2021 International Solar Energy Provisions® and Commentary

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PREFACE

Internationally, code officials recognize the need for modern, up-to-date solar provisions addressing the design and installation of solar systems through requirements emphasizing performance and including prescriptive criteria. The *International Solar Energy Provisions*® (ISEP®) is designed to meet these needs through model code provisions that result in efficient renewable energy systems and safeguard the public health and safety in all communities, large and small.

The principal purpose of this Commentary is to provide a basic volume of knowledge and facts relating to the International Code Council's family of codes' (I-Codes) solar provisions. The Commentary provides this volume of knowledge through coverage of many issues likely to be dealt with when using the *International Solar Energy Provisions*—and then supplements that coverage with historical and technical background.

Strenuous effort has been put into keeping the vast quantity of material accessible and its method of presentation useful. With a comprehensive yet concise summary of each section, the Commentary is a convenient reference for solar provisions. In the chapters that follow, discussions focus on the full meaning and implications of the code text. Guidelines suggest the most effective method of application, and the consequences of not adhering to the code text. Illustrations are provided to aid understanding; they do not necessarily illustrate the only methods of achieving code compliance.

The format of the Commentary includes the full text of each section, table and figure in the solar provisions, followed immediately by the commentary applicable to that text. At the time of printing, the Commentary reflects the most up-to-date text of the 2021 *International Solar Energy Provisions*. Each section's narrative includes a statement of its objective and intent, and usually includes a discussion about why the requirement commands the conditions set forth. Code text and commentary text are easily distinguished from each other. All code text is shown as it appears in the *International Solar Energy Provisions*, and all commentary is indented below the code text and begins with the symbol ❖. The italicized text in the Commentary portion of this publication is additional informational commentary to the *International Solar Energy Provisions*.

Readers should note that the Commentary is to be used in conjunction with the *International Solar Energy Provisions* or the source I-Code provisions and not as a substitute for the code. **The Commentary is advisory only;** the code official alone possesses the authority and responsibility for interpreting the code.

Technological advancements result in innovative products and new solar technologies to be introduced into the market on a regular basis. The International Code Council Evaluation Service® (ICC-ES®) evaluates and issues Evaluation Service Reports (ESR) for code compliance of building products. Evaluations are based on codes and standards, and in the absence of specific standards, ICC-ES develops Acceptance Criteria (AC) that is used as the basis of the evaluation. Code users should visit the ICC-ES website at www.icc-es.org to view all ICC-ES Evaluation Reports including solar products such as solar shingles, modular bracket assemblies, solar skylights, solar water heating systems, solar collectors and other evaluated solar products.

As electrical-related components and systems are a critical part of any solar energy system, those provisions of the *National Electrical Code*® (NEC®) (NFPA 70) that are most directly related to solar energy systems have been extracted and reprinted in this Commentary. These electrical provisions have been organized in specific coordinated sections such as definitions, solar water heating and photovoltaic systems, in much the same format as the ISEP chapters, so that the user can easily and conveniently locate and apply them. The *National Electrical Code*® (NEC®) provisions are copyrighted by and have been included with the permission and cooperation of the National Fire Protection Association. The NEC provisions in the *International Solar Energy Provisions® and Commentary* apply to both commercial and residential systems and are a part of the ISEP Commercial and ISEP Residential provisions. Readers should refer to NFPA's 2020 *Electrical Code Handbook* for the reasoning behind the NFPA 70®, including NEC concepts, real-world examples and the background behind code revisions.

Comments and recommendations are encouraged, for through your input, we can improve future editions. Please direct your comments to the Codes and Standards Development Department at the Central Regional Office.

ICC gratefully acknowledges the contributions to the third edition of this commentary provided by long-time solar expert, building inspector, supporter of solar codes, and former SRCC Board member Mark Thornbloom. Mark Thornbloom also edited the second edition. Jerry Henderson, a national expert and consultant on solar systems; Shawn Martin, ICC-SRCC Vice President of Technical Services; and Jim Huggins, former SRCC Technical Director were responsible for the development of the earliest edition of the International Solar Energy Provisions® and Commentary.

Solar System Basics

Introduction

The *International Codes*® (I-Codes®) provide a set of minimum standards to regulate the design and installation of solar systems used in the built environment in order to safeguard health and safety. Solar systems are fairly unique in that their installation and operation always involve several building systems, and so, will be addressed by code requirements from several different codes and sections of code in any given installation. Solar thermal systems have components that are regulated by different codes such as an electrical code (NEC), building code, mechanical code, plumbing code or other codes. For example, a solar thermal system might have collectors installed on a roof (Building code) with piping which penetrates the building envelope (Building and Fire code), carrying a heat transfer fluid (Mechanical code) to a heat exchanger in a domestic water heater (Plumbing code). The *International Solar Energy Provisions*® (ISEP®) was created to address these relationships, recognizing that only a complete and comprehensive point of reference for the interaction of all disciplines will achieve the level of safety necessary to meet the high standards of the I-Codes. This approach simplifies and clarifies the design, installation, implementation for the solar industry and enforcement for jurisdictions which will use the document.

Solar systems are generally comprised of a collector, or set of collectors, positioned to collect radiant energy from the sun and convert it to heat (thermal energy) or electricity, a conduit to carry the energy from the collectors to the load that it serves or to storage for use later by the load, and the equipment that interacts with the load or storage devices. A photovoltaic (PV) system has collectors that produce electrical energy; the electrical energy is then conducted to an electrical load for immediate use, or to batteries for storage. Energy collected or dissipated by a Solar Thermal (ST) system is usually carried by fluid transfer, and collected energy can be immediately utilized, or stored in fluid-filled tanks or other media. The collectors for both systems are most efficient at collecting solar energy when installed in an area providing a good solar resource with a favorable tilt and limited or no shading, facing the equator. Efficiency losses can be minimal up to 90 degrees east or west of the equator (see ISEP Resource B).

In this Solar System Basics, overviews will be provided of the basic construction of solar systems, with code references to some commonly used requirements. It is not meant to be a comprehensive requirement reference, nor is it intended to limit the application of other standards and requirements to the referenced installations. The sources for the code provisions and standards in this document are the 2021 I-codes, the 2020 *National Electrical Code*® (NEC®), and ICC 900/SRCC 300—2020.

Photovoltaic Systems

The fastest growing implementation of solar systems is found in the production of electrical energy. PV provides a source of distributed power generation which can be sited in a great variety of locations. PV systems are regulated by provisions in the following I-Codes: the *International Building Code*® (IBC®), *International Energy Conservation Code*® (IECC®), *International Fire Code*® (IFC®), and *International Residential Code*® (IRC®), as well as the NEC (NFPA 70). Articles 690 and 705 of the NEC have many requirements specific to PV systems and their installation.

Figure 1: Example Rooftop PV

Figure 2: Example Groundmount PV

PV modules that are comprised of crystalline silicon PV cells encapsulated and laminated with polymer layers and attached to glass make up most of the PV market. The modules must be listed to UL 1703 or after December 4, 2019, to UL 61730 (these standards cover modules intended for use in systems with a maximum system voltage of 1500 volts). Mounting is usually on rails or standoffs installed on the roof of an existing structure (see Figure 1), or on a rack located on the ground (see Figure 2). The racks, rails and mounts must be installed to the applicable requirements found in the IBC or IRC and IFC, and there are specific requirements as to size and location of an array found in ISEP Section CS509/IFC Section 605 (see Figures 3 and 4). An equipment grounding conductor (EGC) must be connected to the mounting system and the PV modules in accordance with NEC 690.43(A). If the mounting system is listed to UL 2703, the equipment ground is integral to a completed system and there are limited places, sometimes only one, where the EGC is required to be connected.

Individual PV modules are typically connected in series (also called a "string") and then in parallel into an "array" to create a PV energy system. Note that the term "panel" has been used interchangeably with the term "module." The direct current (DC) power created in the modules may be used to charge batteries or serve other DC loads, but is typically supplied to an inverter to be transformed to alternating current (AC) electricity. With systems employing an inverter, the energy not immediately used is usually allowed to flow through to the utility grid to be utilized from there. This allowance, and the rules governing it, varies from state to state.

Conductors leaving the modules may be installed under the array, in the open air, if installed per their rating in accordance with NEC 690.31(C)(1) which applies to single-conductor cable Type USE-2, and single-conductor cable listed and labeled as PV wire. The methods used to collect and conduct the wiring away from the array depends on the inverter(s) used. With an AC module, (which is a PV module with a microinverter connected to its output and located on or immediately beneath the module), the conductors are carrying AC electricity (see Figure 5). The conductors are subject to different requirements than systems with a string inverter mounted remotely from an array where they carry DC electricity away from the array to the inverter (see Figure 6).

AC systems may collect the inverter output circuit into listed cords, the cords are then transitioned to conductors installed within conduit, or another approved wiring method, as they leave the area of the array. Those conductors then travel to a disconnect (see NEC 705.20) and are interconnected to feed the electrical distribution system.

Conductors carrying DC electricity away from the array, known as PV output circuits, will transition to conduit as they leave the area of the array, and if they enter a structure, that conduit will require a grounded metallic raceway, in accordance with NEC 690.31(G). Type MC metal-clad cable complying with NEC 250.118(10) and metal enclosures are also permitted. Those conductors then travel to a properly located DC disconnect (see NEC 690.13), and from there to the inverter. On smaller systems, the DC disconnect might be integral to (but separable from) the inverter assembly. The conductors making up the inverter output circuit travel to the point of interconnection [see NEC Figures 690.1(a) and (b)].

Interconnection is generally accomplished in one of two ways, a supply-side connection (splice or tap) between the utility's meter and a service disconnect; or a load-side connection via a back-fed breaker located in a panelboard. Both connections require a dedicated circuit breaker or fusible disconnecting means. Specific requirements can be found in NEC 705.12. There are also many labeling and communication requirements in NEC 690 and 705 that must be followed.

Supply side connections are allowed for PV systems under NEC 230.82(6). The conductors of the inverter output circuit are passed through a fusible disconnect rated for a minimum of 60 amps, in accordance with NEC 230.79(D), to the splice point, usually in a main panelboard, a meter main, a generator panel or similar device.

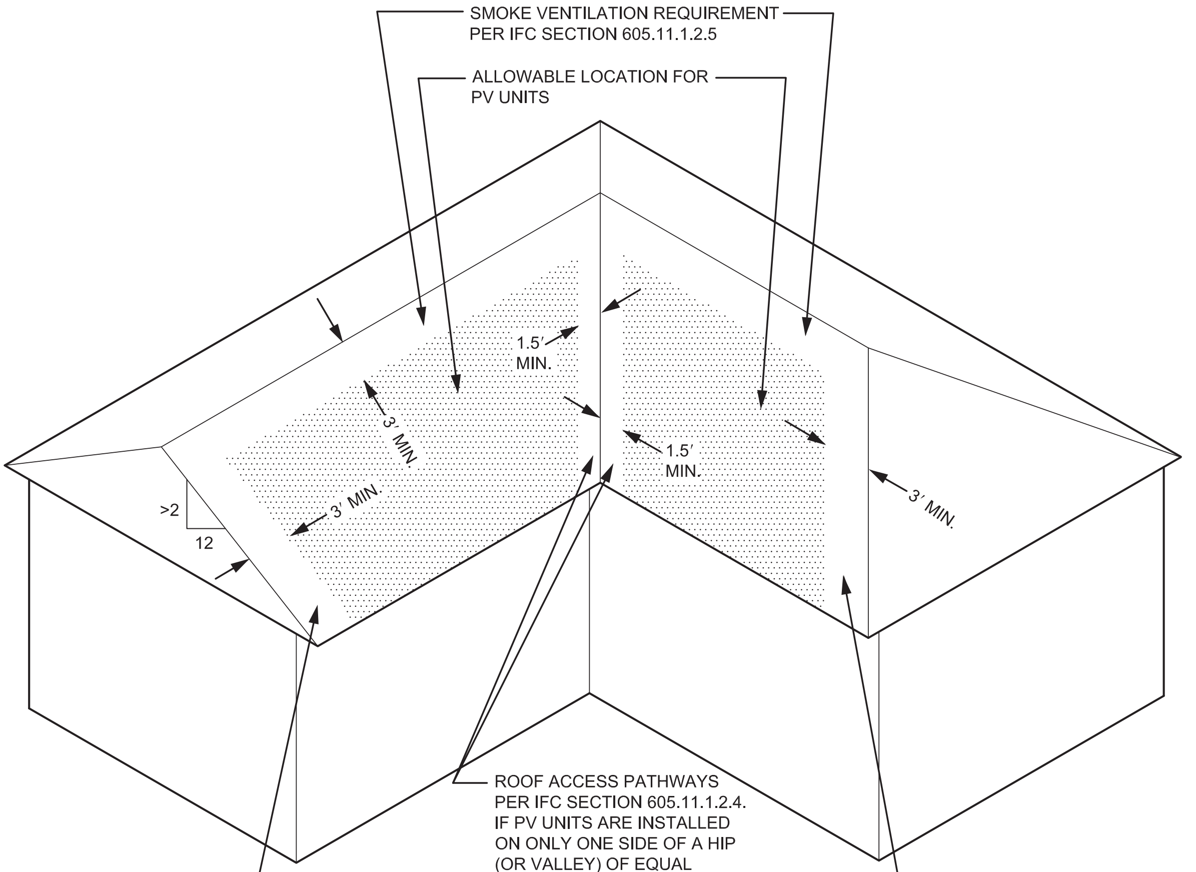

Figure 3: NRCA Residential PV Location

A circuit breaker used as the load side point of connection must be rated for backfeed in accordance with NEC 705.12(D)(4), and may need to occupy a space in the panelboard at the opposite end of the busbar from the service disconnect [see Figure 10, and NEC 705.12(D)(2)(3)(b)]. If the inverter output connection is made at a subpanel, then the conductors, connections and overcurrent

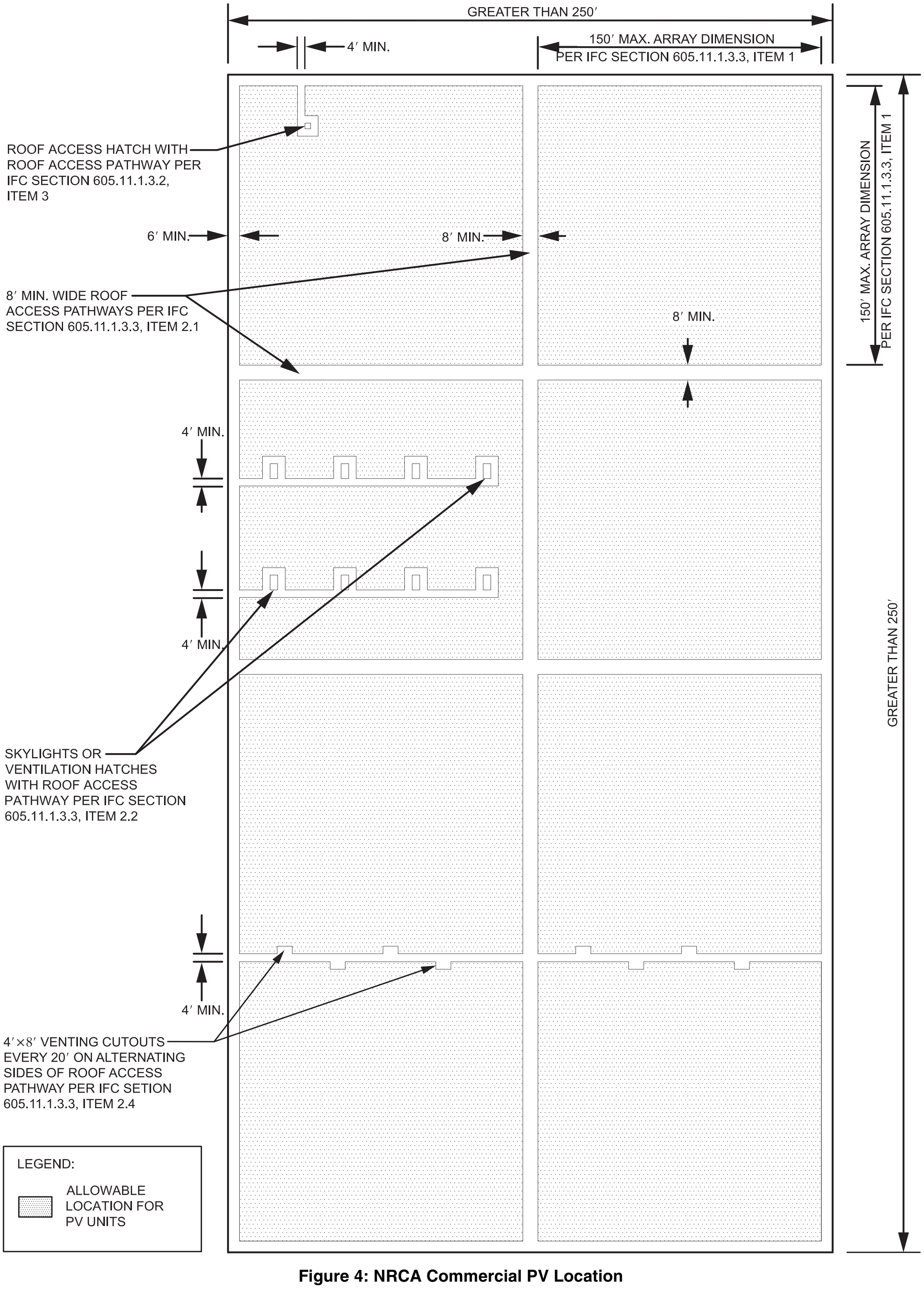

Figure 4: NRCA Commercial PV Location

protection from the subpanel to the service need to be treated as part of the backfeed circuit.

Solar Thermal Systems

Solar Thermal (ST) systems have been around since mankind began collecting water in containers to be heated by the sun. Their energy is used in all manner of human endeavors: residential, industrial, agricultural and recreational. ST systems used to heat water and air within habitable structures have been fairly commonplace since the 1800s, with their popularity rising and falling with their affordability in relation with that of other heating sources. Solar thermal systems are regulated by provisions in the IBC, IECC, IFC, *International Mechanical Code*® (IMC®), *International Plumbing Code*® (IPC®) and the IRC, as well as the NEC (NFPA 70).

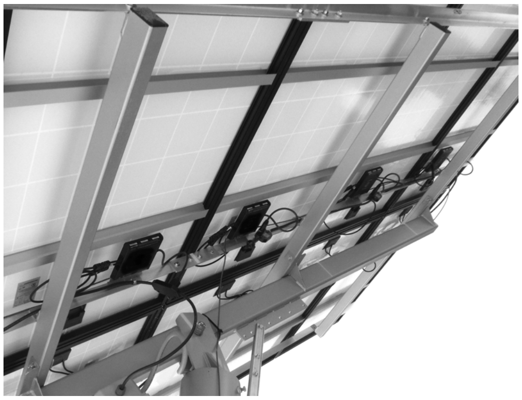

Figure 5: Example Microinverter

Figure 6: Example String Inverter

ST collectors are generally comprised of an absorber typically made of polymer (for lower temperature uses such as swimming pool heating) or metal (for intermediate or higher temperature uses such as domestic hot water, space heating or process heating) which converts radiant solar energy to thermal energy. When higher operating temperatures are desired, the absorber is placed in an enclosure and insulated to minimize losses, and an aperture of glass or other transmissive material allows sunlight into the enclosure. The absorber conducts thermal energy to a heat transfer fluid, typically air, water, or an antifreeze solution, which is then transferred to the load or stored for later use. Collectors can be as simple as spaces created between outside walls to capture warmed air, or as complex as multielement evacuated tube collectors with water-based heat transfer fluids, or concentrating collectors with other heat transfer fluids. There are also collectors with no container, in which a quantity of ductwork or piping is installed in such a manner to capture the direct effects of solar radiation and provide a conduit for heated fluid. Standards for the construction of collectors, along with systems to rate the energy produced by collectors, have been developed by national standards organizations like the Solar Rating & Certification Corporation® (SRCC®). The 2020 SRCC Standards have been included in the ISEP, and are referenced by the 2021 IRC. Listing and labeling requirements for collectors in residential installations can be found in ISEP Section RS301.3.1.

The most common ST storage units are tanks filled with water, and these must meet the requirements of ISEP Sections CS404.2 and RS301.3.2, as well as the referenced standards of any other applicable code. There are also a variety of storage media (phase-change materials, solid media) that require an engineered and approved design.

All systems must have protections against overheating the fluid and/or components to temperatures that exceed the capabilities of the fluid or components. If ST systems are installed in cold climates, then all components including heat transfer fluids must be protected against or be able to withstand freezing. Note that, because of the nature of some absorber surfaces, some absorbers interacting radiatively with cold, clear, night skies can experience depressed temperatures below freezing even when the ambient air temperature is still 45°F (8°C) or below. All of the components of the system must be protected from the effects of direct temperature, thermal expansion, excessive pressures and environmental degradation. These are addressed in ISEP Sections CS402 and RS301.

In order to discuss most encountered ST systems, those used to heat domestic water, an understanding of some of the differences in the way the systems operate is needed. Some systems have the same water in the collector loop and collectors as is in the water distribution system (Direct) (see Figure 7). Other systems utilize a water-based heat transfer fluid in the collectors and piping, and a heat exchanger to transfer energy to the water in the distribution system without contact with that water (Indirect). Also, some systems use pumps or blowers to move the heat transfer fluid through the collector loop (Active), while others rely on the change in water density to create flow via thermosyphon as cold water sinks from the storage unit down through the collector(s) to be heated, where it then rises. Still others use tanks or large pipes in the water distribution system which are exposed to the sunlight to heat the water (Passive). Each system type has advantages and disadvantages. For example, a direct system cannot be used in most of the United States because of the likelihood of freezing, and in some nonfreezing environments they are disallowed by city water quality rules. Each system type can be subject to different code requirements and standards, as well.

Freezing or overheating is a concern for many ST systems, and the dangers vary by climate. A common way to control for these conditions is with system sizing and design, but there are also chemical, mechanical and control strategies, as well. An oversized or underutilized ST system is more likely to overheat because the energy cannot be or is not removed from the collector loop as efficiently as it should be for effective operation. Systems in which unprotected fluid susceptible to freezing remains in the collector loop during a freeze condition are more likely to be damaged. With thermal control strategies employing chemicals, systems in which the heat transfer fluid drains back to a reservoir (Drainback) and other system types, the heat transfer fluid can be nonpotable. Systems which use a nonpotable heat transfer fluid or, in the case of many drainback systems, a dedicated quantity of water which becomes nonpotable, require a heat exchanger. Heat exchangers used with toxic fluids must be double-wall in construction with a draining interstitial space. Essentially toxic transfer fluids shall not be used in residential applications (see ISEP Section RS301.4). If an essentially nontoxic transfer fluid is used, the heat exchanger may be of single wall construction (see Figure 8). See ISEP Section RS303.1.2.

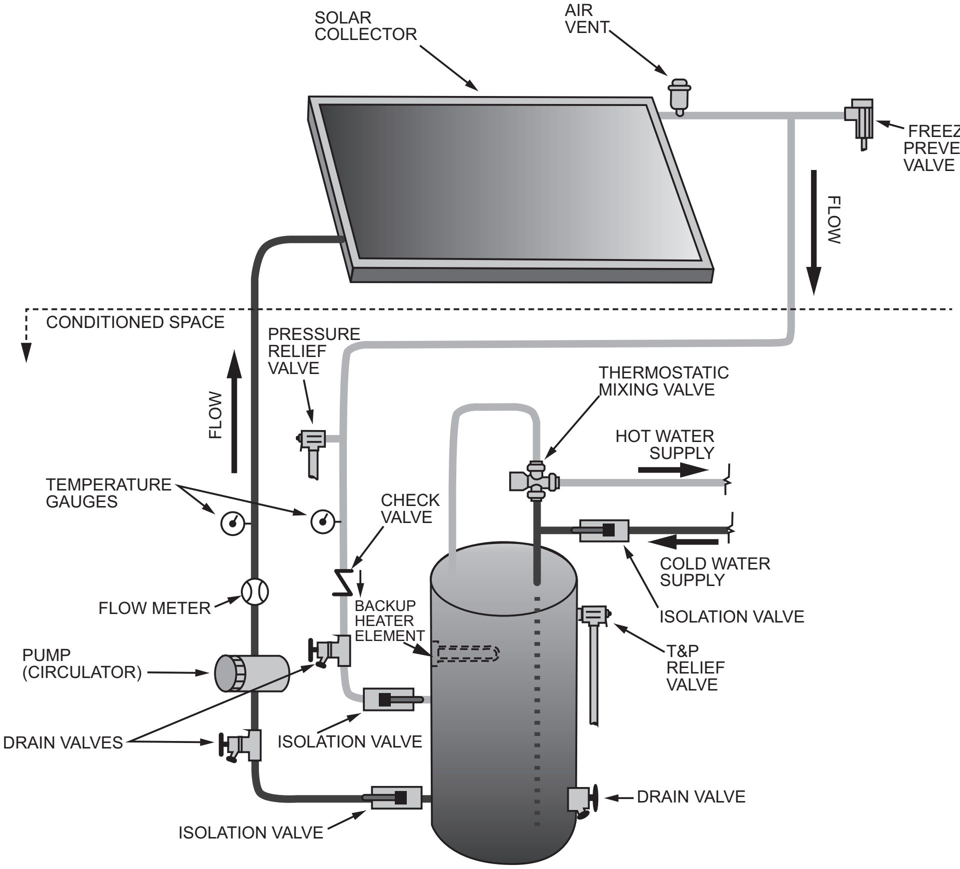

Figure 7: Active Direct ST System

As an example, we will consider the design and operation of an active indirect drainback system (see Figure 9). This is a very common system type in areas that may experience freezing temperatures or where components in the collector loop must be protected from aggressive water supply. Since the drainback collector loop is usually operated at atmospheric pressure or other pressure lower than the municipal water supply pressure, a heat exchanger is required to separate the collector loop pressure from the municipal water supply pressure. The sun heats the collector, and when the temperature of the collector reaches a setpoint (usually 8°–15° F) above the temperature of the water in the solar storage tank, the controller switches the pump power on, sending heat transfer fluid (HTF) along the collector loop up to the collector. The HTF in a drainback system is usually nontoxic (distilled water with no additives), but if there is interaction with system components that are not approved for contact with potable water, it will render the HTF nonpotable. As the HTF flows back down from the collector, the heat energy it carries is transferred to the potable water in the solar storage tank through the heat exchanger. Heat exchangers may be separate from the tank or wrapped around the tank (External), or immersed in the domestic water (Internal). When the water in the storage tank reaches its setpoint (usually around 165° F), the controller switches the pump off and the HTF drains back to a reservoir within the conditioned space of the structure, preventing it from freezing or overheating.

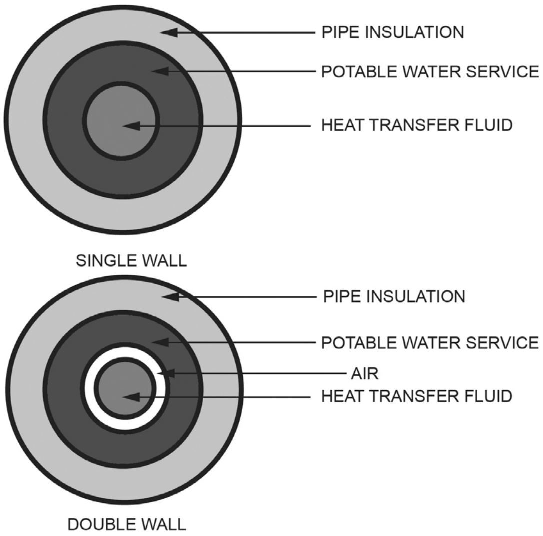

Figure 8: Heat Exchanger Cross Section

On the domestic side of the system, when there is a demand for hot water, the cold water flows into the solar storage tank, transferring the heated water to a backup (or auxiliary) water heater to add heat, if necessary. The heated water then flows through a thermostatically controlled mixing valve, in accordance with ANSI/ASSE 1017 (see ISEP Section RS302.3). The thermostatically controlled mixing valve is required because daily temperatures delivered by the solar water heater commonly exceed 140° F. The backup heater may be almost any type of water heater that accepts preheated water as a source. In the case of tankless water heaters, and other types of water heaters, the mixing valve might be placed at the outlet of the solar storage tank, if required by the water heater manufacturer. In some systems there is no separate backup water heater; a single tank with a heating element or an internal heat exchanger from another indirect source, sized to provide a sufficient supply of hot water when there is no solar gain, may be used.

A drainback solar water heater provides positive protection against overheating and freezing, and the use of only water as the HTF increases the heat transfer, but there is a practical design restriction, the collector loop must continually slope back to the drainback reservoir in order for the HTF to drain by gravity. In those cases where continuous drainback slope cannot be attained, or if there are other design considerations or preferences to be met, an active indirect system with an HTF containing protective additives filling the collector loop and collector at all times may be employed. These systems have design considerations similar to those used in the hydronic space heating industry and will specify an antifreeze HTF (such as glycol). In addition to nonsolar hydronic heating design considerations, solar heated hydronic systems must employ design features which protect the HTFs and other components from excessive temperatures exceeding the breakdown temperatures of the HTF which may occur, for example, when the collector loop is in a no-flow stagnation condition. Both the drainback design and pressurized "hydronic" design can protect against overheating damage and freeze damage, but have unique design features which must be considered. Certified systems, such as those reviewed and certified to the ICC 900/SRCC 300 standard, have been reviewed for design considerations such as these. Depending on the load type and size, these systems can be sized to meet most or all of the heating load.

The wide variety of ST systems, with uses that range from water heating, to food processing, to swimming pools (see ISEP Section RS309), to space heating, to desalinization, is too big a topic to cover in this resource, but the basics of each system remain the same.

Additional information for both Solar Thermal and Photovoltaic systems is available from ICC trainings and publications (http://www.iccsafe.org/education-certification/education/), as well as from on-line public resources such as the National Renewable Energy Laboratory (http://www.nrel.gov/) and the US Department of Energy (http://energy.gov/eere/office-energy-efficiency-renewable-energy).

Figure 10: Back-fed Breaker Location

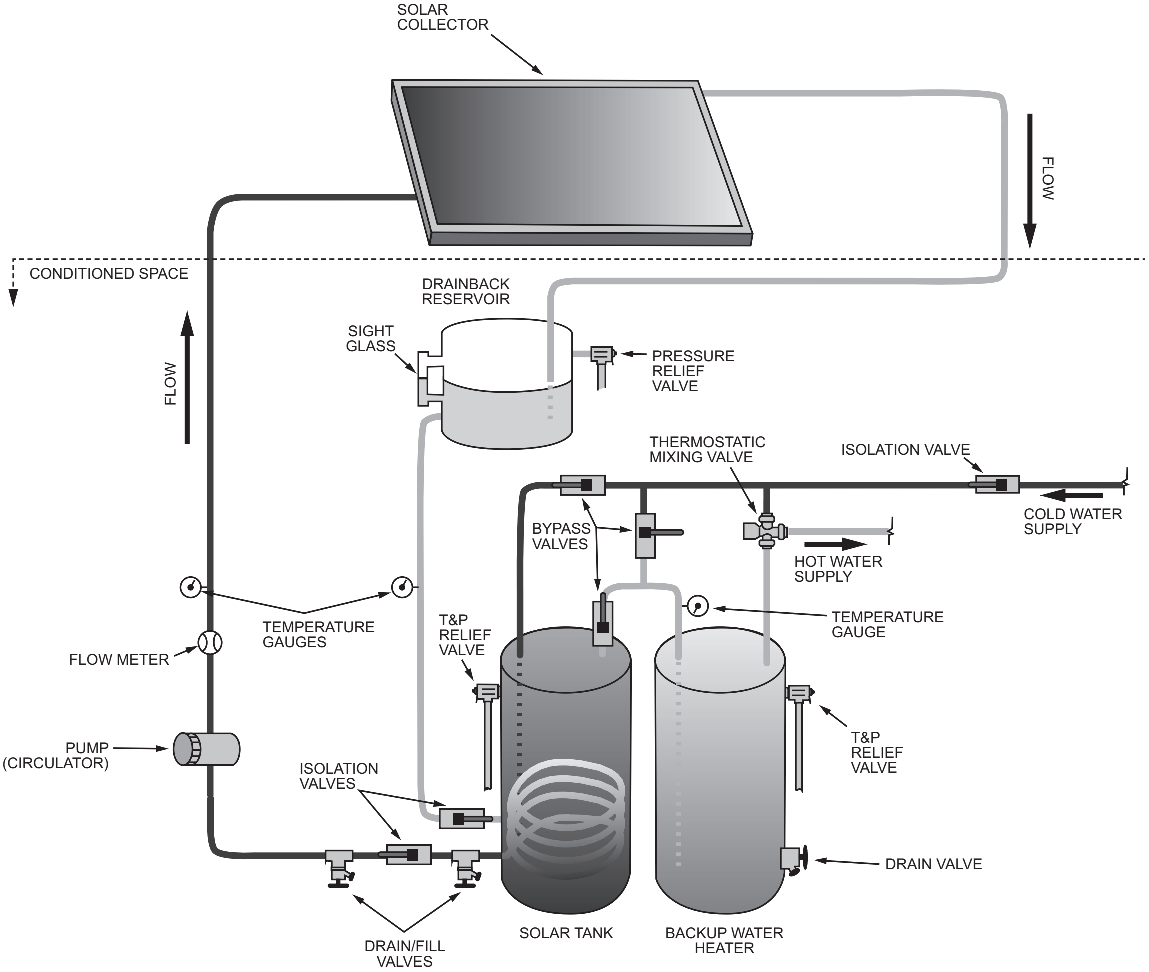

Figure 9: Active Indirect Drainback System

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