezing**
IRC	Solar Systems	2701.2.6	**Expansion tanks**
IRC	Solar Systems	2701.2.7	**Roof penetration**
IRC	Solar Systems	2701.3.1	Labeling of **Collectors**
IRC	Solar Systems	2701.3.2	Labeling of **Thermal storage units**
IRC	Solar Systems	2701.4	**Prohibited fluids**
IRC	Solar Systems	2701.5	**Backflow protection**
IRC	Plumbing Administration	2903.6	**Water-supply system testing**
IRC	Building Planning	301.1	**Design**

Code	Section	Reference No	Description
IRC	Building Planning	301.2	**Climatic and geography design criteria**
IRC	Building Planning	301.2.1	**Wind Limitations**
IRC	Building Planning	301.2.1.1	**Design Criteria** for Wind
IRC	Building Planning	301.2.2.2	**Anchored Stone and Masonry Veneer**
IRC	Building Planning	301.2.2.4	**Weight of Materials**
IRC	Building Planning	301.2.2.5	**Height Limitations**
IRC	Building Planning	301.3	**Dead Load**
IRC	Building Planning	308.3	**Human impact loads** for glazing units
IRC	Building Planning	308.4	**Hazardous locations** for glazing units
IRC	Building Planning	308.5	**Wind, Snow and dead loads on glass**
IRC	Building Planning	308.5.1	**Vertical glass** loads
IRC	Building Planning	308.5.2	**Sloped glass** loads
IRC	General Plumbing Requirements	3101.1	**Scope**
IRC	General Plumbing Requirements	3105	**Support**
IRC	General Plumbing Requirements	3109.1	**Materials Evaluation and Listing**
IRC	General Plumbing Requirements	3109.2	**Water-supply systems**
IRC	Building Planning	317.1.1	Foam plastic **Surface burning characteristics**
IRC	Building Planning	317.1.2	**Thermal barrier** of foam plastics
IRC	Building Planning	317.2.1	**Masonry or concrete construction** with foam plastic materials

Code	Section	Reference No	Description
IRC	Building Planning	317.2.2	**Roofing** with foam plastic materials
IRC	Building Planning	317.2.3	**Attics** with foam plastic materials
IRC	Building Planning	319.1	**Insulation**
IRC	Building Planning	320.4	**Penetrations** between separate dwelling units
IRC	Water Heaters	3301.1	**Required** water heaters
IRC	Water Heaters	3301.3	**Location**
IRC	Water Heaters	3301.5	**Required pan**
IRC	Water Heaters	3301.7	**Energy cutoff device**
IRC	Water Heaters	3302.1	**Protection of potable water** for water heaters used for space heating
IRC	Water Heaters	3302.2	**Scald protection** for water heaters used for space heating
IRC	Water Supply and Distribution	3401.1	**Potable water required**
IRC	Water Supply and Distribution	3402.1	Protection of Potable Water Supply: **Connections**
IRC	Water Supply and Distribution	3402.2.1	**Air gaps**
IRC	Water Supply and Distribution	3402.2.2	**Atmospheric vacuum breakers**
IRC	Water Supply and Distribution	3402.2.3	**Backflow preventer with intermediate atmospheric vent**
IRC	Water Supply and Distribution	3402.2.5	**Pressure-type vacuum breakers**
IRC	Water Supply and Distribution	3402.2.6	**Reduced pressure principal backflow preventer**
IRC	Water Supply and Distribution	3402.4.3	**Solar systems**
IRC	Water Supply and Distribution	3403.5	**Determining water-supply fixture units**

Code	Section	Reference No	Description
IRC	Water Supply and Distribution	3403.8	**Size of water-service mains, branch mains and risers**
IRC	Energy Conservation	38	**Energy Conservation**
IRC	Building Planning	391.1 Exception 1	**Insulation**
IRC	Building Planning	391.1 Exception 2	**Insulation**
IRC	Roof-Ceiling Construction	801.2	**Requirements** for Roof-Ceiling Construction
IRC	Roof Assemblies and Rooftop Structures	902	**Roof covering materials**
IRC	Roof Assemblies and Rooftop Structures	904.3	**Material specifications and physical characteristics**
IRC	Roof Assemblies and Rooftop Structures	904.4	**Product identification**
IRC	Roof Assemblies and Rooftop Structures	905	**Roof coverings with slopes 2:12 or greater**
IRC	Roof Assemblies and Rooftop Structures	905.4	**Metal roof panels**
IRC	Roof Assemblies and Rooftop Structures	908.2	Rooftop structures: **Towers, spires, dome and cupolas**

Appendix F

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13. ABSTRACT *(Maximum 200 words)*
This report describes the building code requirements and impediments to applying photovoltaic (PV) and solar-thermal technologies in residential buildings (one- or two-family dwellings). It reviews six modern model building codes that represent the codes to be adopted by most locations in the coming years: International Residential Code, First Draft (IRC), International Energy Conservation Code (IECC), International Mechanical Code (IMC), International Plumbing Code (IPC), International Fuel Gas Code (IFGC), and National Electrical Code (NEC). The IRC may become the basis for many of the building codes in the United States after it is released in 2000, and it references the other codes that will also likely become applicable at that time. These codes are reviewed as they apply to photovoltaic systems in buildings and building-integrated photovoltaic systems and to active-solar domestic hot-water and space-heating systems. The first discussion is on general code issues that impact these technologies—for example, solar access and sustainability. Then, secondly, the discussion investigates the relationship of the technologies to the codes, providing examples, while keeping two major issues in mind: How do the codes treat these technologies as building components? and Do the IECC and other codes allow reasonable credit for the energy impacts of the technologies? The codes can impact the implementation of the above technologies in several ways: (1) The technology is not mentioned in the codes. It may be an obstacle to implementing the technology, and the solution is to develop appropriate explicit sections or language in the codes. (2) The technology is discussed by the codes, but the language is confusing or ambiguous. The solution is to clarify the language. (3) The technology is discussed in the codes, but the discussion is spread over several sections or different codes. Practitioners may not easily find all of the relevant material that should be considered. The solution is to put all relevant information in one section or to more clearly reference relevant sections. (4) The technology is prohibited by the code. Examples of this situation were not found. However, energy credit for some technologies cannot be achieved with the requirements of these codes. Finally, four types of future action are recommended to make the codes reviewed in this report more accommodating to renewable energy technologies: (1) Include suggested language additions and changes in the codes; (2) Create new code sections that place all of the requirements for a technology in one section of an appropriate code; (3) Apply existing standards, as appropriate, to innovative renewable energy and energy conservation technologies; and (4) Develop new standards, as necessary, to ease code compliance. A synergy may be possible in developing suitable code language changes for both photovoltaic and solar hot-water systems. The installation of rooftop photovoltaic panels and solar hot-water collectors involves many overlapping issues. Roof loading, weather tightness, mounting systems, roof penetrations, and similar concerns are identical for both technologies. If such work can be coordinated, organizations supporting both technologies could work together to implement the appropriate revisions and additions to the codes.

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