UFC 3-440-01
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UNIFIED FACILITIES CRITERIA (UFC)

FACILITY-SCALE RENEWABLE ENERGY SYSTEMS

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FACILITY-SCALE RENEWABLE ENERGY SYSTEMS

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 3-440-01, dated 14 June 2002 and UFC 3-440-04N, dated 16 January 2004.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Refer to UFC 1-200-01, *General Building Requirements*, for implementation of new issuances on projects.

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-440-01, *Facility-Scale Renewable Energy Systems*

Superseding: UFC 3-440-01, *Active Solar Preheat Systems* and UFC 3-440-04N, *Solar Heating of Buildings and Domestic Hot Water*

Description: This new UFC 3-440-01 consolidates into one Tri-Service document the renewable energy criteria applicable to solar thermal energy that was in the superseded documents, and new solar photovoltaic electrical energy generation. This UFC applies to facility-scale renewable energy systems and is not intended for utility-scale energy generation.

Reasons for Document:

- To provide unified Department of Defense renewable energy power generation criteria and create more consistency in DoD designs.

Impact:

This uniform effort will result in the more effective use of DoD funds in the following ways:

- Standardized guidance of facility-scaled renewable energy power production planning, design, construction, and operations and maintenance among the Services.
- The consolidation of the UFC 3-440-01 will positively impact the project costs incurred, as a result of the following direct benefits:
  - Reduction in ambiguity and the need for interpretation reduces the potential for design and construction conflicts.
  - The reduction in the number of documents and the use of industry standards improves the ease of updating the revising this reference document as better information becomes available.

Unification Issues:

The Air Force does not allow paralleling facility-level renewable energy systems with any standby power regardless of whether it is for emergency, Critical Operations Power Systems (COPS), or other purposes.

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE

This UFC is issued to provide guidance for designing and installing facility-scale renewable energy systems. The criteria contained herein are intended to ensure durable, efficient, and reliable systems and installations. Guidelines apply to facility-scale applications. A facility-scale project has the interconnection point at the facility's service entrance equipment and generally provides electricity for the facility. A utility-scale project has the interconnection point directly to the utility distribution grid. Facility-scale projects are typically less than 1 megawatt, and utility-scale projects are usually greater than 1 megawatt. For renewable energy systems designed to generate power on a utility-scale, and privately-financed projects, see UFC 3-540-08 (Draft).

Future revisions of this UFC will address additional renewable energy system technologies and components that can be applied on a facility-scale level, such as geothermal energy, wind energy, and on-site energy storage (batteries). Whenever unique conditions and problems are not specifically covered by this UFC, use the applicable referenced industry standards and other documents for design guidance.

Note that this document does not constitute a detailed technical design, maintenance or operations manual, and is issued as a general guide to the considerations associated with design of economical, efficient and environmentally acceptable facility-scale renewable energy systems.

1-2 ORGANIZATION

This UFC is comprised of three sections. Chapter 1 provides an introduction and a general reference to other documents closely related to the subject. Chapter 2 provides general criteria for the design of solar thermal systems. Chapter 3 provides general criteria for the design of solar photovoltaic power generation systems.

1-3 APPLICABLITY

This UFC applies to all planning, design and construction, renovation, repair, maintenance and operation, and equipment installation in new and existing facilities and installations, regardless of funding source that result in DoD real property assets. The designs developed in this document are targeted for new construction, although most are also appropriate for renovation applications.

1-4 GENERAL BUILDING REQUIREMENTS

Comply with UFC 1-200-01, *General Building Requirements*. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

Comply with UFC 3-560-01, *Electrical Safety, O&M*, for electrical safety requirements applicable to the installation and operation of electrical systems.

1-5 LIFE-CYCLE COST ANALYSIS (LCCA)

Provide a Life Cycle Cost Analysis in accordance with UFC 1-200-02, paragraph entitled " LIFE CYCLE COST ANALYSIS (LCCA)".

1-6 AIRSPACE COORDINATION

Comply with UFC 3-260-01 when evaluating renewable power generation systems and equipment to be sited near an airfield or related facilities and equipment used to sustain flight operations. Submit plans to site renewable power generation systems and equipment near an airfield to the airfield manager and safety officer (among other stakeholders) for approval.

1-6.1 Military Training Route and DoD Siting Clearinghouse

The Military Training Route (MTR) program is a joint venture by the Federal Aviation Administration (FAA) and the DoD to develop routes for the purpose of conducting low-altitude, high-speed testing and training activities. Improper site planning can negatively affect the MTR program. Contact the DoD Siting Clearinghouse (http://www.acq.osd.mil/dodsc/) during initial planning, and prior to applying for permits on any federal or non-federal lands, for project site vetting. Provide applicable data items required for the DoD Siting coordination.

1-6.2 FAA Requirements

FAA requires early planning coordination for structures and assessment of glare from solar panels. For structure assessment, complete FAA Form 7460. Glare assessments are covered under FAA interim policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports. This interim policy requires use of the Solar Glare Hazard Analysis Tool (SGHAT). Provide both FAA Form 7460 and SGHAT report to the DoD Siting Clearinghouse.

1-7 CYBERSECURITY

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with DoD Instruction 8500.01, DoD Instruction 8510.01, and as required by individual Service Implementation Policy.

1-8 REFERENCES

Appendix A contains a list of references used in this document. The publication date of the code or standard is not included in this document. In general, the latest available issuance of the reference is used.

1-9 BEST PRACTICES

Appendix B contains background information and best practices for accomplishing certain renewable energy design and engineering services.

1-10 GLOSSARY

Appendix C contains acronyms, abbreviations, and terms.

1-11 ADDITIONAL RESOURCES

For additional resources on renewable energy applications and systems, refer to the Whole Building Design Guide (WBDG) Internet site: http://www.wbdg.org/resources/.

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CHAPTER 2 SOLAR THERMAL TECHNICAL REQUIREMENTS

2-1 GENERAL REQUIREMENTS

2-1.1 Economic Feasibility Study

As required in UFC 1-200-02, Section 523 of the Energy Independence and Security Act (EISA) 2007 requires that at least 30% of the domestic hot water demand for each new federal building (or major renovations to existing federal buildings) be met through the use of solar water heating, if life cycle cost-effective.

Perform a life-cycle cost analysis for all new military construction to determine whether the use of renewable forms of energy will result in a net monetary savings to the government. The methodologies and parameters required for Federal energy project feasibility studies are mandated by Federal law (10 CFR 436). Provide a solar thermal energy system when life-cycle cost effective.

2-1.2 Screening Procedures

Perform the initial evaluation for solar hot water system viability. Generate a final report containing at least the solar hot water system size, system cost, annual energy savings, annual cost savings, savings-to-investment ratio (SIR), simple payback, solar fraction, and annual greenhouse gas reduction. See Appendix B for recommended tools.

2-1.3 Detailed Analysis and Study

If the results of the screening procedure indicate that a solar hot water system is a viable consideration, then perform a detailed life-cycle cost analysis (LCCA) to determine the most effective design alternative to develop. Perform LCCA calculations and reports. See Appendix B for recommended tools. Budget constraints, maintenance capabilities of customer, system complexities, and other factors in addition to the LCCA influence the final selected system design.

2-1.4 System Applications

2-1.4.1 Domestic Hot Water

For domestic hot water systems (DHW) without combined space heating, provide lined, insulated, pressurized tanks similar to the conventional water heater. Provide appropriate temperature and pressure relief valves. Provide a tempering or mixing valve. To size the collectors and storage tank it is necessary to estimate or measure the hot water consumption of the facility or building. See Appendix B for recommended estimating tools.

2-1.4.2 Hydronic Space Heating Combined with Domestic Hot Water

Size the collectors and storage tank to provide the greater loads of space heating plus domestic hot water. A heat delivery system is added to the domestic hot water system. Provide an auxiliary heating source to supply heat when the solar system cannot supply sufficient heat. Provide corrosion and freeze protection through the use of a closed collector loop and heat exchanger.

2-1.5 Solar Thermal Basis of Design

At a preliminary design stage equivalent to 35% design, the designer of record must provide a basis of design which covers the general facility design requirements in accordance with UFC 1-200-01 and its referenced documents. In addition to the UFC 3-401-01 requirements for preliminary basis of design and follow-on submittals, provide the following general system specific analysis information:

- Narrative
  - FY Year, Project Number, and project location.
  - Briefly state scope, project description, references, and calculation method used.
  - Geographic and operating environment, including coastal locations/corrosive conditions, humidity, altitude, seismic zones, and ambient temperature extremes.
  - Type of solar energy system (domestic hot water, space heating).
- Life Cycle Cost Effectiveness
  - Life Cycle Cost Analysis results.
  - Solar energy system design cost (study and design costs itemized).
  - Average annual energy savings and fuel used.
  - Fuel costs provided in the study.
  - Percent energy contribution from solar energy system.
  - Savings to investment ratios (SIR).
  - Estimate of solar energy system installed costs [exclusive of supervision, inspection and overhead (SIOH) and contingency].
  - Initial year O&M costs and requirements.
- Design Feasibility
  - Schematic of system layout.
  - Structural design considerations (roof mounting discussion, life span of roof, structural adequacy).
  - Type and area of collectors.
  - Description of freeze and high temperatures and pressure protection.

- o Description of control sequence.
- o Description of operating sequence.
  - Startup procedures.
  - Shut off procedures.
  - Normal positions of valves, controls.
  - Typical temperatures at key locations.
- o Calculations used: input data, analysis, method used.

2-2 SYSTEM SELECTION

2-2.1 Standard System Types

2-2.1.1 Closed-Loop (Indirect) System

Closed-loop circulation systems circulate a heat transfer fluid through the solar collectors and implement a heat exchanger to heat potable water. While the closed loop solar energy system can provide reliable service in any climate, take certain design precautions:

- Closed-loop circulation systems must be pressurized. Drainback systems are prohibited.
- Provide a check valve in the collector loop to prevent reverse thermosiphoning. Locate check valves so that the fluid in the collector loop can be drained if necessary.
- Use non-ferrous piping and components. Size the expansion tank and pressure relief valves to prevent loss of solution and opening of the collector loop in the event of high pressure stagnation. See Expansion Tank Paragraph for expansion tank design. Provide for the collection and recovery of freeze protection solution in the event of pressure relief.
- Do not use the cold-water leg between the mixing valve and the cold water supply to the solar storage tank for connection to any other fixture.

2-2.1.2 Open-Loop (Direct) Circulation System

Direct circulation systems circulate potable water through the solar collectors and do not implement a separate heat exchanger. Direct circulation systems must be active. Drain-down systems are prohibited. Limit use of direct circulation systems to locations where there are no freezing days, and where the water supply is of sufficiently high quality, between 0-0.015 oz/gallon (0-120 mg/L) calcium carbonate. Obtain water supply quality information from the local water authority. Where the water supply is of poor quality, it is necessary to treat the incoming water supply so that it is within quality limits using a mechanical water softener, water conditioner, or ion-exchange device.

2-2.1.3 Thermosiphon and Integral Storage Collector Systems

Mount the bottom of the thermosiphon system tank approximately 2 feet (0.6 meters) higher than the highest point of the collector. Test integral storage collector (ISC) units as whole systems and using the method given in ASHRAE Standard 95. Only install ISC systems in areas where temperatures rarely fall below freezing. The results of system tests on these models are reported in the Directory of SRCC Ratings: http://www.solar-rating.org.

2-2.2 Mount Types

2-2.2.1 Roof Mounting

Comply with UFC 3-301-01 for requirements related to wind and seismic loads on rooftop solar thermal arrays. Use rooftop mounting systems of the same manufacturer for the entire project array.

2-2.2.2 Ground Mounting

Comply with UFC 3-301-01 for requirements related to the foundation, soil stability, and seismic analysis. Use ground mounting systems of the same manufacturer for the entire project array. The system must withstand the expected wind loads for the location. Complete an environmental impact assessment for the site. Foundation must be either concrete, concrete pad ballast, driven pile, or helical pile.

2-2.3 Collector Types

Solar thermal system collectors are either flat plate or evacuated tube. Use flat plate collectors in ASHRAE Climate Zones 1-3. Use evacuated tube collectors in ASHRAE Climate Zones 4 and above or within zones 1-3 when water heating above 140 degrees F (60 degrees C) is required.

2-2.3.1 Flat Plate Selective Surfaces

Use Collector surface of highly selective black absorber coating, which absorbs the high frequency incoming solar radiation and emits low frequency infrared radiation poorly, with a minimum absorptivity of 0.85.

2-2.3.2 Flat Plate Collector Insulation

Use Collector insulation that is not flammable, has a low thermal expansion coefficient, will not melt or outgas at collector stagnation temperatures 300 degrees F – 400 degrees F (149 degrees C – 204 degrees C), and contains reflective foil to reflect thermal radiation back to the absorber.

2-2.3.3 Flat Plate Collector Housings

Construct housing of powder-coated aluminum. Do not use wood as a structural member, spacer, or anchor for panels due to its susceptibility to deterioration and flammability. Provide adequate room for expansion of the internal manifold and absorber plate assembly within the collector housing.

2-2.3.4 Evacuated Tubes

The evacuated tube collector's individual tubes must be easily replaceable, and made of low emissivity borosilicate glass with a highly selective coating.

2-2.3.5 Collector Gaskets & Sealants

Provide gaskets and seals that:

- Withstand significant expansion and contraction without destruction.
- Adhere effectively to all surfaces.
- Resist ultraviolet degradation.
- Resist outdoor weathering.
- Do not harden or become brittle.
- Withstand temperature cycling from -30 degrees F to 400 degrees F (-34 degrees C to 204 degrees C).
- Do not outgas at high temperatures.

2-2.3.6 Fill Ports and Drains

Provide fill ports and drains that are tamper-resistant.

2-2.4 Fluid Types

Provide heat transfer fluid that is nonionic, high dielectric, nonreactive, noncorrosive, and stable with temperature and time. If system design requirement mandates the use of toxic fluid, receive approval from the installation. The closed-cup flashpoint must be provided by the heat transfer fluid manufacturer and determined using the methods described in NFPA 30. To reduce the risk of fire, the closed-cup flashpoint of the liquid heat transfer fluid must equal or exceed the highest temperature determined from below:

- A temperature of 50 degrees F (28 degrees C) above the design maximum flow temperature of the fluid in the solar system; or
- A temperature of 50 degrees F (28 degrees C) above the maximum no-flow temperature to be reached by the fluid in the collector.
- 100 degrees F (56 degrees C) greater than the maximum expected collector temperature.

To minimize the probability of contamination of potable water systems, address the following items:

- Use tags, color coding, and different pipe connections to preclude the possibility of cross connection of potable water piping with heat transfer fluid piping is required. Use of double-wall separation is required.
- Hydrostatic testing of system to find leaks.
- Color indicators in heat transfer fluid to find leaks.
- Safe designs for heat exchangers.
- Determine toxicity classification of heat transfer fluids.

2-2.4.2 Hydrocarbon Oils

Hydrocarbon oil must have a closed-cup flashpoint 100 degrees F (38 degrees C) higher than maximum expected collector temperature. Provide synthetic hydrocarbon oils.

2-2.4.3 Glycol/Water Mixture

Mixtures must be either a 50/50 or 60/40 glycol-to-water ratio. Circulate glycol/water liquids in a closed loop with a double wall heat exchanger between the collector loop and the storage tank. Maintain the pH between 6.5 and 8.0. Replacement of the glycol/water solution may be as often as every 12-24 months or even sooner in high temperature systems. The glycol manufacturer specifies the expected life of the solution and the amount of monitoring required. Consider the cost of periodic fluid replacement and monitoring in the economic analysis.

2-3 SYSTEM DESIGN

For potable water systems, all components must meet potable water requirements of UFC 3-420-01.

2-3.1 Checklist

2-3.1.1 Schematic

Appendix D provides a checklist of items to consider as part of system planning and design.

2-3.1.2 Component Connections

Provide isolation valves on all major system components, such as the collector banks, storage tank, heat exchanger, and circulation pumps, for removal, cleaning, repair, or replacement.

2-3.1.3 Roof Penetrations

Design roof penetrations for the array supply and return piping and sensor wiring conduit to prevent leaking and to account for movement due to thermal expansion.

2-3.2 Collector Sub-System

2-3.2.1 Array Tilt Angle

For annual loads, tilt collectors to the value of the local latitude. To accommodate for seasonal load variation, tilt the array to the latitude minus an offset up to 10 degrees (to favor summer energy output) or to the latitude plus an offset up to 10 degrees (to favor winter energy output). It should be noted that as the tilt angle increases, the minimum spacing between rows due to shading must be increased due to shading, requiring a larger area.

Anticipate any future structures or vegetation (trees) that could block future solar access, and generally keep the collectors out of the shade between 9 a.m. and 3 p.m., when the bulk of the energy collection occurs.

2-3.2.2 Array Azimuth Angle

Consider the orientation of a collector (i.e. the direction the collector faces). For optimum performance, orient the collector true south, however slightly west of south (azimuth angle of true south plus 10 degrees) may be preferable in some locations if an early morning haze or fog is a regular occurrence. Design the array's azimuth angle within plus or minus 20 degrees from due south.

2-3.2.3 Pressure Drop

2-3.2.3.1 The 30 Percent Rule

To ensure uniform flow through the piped collector bank array, the ratio of a manifold's pressure drop to its riser pressure drop should be designed to be around 10 percent, and under no circumstances exceed 30 percent (for a pressure drop ratio of 30 percent, the flow in any riser should not deviate from the average riser flow rate by more than plus or minus 5 percent).

2-3.2.3.2 Pressure Drop Across Banks and Rows

Determine the pressure drop across a bank of collectors in order to calculate the pipe sizes necessary to achieve balanced flow in the array. Once the array layout is determined and assuming that the pressure drop across each collector unit at the recommended flow rate is known, the pressure drop associated with each branch extending from a manifold can be determined.

2-3.2.4 Collector Grouping

Group internal-manifold collectors into banks ranging from four to seven collectors, with each bank containing the same number of collectors to maintain uniform flow throughout the array and minimize thermal expansion.

2-3.2.5 Minimum Array Row Spacing

Calculate the minimum row spacing for multi-row arrays. Base north-south spacing of collector banks on no shading of the array on the "worst" solar day of the year (21

December, when the sun is lowest in the sky in the northern hemisphere) for the designated time period of 10 a.m. to 2 p.m. solar time.

2-3.2.5.1 Roof Pitch

If the roof pitch does not allow flush mounting of the collectors, or if the tilt angle must be fixed, coordinate the array design with the roof pitch so that the collectors are raised at one end to give a tilt per paragraph entitled “Array Azimuth Angle.”

2-3.2.5.2 Array Layout

Determine the array layout keeping the piping length minimized while geometric symmetry is maintained, so that banks contain as many collectors as possible, and the array layout is rectangular in area with an even number of banks installed in multiple rows.

2-3.2.5.3 Array Support Structure

Meet all code requirements and coordinate design with, or review by, a licensed professional structural engineer. Design stepped arrays with elevated walkways for maintenance personnel. Coordinate with roof design and coordinate with support structure manufacturer to identify materials options. Use galvanic barrier when design uses incompatible metals. Comply with UFC 3-575-01 for utilizing lightning protection requirements.

2-3.2.5.4 Lightning Protection Requirements

Comply with UFC 3-501-01 for requirements related to providing a lightning risk assessment.

If lightning protection is a design requirement, provide UL listed lightning arrestor and comply with UFC 3-575-01 for requirements related to providing a lightning protection system. Provide side flash calculations as required by NFPA 780.

2-3.2.6 Collector Selection

Provide a collector with a minimum Clear C of 0.98 kBtu/(ft^2·day) (11 MJ/(m^2·day)) as reported by the Solar Rating and Certification Corporation (SRCC): http://www.solar-rating.org/. To validate that the array size and layout is a viable option, information required by the designer and to be submitted by the manufacturer on the shop drawings includes the net aperture area; ranges of overall dimensions of length or height and width; the manufacturer's recommended collector flow rates and the pressure drop across the collector at that flow rate; the internal manifold tube diameter; and the collector weight when filled. Note on the drawings the number of collectors per bank and whether the manufacturer recommends a maximum number of collectors per bank less than seven.

2-3.2.7 Collector Sub-System Piping

2-3.2.7.1 Manifolds

Each collector must have internal manifolds. External manifolds are not permitted.

2-3.2.7.2 Flow Balancing

Design the array plumbing for passive flow balancing, so that uniform flow will occur as naturally as possible in the array. Provide flow control balancing valves on the outlet of each bank to adjust for any flow imbalances after construction.

2-3.2.7.3 Reverse-Return Piping Layout – Diagonal Attachment Rule

The reverse-return strategy of providing approximately equal length flow paths for supply and return pipes attached to the array at any two opposite diagonal corners of the array must be used for all projects.

2-3.2.7.4 Reverse-Return Piping Design

Use the corner closest to the pipe roof penetrations as the return point since this will result in the shortest pipe length for the heated fluid. If the pipe roof penetrations are near the centerline of a multiple row, multiple column array with an even number of columns, save pipe length by feeding the array on the outside and returning the heated fluid from the center of the array.

2-3.2.7.5 Stepped Collector Rows

Although a true reverse-return design is not possible for stepped collector rows, use the same diagonal attachment strategy and the pipe length for each elevation must be accounted for in the pressure drop/pump sizing calculation.

2-3.2.7.6 Array Layout and Piping Schematic

Note the array layout and piping schematic in the construction drawings to pipe the array exactly as that shown to ensure flow balance.

2-3.2.8 Pipe Sizing

Flow throughout the array must be in balance at the proper flow rates, while maintaining a maximum velocity limit of 5 ft/s (1.5 m/s).

2-3.2.9 Volumetric Flow Rates

Use the manufacturer's recommended collector flow rate and the piping schematic to determine the design flow rates throughout the collector sub-system. The total array flow rate is determined by multiplying the collector flow rate by the actual number of collectors. Bank flow rates and row or other branch flow rates are determined by multiplying the collector flow rate by the number of collectors per bank or per row.

2-3.2.10 Pressure Drop Models and the Fluid Velocity Constraints

The design operating temperature of the collector loop inlet (return, entering the collector) should be between 60 and 90 degrees F (15 and 32 degrees C), with the 60 degrees F (15 degrees C) value preferred because it is the lowest temperature (thus highest viscosity and pressure drop) that steady-state operation could be expected. If a higher temperature is to be used, the designer should apply the standard temperature corrections for water before correcting for the use of propylene glycol.

2-3.2.11 Collector Sub-System Plumbing Details

The collector banks must be able to be valved off for maintenance, repair, or replacement. Use ball valves for collector bank isolation. Manually operated, calibrated balancing valves must be located at the outlet to each collector bank to adjust for any flow imbalances present after construction. Drain valves must be located at all low points in the collector sub-system to allow the collectors to be drained if necessary. Pressure relief valves must be located on each collector bank. Manual air vents must be located at the high points of the collector loop to allow air to escape during the filling process. The differential expansion between the system flow paths and the system and the support structure must be considered in the design.

2-3.2.12 Thermal Expansion

When long pipe runs are required, ensure that the resulting expansion or contraction will not harm system components or cause undue stress on the system or the building. Provide pipe anchors, supports, guides, and expansion loops to allow freedom of movement in the direction of motion.

2-3.3 Storage Sub-System

2-3.3.1 Supplementary Heat

Supplementary heat sources are required and shall supply 100% of the system required loads. Operate the auxiliary heater automatically as needed, use the most economical fuel, and share a common heat delivery system with the solar system.

2-3.3.2 Location

Design the equipment room to house the solar storage tank, pumps, heat exchangers, controls, and all system components except the solar collectors.

2-3.3.3 Legionella or Legionnaire's Disease

For domestic use, heat the water in the storage tank to a minimum of 140 degrees F (60 degrees C) in order to avoid any potential source of Legionnaire's disease. For additional information on Legionnaire's disease refer to: http://www.wbdg.org/pdfs/legionella.pdf.

2-3.3.4 Tank Support and Floor Loads

Provide reinforced concrete pads and footings to ensure that the weight of the tank does not endanger the structural integrity of the building. The design load calculation must take into account the estimated weight of the empty tank, the water to be stored in the tank, the insulation, and the tank support structure.

2-3.3.5 Storage Tank Construction

Insulate solar storage tanks to a minimum value of R-30. The storage tank must be equipped with a minimum of four pipe connections, two located near the top of the tank and two located near the bottom. To take advantage of storage tank stratification, pipes supplying the collector array and the cold-water inlet must be connected to the bottom penetrations, and the pipes returning to the tank from the collector array and hot water supplied to the load must be connected to the penetrations near the top. Instrumentation openings will be required as well as openings for relief valves, and drains. Since copper is to be used for all system plumbing, a dielectric coupling must be included in the design of any necessary penetrations of the storage tank**.**

2-3.3.6 Storage Tank Sizing

Specify the solar storage tank based on the sizing criteria that the volume is between 1.5 to 2 gals per square foot (61 to 82 L per square meter) of total array collector area.

2-3.3.7 Storage Sub-System Flow Rate

To ensure that the storage loop can accept the energy available, the thermal capacity on the storage side of the heat exchanger (the product of the mass flow rate and constant pressure specific heat) must be greater than or equal to the thermal capacity on the collector side of the heat exchanger. The storage sub-system volumetric flow rate must be at least 0.9 times that of the total array volumetric flow rate.

2-3.4 Heat Exchanger

2-3.4.1 Sizing

Size the heat exchanger to a minimum effectiveness of 0.5.

2-3.4.2 Specification

The heat exchanger area and pressure drop must be indicated on the drawings and provided by the designer. All materials used in the heat exchanger must be compatible with the fluids used.

2-3.5 Piping

Design piping for low pressure drop. All exposed piping must be well-insulated with approved weather-resistant insulation. Use dielectric unions at connections between dissimilar metals. Provide thermal expansion for all piping.

2-3.5.1 Materials

Piping materials must be copper or steel. Only tin-antimony (Sn-Sb) solders are allowed (Sb5, Sn94, Sn95, and Sn96). Lead solders are forbidden in any part of the potable water system.

2-3.5.2 Insulation

Coordinate insulation requirements with specification UFGS 23 07 00. Insulation must withstand temperatures up to 400 degrees F (204 degrees C) within 1.5 ft. (457 mm) of the collector absorber surface, and 250 degrees F (121 degrees C) at all other locations. Insulation exposed to the outside environment must be weatherproof and protected against ultraviolet degradation. A minimum of R-4 insulation must be specified on all piping.

2-3.6 Expansion Tank

2-3.6.1 Location

Locate the expansion tank in the equipment room or existing mechanical room on the suction side of the pump.

2-3.6.2 Determination of Acceptance Volume

Size the expansion tank to account for the displacement of all the fluid contained in the collector array that is subject to vaporization. During stagnation conditions, only the volume of fluid located in the collector array and associated piping above the lowest point of the collectors is subject to vaporization. The required acceptance volume is determined by adding the total volume of all collectors plus the volume of any piping at or above the elevation of the collector inlets.

2-3.6.3 Determination of Design Pressures

The air-side of closed expansion tanks must be precharged by the manufacturer. This initial or precharged pressure (P_i) must be determined, along with the collector loop fill pressure (P_f) and the maximum relief pressure allowed in the system (P_r). The maximum pressure in the collector loop should be 125 psi (862 kPa). The system-fill pressure should result in a +10 to +15 psi (+69 to +103 kPa) pressure at the highest point of the system. The expansion tank precharge pressure should be equal to the fill pressure at the expansion tank inlet, minus 5 to 10 psi (35 to 69 kPa). This initial condition allows fluid to be contained within the expansion tank at the time of filling and will provide positive pressure in the event of the system operating at temperatures below that occurring when the system is filled.

2-3.6.4 Sizing and Specification

The designer must specify operating modes and freeze/over-temperature protection methods.

2-3.7 Fittings

Valves, other than seasonal or emergency shut-off valves, should be electrically operated and located out of the weather or well-protected. A vent must be provided at the high point in liquid systems to eliminate entrapped air and it should also serve as a vacuum breaker to allow draining of the system. To avoid multiple venting, systems should be piped to avoid having more than one high point. Pressure relief must be provided in each flow circuit. Add check valves to prevent thermally induced gravity circulation. A flow-check valve (used in the hydronic heating industry) will also accomplish the same purpose. Mixing valves should be used to protect DHW systems from delivering water hotter than specified [usually 120–140 degrees F (49–60 degrees C)].

2-3.7.1 Isolation Valves

Use gate valves only in locations where only on/off operation is required. Ball valves must be used at locations where partial flow may be required, such as on the outlet side of the collector banks. These valves are manually operated and must have a key or special tool to prevent unauthorized tampering. Isolation valve locations must ensure that system pressure relief cannot be valved off accidentally. Globe-type valves must not be used.

2-3.7.2 Thumb Valves

Thumb valves also function as on/off valves and only for smaller sized tubing [1/4 inch (6 mm) or less], used to manually open pressure gauges or flow indicators to local flow and are not meant for constant use.

2-3.7.3 Drain Valves

Drain valves are required at all system low points. Specifically, these locations include the low points of the collector banks, the bottom of the storage tank, and two at the bottom of the collector loop between the expansion tank and the pump. The latter two drain valves are used for filling and draining and must be separated by a gate valve.

2-3.7.4 Check Valves

Locate a spring-type check valve in the system between the pump and the collector array, on the supply side.

2-3.7.5 Pressure Relief Valves

A pressure relief valve is required in any line containing a heat source that can be isolated (such as a collector row) and also must be provided between the heat exchanger and the suction side of the collector loop pump. Pressure relief for solar systems must be set at 125 psi (862 kPa) (maximum system design pressure). The discharge from pressure relief valves must be either routed to an appropriate floor drain or captured as required by either local or state regulatory requirements. The discharge must be piped to avoid personnel injury from the hot fluid.

2-3.7.6 Temperature-Pressure Relief Valves

Install temperature-pressure relief valves on the solar storage tank and set for 125 psi (862 kPa) or 210 degrees F (99 degrees C).

2-3.7.7 Balancing Valve

Provide balancing valve with taps to read flow across outlet of each collector bank.

2-3.7.8 Manual Air Vents

Locate manual air vents at the high point(s) of the system where air will accumulate.

2-3.7.9 Strainers

Locate a strainer before the pump to test for system flush.

2-3.8 Pumps

2-3.8.1 Operation

Circulation pumps in both the collector and storage loops must be activated simultaneously by the control sub-system when it has been determined that net energy collection can occur.

2-3.8.2 Pump Sizing and Specification

Select the pump using the manufacturer's standard tables and graphs. After the selected pump is installed and the system is started, balance the system. Provide ECM pump. Comply with UFC 3-420-01 for requirements related to potable water systems.

2-3.9 Control Sub-System

The differential temperature controller (DTC) and all solar thermal system control components must be compatible with the building automation system (BAS) controls specified in the project.

2-3.9.1 Control Strategy

Specify operating modes and freeze/over-temperature protection methods. Connect the control sub-system to the BAS to access at a minimum the following:

- BTU meter in storage loop to measure and record thermal energy sent to storage tank.
- Indicate and record elapsed time of activated pumps.
- Activation of conventional system in event of solar thermal system failure.

Specify at a minimum the following control sequences:

- DTC--activates solar loop pump at preset temperature delta between collector and storage.

- Simultaneous activation of storage loop pump and collector loop pump after input from DTC.

Specify at a minimum the following control points:

- Collector temperature sensor (located at manufacturer's recommendation).
- Storage temperature tank sensor (located in coolest section of tank).
- Heat exchanger temperature sensors at inlet and outlet.
- Pressure indicators at supply and discharge sides of storage loop pump and collector loop pump.
- Pressure indicators at inlet and outlet of heat exchanger.
- Pressure indicator at storage tank.
- Flow indicator in collector loop.
- Flow indicator in storage loop.

2-3.9.2 Location of Controls

Panel-mount electronic displays and visual pressure and temperature gauges together in the mechanical room.

2-3.9.3 Differential Temperature Control Unit (DTC)

The DTC must include a solid-state design with an integral transformer. The DTC must allow the on and off set-points to be variable, and must allow the instantaneous temperatures of the collector and storage tank to be displayed by the system operator or maintenance personnel. The DTC must be able to diagnose and flag open or short circuits.

Using the DTC, the collector and storage loop pumps must be energized whenever the difference between the absorber plate and storage tank temperatures is greater than the high setpoint differential temperature, typically 15 to 25 degrees F (8 to 14 degrees C). The pumps must stay on until that temperature difference is less than the low setpoint differential temperature, usually 5 to 8 degrees F (3 to 4 degrees C).

2-3.9.4 Temperature Sensors and Locations

Provide sensors that are platinum resistance temperature detectors (RTDs) or 10 K-ohm thermistors. Sensors must be easily accessible for calibration and servicing.

2-3.9.4.1 Collector Temperature Sensor

To determine when sufficient energy is available for collection, locate one sensor on the collector array, either in the fluid stream (on a nearby collector bank and in the top internal manifold piping between two collectors) or fastened directly to the absorber plate (only if the collector manufacturer provides this service at the factory). Do not use threaded wells that consist of ferrous materials due to material compatibility with glycol heat transfer fluid. Cover the sensor assembly with a weatherproof junction box.

2-3.9.4.2 Storage Tank Sensor

Locate the storage tank sensor within a well protruding into the storage tank near the outlet to the heat exchanger.

2-3.9.4.3 Sensor Wiring

Locate wiring from the controller to the collector and storage sensors within metal conduit. Keep color-coding consistent from the controller to the sensor, and do not locate junctions or pull boxes in concealed areas.

2-3.9.5 Monitoring Equipment

2-3.9.5.1 Pressure Indicators

Install pressure gauges on the supply and discharge sides of both pumps, on all inlets and outlets of the heat exchanger, and on the storage tank. Duplex gauges can be used or single pressure gauges can be connected to supply and discharge pipe with small plug valves installed in the gage lines. Pressure gauges must be rated for 150 psi (1,034 kPa) and 210 degrees F (99 degrees C) operation.

2-3.9.5.2 Temperature Indicators

Provide thermometers at the heat exchanger inlets and outlets and at the top and bottom of the solar storage tank.

2-3.9.5.3 Flow Indicators

Specify a flow indicator in the collector loop and in the storage loop, after the pump(s). Use venturi-type flow meters to quantify flow measurement with flow indicator components made of brass, bronze, or other compatible non-ferrous material. Install flow devices at least five pipe diameters downstream of any other fittings. Connect flow indicators to the building automation system.

2-3.9.5.4 Elapsed Time Monitor

Record operating time of each circulation pump with an elapsed time monitor.

2-3.9.5.5 BTU Meter

When the solar energy system performance is monitored, specify a BTU meter, and install according to the manufacturer's recommendation.

2-3.10 Design Precautions

2-3.10.1 Collector Loop Check Valve

Locate check valves so that the fluid in the collector loop can be completely drained.

2-3.10.2 Mixing Valves

Ensure that the cold water leg between the mixing valve and the cold water supply to the solar storage tank is not used for connection to any other fixture.

2-3.11 **Safety Features**

2-3.11.1 Fall Protection

Design equipment to minimize work at heights and minimize fall hazards during maintenance, repair, and inspection or cleaning. Design must include prevention systems, such as guardrails, catwalks, and platforms, and anchor points compatible with the job tasks and work environment.

2-3.11.2 Equipment Lockout and Disconnect

Machinery and equipment layout must ensure safe access to lockout devices and provide equipment with independent disconnects. All equipment and utilities must have lockout capability and any replacement, major repair, renovation, or modification of equipment must still accept lockout devices. Emergency and non-emergency shutoff controls must be located in the equipment room and have easy access and usability.

2-3.12 Coordination

The system designer is responsible for ensuring the requirements below are coordinated appropriately between the architect and structural engineer.

2-3.12.1 Roof Requirements

Provide a minimum space of 4 inches (100 mm) between the collector and the roof. Provide a roof design with penetrations near the array for collector supply and return lines. Other architectural requirements for roof design include designing the array support structure and provide calculations assuring that the roof structure is adequate to support the added loading and point loading from the new system; allowing adequate access to the array for maintenance; including access to the roof for personnel path (and equipment); including fire path access; and including walkways around the array and between adjacent arrays. Coordinate with paragraph entitled “Fire Safety Design” Requirements herein.

2-3.12.2 Equipment Room

There must be an equipment room for the solar energy system hardware in one location, and it must contain the storage tank, heat exchanger, expansion tank, pumps, control system, and related plumbing. The equipment room must be configured and sized to allow personnel easy access to maintain and replace equipment. A floor drain must be provided near the storage tank relief valve. Control panels must be installed in an accessible area within line of sight of the equipment room door.

2-3.12.3 Maintenance and Accessibility

Do not use protective mesh screens to cover collectors. Collectors and mounts must withstand expected wind and snow loads. Collector design must allow for rapid replacement of glass covers. Pumps, pipes, and controls must be accessible to allow for repair or replacement. Water pumps must be located so that leakage does not cause serious damage. The operations and maintenance (O&M) manual must be developed by the contractor for the specific design of the solar system.

CHAPTER 3 SOLAR PHOTOVOLTAIC TECHNICAL REQUIREMENTS

3-1 GENERAL REQUIREMENTS

3-1.1 Economic Feasibility Study

As required in UFC 1-200-02, provide on-site renewable energy systems in accordance with ASHRAE 189.1 Section 7.4.1.1 (On-Site Renewable Energy Systems), if life cycle cost-effective. ASHRAE 189.1 requires a minimum annual renewable energy production requirement based on the size of the total roof area. This result refers to the rated DC nameplate capacity of the system.

Perform a life-cycle cost analysis for all new military construction to determine whether the use of renewable forms of energy will result in a net monetary savings to the government. The methodologies and parameters required for Federal energy project feasibility studies are mandated by Federal law (10 CFR 436). Provide a solar photovoltaic energy system when life-cycle cost effective.

3-1.2 Screening Procedures

Perform the initial evaluation for solar photovoltaic system viability. Generate a final report containing at least the solar photovoltaic system size, system cost, annual energy savings, annual cost savings, savings-to-investment ratio (SIR), simple payback, solar fraction, and annual greenhouse gas reduction. The utility rate used for calculating savings must be the burdened rate. See Appendix B for recommended tools.

3-1.3 Detailed Analysis and Study

If the results of the screening procedure indicate that a solar photovoltaic system is a viable consideration, then the next step will be to perform a detailed life-cycle cost analysis (LCCA) to determine the most effective design alternative to develop. Perform LCCA calculations and reports. Include evaluation of tracking array. See Appendix B for recommended tools.

3-1.4 Energy Security Risk Mitigation

On-site renewable energy system designs must include the following requirements in accordance with UFC 3-501-01 in order to limit the risk to energy security:

a. Direct interconnection of system to installation-wide electrical system (grid):

   - For renewable energy systems that include a tie-in by a direct connection to the primary distribution system, provide a cumulative renewable energy load analysis of both the direct connection and building renewable power systems.
   - Evaluate the proposed systems and verify there are no adverse effects on the installation-wide electrical system frequency control, voltage

regulation, and power quality. See Appendix B for issues that should be considered.

b. Direct interconnection of system to buildings that utilize engine generators that may operate in parallel with the renewable energy generation[1]:

- o Evaluate the proposed systems and verify there are no adverse effects on the generator's ability to maintain frequency control, voltage regulation, and power quality. See Appendix B for issues that should be considered.
- o If the stability of the combined systems cannot be confirmed, then design system to automatically disconnect renewable power generation when the backup generator is in operation.

c. Direct interconnection of system to buildings that either do not utilize engine generators or have backup power systems that would never operate in parallel with the renewable energy generation, such as a backup generator supplying power via an automatic transfer switch:

- o Provide analysis validating that the electrical system design addresses the electrical characteristics (real and reactive power output) of the renewable energy system.

3-1.5 Solar Photovoltaic Basis of Design

At a preliminary design stage equivalent to 35% design unless stated otherwise, the designer of record must provide a basis of design which covers the general facility design requirements in accordance with UFC 1-200-01 and its referenced documents. In addition to the UFC 3-501-01 requirements for preliminary basis of design and follow-on submittals, provide the following general system specific analysis information:

- Narrative
  - o FY Year, Project Number, and project location.
  - o Project acquisition: Design-Bid-Build or Design-Build.
  - o Briefly state scope, project description, references, and calculation method used.
  - o Geographic and operating environment, including coastal locations/corrosive conditions, humidity, altitude, seismic zones, and ambient temperature extremes.
  - o Type of solar PV system (BIPV, ground mount, roof mount, tracking).
- Life Cycle Cost Effectiveness
  - o Life Cycle Cost Analysis results.
  - o Solar PV system design cost (study and design costs itemized).

[1] The Air Force does not allow paralleling facility-scale renewable energy systems with any standby power regardless if it is emergency, Critical Operations Power Systems (COPS), or other.

- Average annual energy savings and fuel used.
- Fuel costs provided in the study.
- Percent energy contribution from solar PV system.
- Savings to investment ratios (SIR).
- Estimate of solar PV system installed costs [exclusive of supervision, inspection and overhead (SIOH) and contingency].
- Initial year O&M costs and requirements.

- Design Feasibility
  - Consideration must be taken to avoid shadowing from nearby structures and vegetation.
  - Schematic of system layout.
  - Structural design considerations (roof mounting discussion, life span of roof, structural adequacy).
  - Type and area of solar PV modules.
  - Tracking or fixed solar PV array.
  - Azimuth angle of solar PV modules.
  - Tilt angle of solar PV modules.
  - Calculations used: input data, analysis, method used.
- Connection to Facility (50% Design) in accordance with NFPA 70
  - Ground fault protection.
  - Overcurrent protection.
  - Arc-fault circuit protection.
  - Disconnecting means.
  - System grounding.
  - Grounding electrode system.
  - Rating of AC interconnection panel/switchboard and potential for source to exceed busbar rating. Where the busbar rating would be exceeded, provide design alternative for grid interconnection.
  - Calculations used: input data, analysis, method used.
- Solar PV system schedule (50% Design).
  - Solar PV module technology (crystalline-silicon, thin film).
  - Solar PV module wattage.
  - Solar PV source circuits voltage, current, wattage.
  - Solar PV combiner box output circuit voltage, current, wattage.
  - Inverter input and output voltage, current, wattage.

- Description of operating sequence (90% Design).
  - Startup procedures.
  - Shut off procedures (rapid shutdown of PV systems on buildings).

3-2 SYSTEM SELECTION

3-2.1 Photovoltaic Modules

Solar photovoltaic (PV) modules generate direct current (DC) electrical power from semiconductors when they are excited by sunlight. There are a number of solar PV technologies commercially available and can be categorized into crystalline silicon, ribbon sheet, and thin film. See Appendix E for a discussion on each solar PV technology. Select one commercially-available PV module type based on LCCA, required energy production, site location environmental conditions, and maintainability.

3-2.2 Inverter Types

A micro-inverter converts the DC power to AC at each individual solar module. A string inverter converts the DC power to AC for a series of solar modules. Use either micro-inverters mounted on each individual solar PV module, micro-inverters mounted on racking, or string inverters that serve a series of solar PV modules.

NOTE: Utility-size systems in UFC 3-540-08 (Draft) require reactive power; however this is not necessary for facility-size systems. As regulations are enacted and standards evolve, more inverters will feature reactive power adjustment, but currently very few do.

3-2.3 Mount Types

3-2.3.1 Roof Mounting

Comply with UFC 3-110-03 for requirements related to rack-mounted photovoltaic systems. Design mounting systems in accordance with UFC 3-301-01. For racking requirements dependent upon the roof type, comply with NRCA Guidelines for Roof Systems with Rooftop Photovoltaic Components. Use rooftop mounting systems of the same manufacturer for the entire project array.

3-2.3.1.1 Asphalt Shingle Roof Systems

Comply with CEIR PV Racking and Attachment Criteria for Effective Asphalt Shingle Roof System Integration for requirements related to attaching the mounting system to an asphalt shingle roof system.

3-2.3.1.2 Low-Slope Roof Systems

Comply with CEIR PV Racking and Attachment Criteria for Effective Low-Slope Roof System Integration for requirements related to attaching the mounting system to a low-slope roof system.

3-2.3.1.3 Metal Panel Roof Systems

Comply with CEIR PV Racking and Attachment Criteria for Effective Low-Slope Metal Panel Roof System Integration for requirements related to attaching the mounting system to a low-slope metal panel roof system.

3-2.3.2 Ground Mounting

Design mounting systems in accordance with UFC 3-301-01. Foundation must be either concrete, driven pile, or helical pile. Complete an environmental impact assessment for the site.

3-2.3.3 Tracking Array System

Design for solar PV tracking system in accordance with IEC 62727. See Appendix E for tracking system pros and cons.

3-2.4 DC Input Voltage

Maximum DC string input voltage must not exceed 1,000 VDC.

3-2.5 System Warranty

Provide a warranty in the event of component failure due to workmanship, defective components or assemblies for the entire solar PV system at a minimum one year parts and labor. Coordinate all warranty requirements with the LCCA.

3-2.5.1 PV Module Warranty

Provide PV module warranty of minimum 10 years for workmanship material and manufacturing defects from the date of manufacture. Concerning performance, PV module warranty must include manufacturer written guarantee for minimum continuous, linear power output of 80 percent for 25 years.

3-2.5.2 Inverter Warranty

Provide inverter warranty of minimum 15 years.

3-2.5.3 Mounting System Warranty

Provide PV mounting system warranty of minimum 15 years.

3-2.6 Standard Test Conditions

All compliance testing must be completed under Standard Test Conditions (STC) which are defined as 92.9 W/ft^2 (1,000 W/m^2) insolation, 68 degrees F (25 degrees C) cell temperature, and 2.2 mph (1 m/s) average wind velocity. Modules must be supplied with original current/voltage maximum power measurement data.

3-3 SYSTEM DESIGN

Installation must meet requirement based on roof area although it does not have to be installed on the roof (it can be ground-mounted).

3-3.1 Array Tilt Angle

Tilt the array to the latitude plus or minus 10 degrees. It should be noted that as the tilt angle increases, the minimum spacing between rows must be increased due to shading, requiring a larger roof area. Do not allow inter-row shading between 9 a.m. and 3 p.m., when the bulk of the energy collection occurs.

3-3.2 Array Azimuth Angle

For optimum performance, orient the module true south, however slightly west of south (azimuth angle of true south plus 10 degrees) may be preferable in some locations if an early morning haze or fog is a regular occurrence. Design the array's azimuth angle off of due south as coordinated with the Basis of Design.

3-3.3 PV Module Design

The solar photovoltaic module must comply with UL 1703. The backsheet and encapsulent must be specified in accordance with UFGS 26 31 00 with a guarantee of their construction submitted by the manufacturer.

3-3.3.1 Insulation

All module circuitry must be insulated from external surfaces and withstand open-circuit system voltage of 1,000 VDC.

3-3.4 Inverter and Array Design

3-3.4.1 Network Communication

Provide inverter capable of network communication to allow for PV array performance monitoring.

3-3.4.2 Inverter Location

Locate the string inverter(s) in the electrical equipment room or outdoors with appropriate personnel safety to prevent unauthorized access. If a ventilated enclosure is not available, provide enclosure in accordance with UFC 3-501-01, paragraph entitled "Corrosive and High Humidity Areas."

3-3.4.3 Micro-Inverter Systems

For micro-inverter systems, coordinate the maximum number of micro-inverters per branch circuit and overcurrent protection size with the inverter manufacturer. The maximum number will be dependent on the AC system voltage, AC output power, and conductor size of the interconnection cable. Design the array to the best power output using best practices in Appendix B.

3-3.5 Metering and Monitoring

Coordinate revenue metering requirements with the utility provider and DoD installation regarding interconnection-specific data and guidelines, utilizing metering specifications UFGS 26 27 13.10 30 (Air Force only) and UFGS 26 27 14.00 20 (Navy only). Coordinate with Activity for requirements and plan of action to manage excess energy, including the utilization of net metering.

Provide communication and annunciator panel. Monitoring must be module-based if micro-inverters are implemented, otherwise monitoring must be string-inverter based. Provide monitoring based on inverter type utilized (i.e. string inverter or micro-inverter).

3-3.6 Wiring

Provide UL 4703 listed PV wiring. Provide grounding in accordance with NFPA 70.

3-3.7 Sensors and Locations

Provide sensors that are easily accessible for calibration and servicing, and relevant to affecting PV output.

3-3.7.1 Ambient Temperature Sensor

The ambient temperature sensor must be located near the array but not on it, such that it will not cast a shadow on the array, is at the same mean height as the array, and is exposed to the same hours of sunlight as the majority of the array panels.

3-3.7.2 Panel Temperature Sensor

The panel temperature sensor must be located on the array, fastened directly to the center of the back side of a solar panel. Sensors must be either thermocouple platinum or digital, and fully encapsulated including a minimum 3/8 inch (10 mm) thick insulation block.

3-3.7.3 Insolation Sensor

The solar insolation sensor must be located in the plane of the array, fastened directly to the front side of a solar panel frame but must not cast a shadow on the panel cells, and constructed of UV-resistant material.

3-3.7.4 Wind Speed Sensor

Locate the wind speed sensor near the array but not on it, such that it will not cast a shadow on the array, and away from tall obstructions. Wind speed sensor is necessary for solar tracking PV systems to prevent damage.

3-3.7.5 Sensor Wiring

Comply with NFPA 70 for requirements related to sensor wiring.

3-3.8 Lightning and Surge Protection

3-3.8.1 Lightning Protection

Comply with UFC 3-501-01 for requirements related to providing a lightning risk assessment.

If lightning protection is a design requirement, comply with UFC 3-575-01 for requirements related to providing a lightning protection system. Provide side flash calculations as required by NFPA 780.

3-3.8.2 Overcurrent Protection

Provide overcurrent protection in accordance with NFPA 70. Show locations of overcurrent protective device on drawings.

3-3.8.3 Surge Protection

Provide surge protection in accordance with NFPA 780. Comply with UFC 3-520-01 for requirements related to providing surge protection. Show locations of surge protective device on drawings.

3-3.9 System Grounding

Comply with NFPA 70 for requirements related to general system grounding.

3-3.10 Utility Interconnection

Coordinate with local transmission and interconnection services provider for specific procedures in accordance with the provider’s pro forma Open Access Transmission Tariff (OATT). Where the busbar rating would be exceeded, provide design alternatives for interconnection to the grid. Comply with all IEEE 1547 requirements regarding the interconnection technical and testing requirements necessary for electrical systems to operate under normal conditions without degradation. Prior to interconnect, provide proper documentation and certifications for all generation equipment, installation, operation, and maintenance to show that the system is in compliance with IEEE 1547.

3-3.11 Safety Features

3-3.11.1 Emergency Shutdown

Provide system rapid shutdown equipment in accordance with NFPA 70.

3-3.11.2 Fall Protection

Comply with UFC 3-110-03 for requirements related to elimination, prevention, or control of fall hazards. Design equipment to minimize work at heights and minimize fall hazards during maintenance, repair, and inspection or cleaning. Design must include prevention systems, such as guardrails, catwalks, and platforms, and anchor points compatible with the job tasks and work environment.

3-3.12 Fire Safety Design Requirements

Comply with UFC 3-600-01 and all requirements in NFPA 1 related to "Photovoltaic Systems" with the following modifications.

3-3.12.1 Buildings Other Than One- and Two-Family Dwellings and Townhouses.

3-3.12.1.1 Access

Provide a minimum 6 ft (1.8 m) wide clear perimeter around the edges of the roof for all buildings.

3-3.12.1.2 Single Story Smoke Ventilation

Ventilation options shall be provided as required by NFPA 1. It is preferable to provide skylights (that can be manually opened) or manually operated smoke vents in lieu of the "venting cutout options".

3-3.12.1.3 Multistory Smoke Ventilation

Increased pathway width or venting cutout options are not required. The minimum width of any pathway must be 4 ft (1.2 m).

Provide a roof access hatch or skylight above every enclosed stairway. The hatch or skylight must not be less than 16 square ft (1.5 square m) in area and having a minimum dimension of 2 ft (6.1 m).

3-4 COORDINATION

3-4.1.1 Roof Requirements

Architectural requirements for roof design include providing roof penetrations near the array for conduit; designing the array support structure; allowing adequate access to the array for maintenance; including access to the roof for personnel (and equipment); and including walkways around the array.

3-4.1.2 Equipment Locations

Coordinate equipment locations with the system design, and consider the best practices in Appendix B. Design to minimize conductor cable distances. Provide panels in easily accessible areas and clearly visible.

Accommodate the inverters, meters, and subpanels in the electrical equipment room or other designated equipment area. Size area to allow personnel to move about freely and have easy access to replace equipment as necessary in accordance with NFPA 70.

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APPENDIX A REFERENCES

AMERICAN SOCIETY OF HEATING, REFERIGERATING AND AIR CONDITIONING ENGINEERS (ASHRAE)
http://www.ashrae.org/

ASHRAE 93, Methods of Testing to Determine the Thermal Performance of Solar Collectors

ANSI/ASHRAE/USGBC/IES Standard 189.1 (ASHRAE 189.1), Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings

CENTER FOR ENVIRONMENTAL INNOVATION IN ROOFING (CEIR)
http://roofingcenter.org/main/Initiatives/pv

PV Racking and Attachment Criteria for Effective Asphalt Shingle Roof System Integration

PV Racking and Attachment Criteria for Effective Low-Slope Roof System Integration

PV Racking and Attachment Criteria for Effective Low-Slope Metal Panel Roof System Integration

FEDERAL AVIATION ADMINISTRATION (FAA)

Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports, October 23, 2013, https://www.federalregister.gov/articles/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports#h-11

Technical Guidance for Evaluating Selected Solar Technologies on Airports, http://www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide_print.pdf

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems

INTERNATIONAL ELECTROTECHNICAL COMMISSION

IEC 62727, Photovoltaic Systems – Specification for Solar Trackers

MODBUS ORGANIZATION, INC (MODBUS)

Modbus Application Protocol Specification

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)

NEMA C12.20, Electricity Meters – 0.2 and 0.5 Accuracy Classes

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA 1, Fire Code

NFPA 30, Flammable and Combustible Liquids Code

NFPA 70, National Electrical Code

NFPA 780, Standard for the Installation of Lightning Protection Systems

NATIONAL ROOFING CONTRACTORS ASSOCIATION (NRCA)
http://www.nrca.net/

Guidelines for Roof Systems with Rooftop Photovoltaic Components

NORTH AMERICAN BOARD OF CERTIFIED ENERGY PRACTITIONERS
http://www.nabcep.org/

NABCEP Solar Heating Installer Resource Guide

NABCEP PV Installation Professional Resource Guide

UNDERWRITERS LABORATORIES
http://ulstandards.ul.com/

UL 1703, Flat-Plate Photovoltaic Modules and Panels

UNITED STATES DEPARTMENT OF DEFENSE

DoD Instruction 8500.01, Cybersecurity, March 14, 2014, http://www.dtic.mil/whs/directives/corres/ins1.html

DoD Instruction 8510.01, Risk Management Framework (RMF) for DoD Information Technology (IT), March 12, 2014, http://www.dtic.mil/whs/directives/corres/ins1.html

UNITED STATES DEPARTMENT OF DEFENSE, UNIFIED FACILITIES CRITERIA PROGRAM
http://dod.wbdg.org/

UNIFIED FACILITIES CRITERIA (UFC)

UFC 1-200-01, General Building Requirements

UFC 1-200-02, High Performance and Sustainable Building Requirements

UFC 3-110-03, Roofing

UFC 3-260-01, Airfield and Heliport Planning and Design

UFC 3-301-01, Structural Engineering

UFC 3-401-01, Mechanical Engineering

UFC 3-420-01, Plumbing Systems

UFC 3-501-01, Electrical Engineering

UFC 3-520-01, Interior Electrical Systems

UFC 3-540-08, Utility-Scale Renewable Energy Systems (Draft)

UFC 3-560-01, Electrical Safety, O&M

UFC 3-575-01, Lightning and Static Electricity Protection Systems

UFC 3-600-01, Fire Protection Engineering for Facilities

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

UFGS 23 07 00, Thermal Insulation for Mechanical Systems

UFGS 23 09 23, LonWorks Direct Digital Control for HVAC and Other Building Control Systems

UFGS 23 09 23.13 20, BACnet Direct Digital Control Systems for HVAC

UFGS 25 10 10, Utility Monitoring and Control System (UMCS) Front End and Integration

UFGS 26 27 13.10 30, Electric Meters

UFGS 26 27 14.00 20, Electricity Metering

UFGS 26 31 00, Solar Photovoltaic (PV) Components

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APPENDIX B BEST PRACTICES

This appendix identifies background information and practices for accomplishing certain renewable energy design and engineering services. The Designer of Record (DoR) is expected to review and interpret this guidance and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the UFGS or UFC, the UFGS and the UFC must prevail. If a Best Practices document has guidelines or requirements that are not discussed in the UFGS or UFC, the DoR must submit a list of the guidelines or requirements being used for the project with sufficient documentation to the Government Engineer for review and approval prior to completing design.

B-1 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide (www.wbdg.org) provides additional information and discussion on practice and facility design, including a holistic approach to integrated design of facilities.

The WBDG provides access to Construction Criteria Base (CCB) criteria, standards and codes for the DoD Military Departments, National Aeronautics and Space Administration (NASA), and others. These include, UFC, UFGS, Performance Technical Specifications (PTS), design manuals, and specifications.

B-2 RENEWABLE ENERGY SYSTEMS AND ENERGY SECURITY.

Designs should address the following issues concerning the utilization of renewable energy (RE) systems:

B-2.1 Low Energy Security Risk RE Systems.

Waste-to-energy, geothermal, or biomass, are low energy security risk RE systems and are highly desirable.

- No power quality issues.
- Stable, reliable, easily controllable.
- Easily integrated into microgrid topology.
- Straightforward, easily implemented IEEE 1547 standard.

B-2.2 High Energy Security Risk RE Systems.

Photovoltaic and wind renewable energy (RE) systems are high energy security risk due to their possible adverse effect on electric grid frequency control, voltage regulation, and power quality.

B-2.2.1 Wind Energy Generators Systems.

- Consume reactive power – cannot provide reactive power to meet needs of base.

- Lower utility power factor (PF) during operation – creates risk of utility power factor penalty charges or power outages.
- Electromagnetic interference.
- Implementation of IEEE 1547 standard is more complex.

B-2.2.2 Solar PV Energy Systems.

- Provide near unity PF – little to no reactive power.
- Lower utility PF during operation.
- Unstable effect on system frequency control.
- Additional stress on emergency generators supporting critical facilities if operated in parallel.
- Implementation of IEEE 1547 standard is more complex.

B-3 SOLAR THERMAL BEST PRACTICES.

B-3.1 Tools.

B-3.1.1 Screening Tools.

B-3.1.1.1 Solar Hot Water System Calculator.

Use the Solar Hot Water System Calculator developed by the Federal Energy Management Program (FEMP) for the initial evaluation for solar hot water system viability: http://apps1.eere.energy.gov/femp/solar_hotwater_system/.

B-3.1.1.2 System Advisor Model (SAM).

Use the System Advisor Model, a performance and financial model designed to facilitate decision-making for those involved in the renewable energy industry: https://sam.nrel.gov/.

B-3.1.2 Shading Analysis Tools.

B-3.1.2.1 Solar Pathfinder.

Use the Solar Pathfinder tool to determine the most economical and efficient solar thermal array location and position: http://www.solarpathfinder.com/.

B-3.1.2.2 Solmetric SunEye.

Use the Solmetric SunEye tool to determine the most economical and efficient solar thermal array location and position: http://www.solmetric.com/.

B-3.1.2.3 Manual Calculation.

Manual calculations may be an acceptable approach for more experienced designers. Perform calculations justifying the basis of shadowing exclusion areas.

B-3.1.3 LCCA Tools.

B-3.1.3.1 Economic Analysis Package (ECONPACK).

Perform LCCA calculations and reports by utilizing a service's economic analysis program, such as the Economic Analysis Package (ECONPACK): http://www.wbdg.org/tools/econpack.php.

B-3.1.3.2 Building Life-Cycle Cost (BLCC).

Perform LCCA calculations and reports by utilizing a service's economic analysis program, such as the Building Life-Cycle Cost (BLCC) Program: http://www1.eere.energy.gov/femp/information/download_blcc.html.

B-3.1.4 Domestic Hot Water.

The FEMP Solar Hot Water System Calculator (http://apps1.eere.energy.gov/femp/solar_hotwater_system/) incorporates hot water demand estimates for several types of buildings: barracks, dormitory, food service, hospital, motel, office, residence, and school. Other required inputs are: number of persons, cold water temperature, and hot water temperature. The outputs are the total calculated load and estimated system size.

B-3.2 Solar Thermal Heat Transfer Fluids.

Observe the cautions regarding toxic heat transfer fluids as given here: http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12930.

B-3.2.1 Hydrocarbon Oils

Hydrocarbon oils are for systems susceptible to regular freezing or stagnation temperatures, usually in ASHRAE Climate Zones 6 and above. Hydrocarbon must have a minimum closed-cup flashpoint 100 degrees F (38.7 degrees F) higher than the maximum expected collector temperature. Use oxygen scavenger additives when unsaturated hydrocarbons are used as heat transfer fluids. Some non-synthetic hydrocarbons thicken at low temperatures and the resultant higher viscosity can cause pumping problems. Synthetic hydrocarbon oils retain low viscosity at low temperatures, and therefore are required.

B-3.2.2 Distilled Water

Due to distilled water being subject to freezing and boiling, add an anti-freeze/anti-boil agent such as glycol.

B-3.3 Hydronic Heating Combined with Domestic Hot Water

Water-to-air heat exchangers may be placed in existing ductwork, in which case, an unpressurized, unlined tank may be used and represents a minimum heating system. The following is guidance for baseboard heaters:

- Most baseboard heaters have comparatively small surface areas, so they require higher temperatures, typically about 180 degrees F (82.2 degrees C). If larger heat transfer areas are available as in older or modified hot water systems, temperatures of 120 degrees F (48.9 degrees C) may be sufficient. Temperatures of 100 degrees F (37.8 degrees C) are adequate for the system which uses entire floors, walls, and ceilings as radiator surfaces.
- During the winter, typical liquid-type solar systems are seldom operated at delivery temperatures above 150 degrees F (65.6 degrees C). The use of solar heated water in standard baseboard heaters is impractical. Only modified baseboard heaters of adequate size or radiant panels shall be used in hydronic systems which use solar heated water.

B-3.4 Solar Thermal Collector Sub-System Array Design.

Select a specific collector for the detailed design before the actual array size is determined.

B-3.5 Reverse-Return Piping Layout – Diagonal Attachment Rule.

The reverse-return strategy of providing approximately equal length flow paths for supply and return pipes attached to the array at any two opposite diagonal corners of the array must be used for all projects.

B-3.6 Solar Thermal Pressure Drop Across Banks and Rows.

When internal-manifold collectors are banked together in groups of seven or less, it can be assumed that the pressure drop across the entire bank is equal to the pressure drop across a single collector.

B-3.7 Draindown and Drainback Systems.

Draindown (closed-loop) and drainback (open-loop) systems are prohibited due to additional maintenance required over the approved systems.

B-3.8 Over-Temperature Protection.

Over-temperature protection of the collector loop in the event of stagnation is provided through expansion tank sizing, and therefore there are no additional control requirements. The pressure-temperature relief valve located on the storage tank supplies over-temperature protection of the storage loop. If a direct circulating system is supplying water for domestic use, protection is provided through relief and mixing valves.

B-3.9 Heat Exchanger.

Effectiveness is a relatively complex term to calculate. Two methods of heat exchanger analysis are used in design: the log mean temperature difference (LMTD) method and the effectiveness-number of transfer units (e-NTU) method. The LMTD method is used most often for conventional HVAC systems and requires knowledge of three of the four inlet and outlet temperatures. This method cannot be applied directly to solar systems because the inlet temperatures to the heat exchangers from both the collectors and storage are not constant. Since the goal of the solar system heat exchanger is to transfer as much energy as possible, regardless of inlet and outlet temperatures, the e-NTU method should be used. However, a complete e-NTU analysis can be avoided by considering the impact of the heat exchanger on the overall system performance. The annual system solar fraction is decreased by less than 10 percent as heat exchanger effectiveness is decreased from 1.0 to 0.3. By setting a minimum acceptable effectiveness of 0.5, the e-NTU method can be used to generate the temperatures required by the LMTD method. These temperatures and the corresponding flow rates can then be used to size the heat exchanger according to the LMTD method, with the resulting heat exchanger satisfying the minimum effectiveness of 0.5.

Consult manufacturer's representatives and catalogued data to size heat exchangers. A 120 degrees F (49 degrees C) solar loop exit temperature yields an effectiveness of 0.5, and increasing the exit temperature decreases effectiveness. To ensure an effectiveness greater than 0.5 is achieved, the designer provides the following recommended temperatures and flow rates:

- Solar loop inlet temperature = 140 degrees F (60 degrees C)
- Solar loop exit temperature = 120 degrees F (49 degrees C) or less
- Storage side inlet temperature = 100 degrees F (38 degrees C)
- Solar loop flow rate = Average flow rate (AFR)
- Storage loop flow rate = 1.25 × AFR.

B-4 SOLAR PHOTOVOLTAIC (PV) BEST PRACTICES.

B-4.1 Tools.

B-4.1.1 Screening Tools.

B-4.1.1.1 Solar Insolation Map.

Determined with a solar insolation map, sites with an average solar radiation rate above 5.0 kWh/m^2 per day must be carefully considered for solar photovoltaic energy.

B-4.1.1.2 PVsyst.

Consider using the PVsyst software package for preliminary design, project management, and data simulation: http://www.pvsyst.com.

B-4.1.1.3 PVWatts.

Consider using the PVWatts web application, developed to estimate the electricity production of a grid-connected roof- or ground-mounted photovoltaic system based on a few simple inputs: http://www.nrel.gov/rredc/pvwatts/.

B-4.1.1.4 Solar Prospector.

Use the Solar Prospector tool for mapping direct normal irradiance (DNI), developed by the National Renewable Energy Laboratory (NREL) for the initial evaluation for solar photovoltaic system viability: http://maps.nrel.gov/node/10/.

B-4.1.1.5 System Advisor Model (SAM).

Use the System Advisor Model, a performance and financial model designed to facilitate decision-making for those involved in the renewable energy industry: https://sam.nrel.gov/.

B-4.1.2 Shading Analysis Tools.

B-4.1.2.1 Solar Pathfinder.

Consider using the Solar Pathfinder tool to determine the most economical and efficient solar thermal array location and position: http://www.solarpathfinder.com/.

B-4.1.2.2 Solmetric SunEye.

Consider using the Solmetric SunEye tool to determine the most economical and efficient solar thermal array location and position: http://www.solmetric.com/.

B-4.1.2.3 Manual Calculation.

Experienced designers who may be more comfortable with using manual tools such as a tape measure is also an acceptable approach. Provide calculations justifying the basis of shadowing exclusion areas.

B-4.1.3 LCCA Tools.

B-4.1.3.1 Economic Analysis Package (ECONPACK).

Perform LCCA calculations and reports by utilizing a service's economic analysis program, such as the Economic Analysis Package (ECONPACK): http://www.wbdg.org/tools/econpack.php.

B-4.1.3.2 Building Life-Cycle Cost (BLCC).

Perform LCCA calculations and reports by utilizing a service's economic analysis program, such as the Building Life-Cycle Cost (BLCC) Program: http://www1.eere.energy.gov/femp/information/download_blcc.html.

B-4.2 Warranty.

Note that specific system components can have warranties that vary with each manufacturer. Typically, PV module warranty ranges from 5-10 years. Concerning performance, PV module warranty includes manufacturer written guarantee for minimum continuous power output of 80 percent for 20 years. Warranties for inverters have a typical range of 10-25 years depending on the manufacturer and technology. In addition, the PV mounting system warranty typically varies between 5-10 years.

B-4.3 Array Tilt Angle.

Anticipate any future structures or vegetation (trees) that could block future solar access, and keep the modules out of the shade between 9 a.m. and 3 p.m. when the bulk of the energy collection occurs.

B-4.4 Inverter and Array Design.

For string-inverter and micro-inverter systems, because the inverter must be sized for a system to last 20 years, the PV-to-inverter (DC-to-AC) size ratio must be between 1.1 and 1.4, or according to the microinverter manufacturer if microinverters are used. The ideal ratio must be determined by the designer using simulation software. Consider designing the system using smaller inverters so that less power is lost in the event one fails.

B-4.4.1 Maximum Panels for Inverter.

The temperature-corrected open-circuit voltage calculation used in determining the maximum number of panels for the inverter must not use the location record low temperature but rather refer to the Extreme Annual Mean Minimum Design Dry Bulb Temperature data published in ASHRAE Handbook – Fundamentals. The recommended method is to calculate the temperature-corrected, minimum expected module maximum power voltage, Vminmp = Vmp + ((T_rise + T_max – T_stc) X TCVmp), where,

- Vminmp = Minimum expected module maximum power voltage
  - Vmp = Module maximum power voltage
- T_rise = Temperature rise resulting from mounting conditions
- T_max = Average high ambient temperature
- T_stc = Temperature at Standard Test Conditions
- TCVmp = Temperature coefficient at maximum power voltage.

B-4.4.2 Minimum Panels for Inverter.

To determine the minimum number of panels in the string for the inverter, use the equation Nmin = Vmininv / Vmin, where:

- Nmin = Minimum number of panels per inverter string

- Vmininv = Minimum inverter voltage
- Vminmp = Minimum expected module maximum power voltage.

B-4.5 PV Array Zone Labeling.

On the as-built plans, label PV arrays into zones to match with corresponding inverters and combiner boxes. Labeling will help in identifying locations for troubleshooting and repair.

B-4.6 PV Modules and Hot Roofs.

Design for an air gap between continuous rows of PV modules for ventilation.

B-4.7 Equipment Locations.

Depending on the system design, equipment may be located indoors or outdoors. Equipment indoors adds generated heat to the building, but also adds longevity. Equipment outdoors may be subjected to a harsh environment. If equipment is in a desert environment, in addition to the proper NEMA enclosure, it must also be provided with a shading structure.

APPENDIX C GLOSSARY

C-1 ACRONYMS.

AC	Alternating Current
AFR	Average Flow Rate
BAS	Building Automation System
BIA	Bilateral Infrastructure Agreement
BTU	British Thermal Unit
CCB	Construction Criteria Base
CIS/CIGS	Copper Indium [Gallium] (di)Selenide
DC	Direct Current
DoR	Designer of Record
DHW	Domestic Hot Water
DTC	Differential Temperature Controller
ECM	Electronically Commutated Motor
EISA	Energy Independence and Security Act
FEMP	Federal Energy Management Program
HNFA	Host Nation Funded Construction Agreements
ISC	Integral Storage Collector
kW	Kilowatt
kWh	Kilowatt-Hour
LCCA	Life Cycle Cost Analysis
MTR	Military Training Route
NFPA	National Fire Protection Association
NREL	National Renewable Energy Laboratory
O&M	Operation & Maintenance
PV	Photovoltaic

RTD	Resistance Temperature Detector
SAM	System Advisor Model
SGHAT	Solar Glare Hazard Analysis Tool
SIOH	Supervision, Inspection, and Overhead
SIR	Savings-to-Investment Ratio
SRCC	Solar Rating and Certification Corporation
WBDG	Whole Building Design Guide

C-2 DEFINITION OF TERMS.

Albedo: The fraction of solar radiation that is reflected from the ground, ground cover, and bodies of water on the surface of the earth.

Anemometer: An instrument that measures wind speed.

Azimuth Angle: The angle between the horizontal direction (of the sun, for example) and a reference direction (usually North).

Dry-Bulb Temperature: Air temperature measured with a thermometer, similar to ambient temperature.

Fixed-Tilt Array: An array of solar power collectors that do not pivot to follow the track of the Sun in the sky. In the Northern Hemisphere, they are usually mounted with a southern tilt that will maximize the amount of energy that they can receive.

Flat-Plate Collector: A solar power collector that absorbs the Sun’s energy on a flat surface without concentrating or refocusing it.

Insolation: The amount of solar energy that arrives, at a specific area of a surface during a specific time interval. A typical unit is W/m^2.

Nadir: Straight down (toward the center of the Earth)

Net Metering: A service to an electric consumer under which electric energy generated by that electric consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period.

Orientation: The direction that a solar energy collector faces. The two components of orientation are tilt angle (the angle the collector makes from the horizontal) and the aspect angle (the angle the collector makes from North)

Parabolic Collector Trough: A system that tracks the path of the sun by pivoting on one axis (typically East-West or North-South), using shiny parabolic troughs to heat the collector fluid that passes through a tube at the focus

Photovoltaic: Technology for converting sunlight directly into electricity, usually with photovoltaic cells

Solar Absorber: A sheet of metal, usually copper, aluminum, or steel, which forms the surface of a solar collector. It collects and retains solar radiation, which is passed to a heat transfer medium

Tracking Collector/Module: Any collector that changes its orientation throughout the day in order to follow the path of the sun in the sky. Two-axis trackers continually face the sun, while one-axis trackers rotate on one axis so that collectors receive the maximum amount of circumsolar radiation that strikes the axis.

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APPENDIX D EXAMPLE SOLAR THERMAL DRAWINGS AND SCHEDULE CHECKLIST

D-1 PURPOSE.

The drawings and schedule checklist provides the solar thermal system designer, project manager, and quality assurance personnel with a list of those items that are called out by the guide specification to appear on the drawings, or are strongly suggested based on experience with solar thermal system design problems. The designer is encouraged to annotate the drawings to ensure that design changes are properly accounted for, to provide a record of system settings and performance criteria, and to ensure that important details are not overlooked during construction. The following items should be included as part of the system drawings and schedule.

D-2 SUGGESTED DRAWINGS AND SCHEDULE.

D-2.1 Collector Array Layout (No Scale).

The collector array layout will be in accordance with the guidance defined in Chapter 2. As a minimum define the layout, number of collectors, bank sizes, rows (if applicable), and required fittings.

D-2.2 System Schedule.

The job specific system schedule includes the following:

- Note the collector parameters around which the system was designed:
  - Collector net aperture area.
  - Collector fluid volume.
  - Collector gross dimensions (length, width, and thickness).
  - Collector design flow rate (CFR, recommended by manufacturer).
  - Pressure drop at design flow rate.
  - Internal manifold diameter.
- Note the following system parameters:
  - System calculated net aperture area.
  - System (collector loop) flow rate required (AFR = CFR × Number of collectors).
  - Storage loop flow rate = 1.25 × AFR.
  - Propylene glycol concentration required in collector loop.
  - Minimum pressure drop throughout piping loop, corrected for propylene glycol solution, if necessary.
- Note the following information about the heat transfer fluid:

- Recommend only food-grade propylene glycol/distilled water solutions as the heat transfer fluid.
- Percent concentration required (30 percent or 50 percent).
- Tamper-resistant resistant seals are required at all fill ports or drains.

- Note the heat exchanger recommended minimum performance requirements to achieve an effectiveness of 0.5, although this may vary due to the system design and environment:
    - Solar loop (hot) inlet = 140 degrees F (60 degrees C).
    - Storage loop (cold) inlet = 100 degrees F (38 degrees C).
    - Solar loop (hot) outlet = 120 degrees F (49 degrees C), or less.
    - Solar loop (hot) flow rate = AFR.
    - Storage loop (cold) flow rate = 1.25 × AFR.
    - Solar (hot) fluid: 30 percent or 50 percent propylene glycol/water solution.
    - Storage (cold) fluid: water.
    - Note required pipe diameters.
    - Locate expansion tanks near pump inlets.
    - Require expansion tank bladders to be compatible with propylene glycol/water solutions.
    - Require a check valve in the collector loop in order to prevent reverse thermosiphoning.
    - Require isolation valves around the collector banks and all major components.
    - Require pressure relief shown on all banks.
    - Require calibrated balancing valves at all bank outlets.
    - Require drain valves at low points of each collector bank or row.
    - Require thumb valves (if required) to manually open and close pressure gauges and flow indicators not meant for constant use.
    - Require two drain valves, with gate in between, at all low points in the system to allow for filling.
    - Require 125 psi/210 degrees F (862 kPa/99 degrees C), pressure/temperature relief valve on the storage tank.
    - Require manual air vents at all high points of the system plumbing.
    - Locate collector temperature sensor on a nearby collector bank and in the top internal manifold piping between two collectors; or on the collector absorber plate, only if installed by manufacturer.

- o Locate a storage sensor in the thermal well at the bottom of the storage tank.
- o Require sensor wiring be installed in a conduit.
- o Require pressure gauges, rated for 125 psi (862 kPa), on both sides of pump(s), on all ports of the heat exchanger, and on the storage tank.
- o Require thermometers on all ports of the heat exchanger and at the top and bottom of the storage tank.
- o Require flow indicators or meters in each loop to allow either visual or quantified flow measurements to be observed.
- o Require an elapsed time meter be installed on circulation pump(s).
- o Require BTU meter be located across the heat exchanger on the storage side (if needed).

D-2.3 Roof Plan (To Scale Unless Noted).

- For Navy projects, coordinate with FC 1-300-09N.
- Collector groupings in banks and rows as designed.
- Minimum row spacing shown and noted.
- Orientation with respect to due south shown and noted.
- Rooftop mounted equipment, vents, and system penetrations shown and noted.
- Reverse-return piping shown and noted (not to scale).
- Expansion loops (if required) shown and noted.
- Manual air vents, pressure relief, valves and drains shown.
- Walkway, catwalk, or other array access shown and noted.

D-2.4 System Elevation.

- Pipe pitches for positive draining shown and noted.
- Piping elevations from equipment room to system and throughout array shown and system elevation head noted.
- Required collector tilt angle shown and noted.
- Mechanical chase shown between equipment room and roof.
- Array support structure shown.
- Walkway, catwalk, or other array access shown and noted.

D-2.5 Equipment Room Layout.

- Storage tank, pump(s), piping, control panel, heat exchanger, expansion tank, and drain shown.

- Backup water heating unit shown.
- Access is available to all equipment by maintenance personnel for repair, replacement, or monitoring.

D-2.6 Additional Schedules and Instructions.

- Schedule of operation. The operating characteristics (including the on/off temperature differential) of the system should be indicated.
- Installation instructions. Instructions should be provided regarding important installation details. These details include the use of Sb5, Sn94, or Sn96 solder for copper piping and on-site insulating instructions for equipment and piping.
- Design information schedule. Include the system design parameters into a drawing schedule(s).
- System filling and start-up instructions. Instructions on mixing the propylene glycol solution and filing the system will be provided. System fill pressure will be stated.
- Equipment schedule (standard).

D-2.7 Details.

- Storage tank.
  - o Minimum of two tank penetrations each shown at both top and bottom of tank shown and noted.
  - o Minimum insulation value of R-30 (factory or on-site application) shown and noted.
  - o Storage sensor located in thermal well bottom of storage tank shown and noted.
  - o Show and note that incoming water supply and outlet to solar system are connected to bottom of storage tank; inlet from solar thermal system and outlet to backup heating unit are connected to top of tank.
  - o Dielectric couplings will be used on all piping connections.
  - o Note that tank is to be lined with epoxy, glass, or cement.
  - o If outdoors, weather protection and added insulation should be shown and noted.
  - o Storage tank weight when filled should be noted.
  - o Proper foundation for storage tank should be shown and noted.
- Heat exchanger (optional): For shell-in-tube heat exchangers, indicate the access areas allotted for tube bundle removal (to allow cleaning). Indicate that materials in the heat exchanger must be compatible with propylene glycol.
- Array support structure (typical).

   - Collector mounting to support detail at proper tilt (within 10 degrees of site latitude) shown.
   - Support mounting to roof detail shown.
   - Aluminum structure with stainless steel hardware noted.
   - Design loads noted.

- Collector temperature sensor mounting details. Detail showing mounting of the collector array temperature sensor should be provided. The sensor should show either mounting in the upper manifold piping between two collectors or should show mounting by the manufacturer directly to the absorber plate.
- Building piping penetrations. Design of piping penetration is weather tight and will withstand temperature expansion variations from 350 degrees F (177 degrees C) to the design low temperature of the project location.
- Pipe support. Pipe support design allows for temperature expansion variations from 350 degrees F (177 degrees C) to the design low temperature of the project location.

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APPENDIX E SOLAR PHOTOVOLTAIC TECHNOLOGIES

E-1 TECHNOLOGY.

This appendix identifies various solar PV technology alternatives and their main differences, to help the designer select the technology most appropriate for the project.

E-2 CRYSTALLINE SILICON.

Crystalline silicon PV is the most widely used to date with an approximate market share of 85%. There are two types of crystalline silicon: mono-crystalline and poly-crystalline.

E-2.1 Mono-Crystalline Silicon.

Most PV cells are mono-crystalline type. Silicon is purified, melted, and crystallized into ingots, which are then sliced into thin wafers or individual cells. The cells have a uniform color, usually blue or black and all cells in a module are cut from the same silicon ingot. Mono-crystalline possesses the highest conversion efficiency of approximately 18% and are more expensive than poly-crystalline silicon.

E-2.2 Poly-Crystalline Silicon.

Poly-crystalline silicon PV cells are manufactured and operated similar to the mono-crystalline type. The main difference is the usage of silicon that is of lower cost and quality, which results in a conversion efficiency lower than mono-crystalline, of approximately 14%. The surface of poly-crystalline cells has random patterns of crystal borders due to cells in the module cut from different ingots.

E-3 RIBBON SHEET SILICON.

Ribbon sheet cells are produced by growing a ribbon from molten silicon. These cells operate the same manner as mono- and poly-crystalline cells. The surface of these cells is coated with an anti-reflective material giving off a prismatic rainbow appearance.

E-4 THIN FILM.

Thin film technology emerged through successful efforts to reduce the amount of silicon per watt of PV energy generation and to improve the efficiency of cells manufactured when compared to crystalline silicon. Thin film technology is generally classified into three major categories: Amorphous silicon (a-Si), Cadmium Telluride (CdTe), and Copper Indium (Gallium) (di)Selenide (CIS/CIGS).

E-4.1 Amorphous Silicon Film.

Amorphous silicon cells have no particular shape and are deposited on a variety of substrates. Despite having a low conversion efficiency of 6-8%, the cells possess a reliable output in low-light conditions.

E-4.2 Cadmium Telluride Film.

Cadmium Telluride cells are formed from depositing four layers of material onto transparent glass as a substrate. This technology is manufactured at a relatively low cost with a production of 9-10% conversion efficiency.

E-4.3 Copper Indium (Gallium) (di) Selenide Film.

Copper Indium (Gallium) (di) Selenide (CIGS) film has the highest efficiency among thin film technologies. CIGS cells utilize either a rigid or flexible substrate coated with multiple layers of materials with an antireflective coating. Typical conversion efficiency is approximately 10-12%.

E-5 PROS-CONS: PV TECHNOLOGIES AND APPLICATIONS.

Refer to the Table E-1 for guidance on how to select the most appropriate PV technology.

Table E-1 PV Technologies Pros and Cons

Technology/Application	Pros	Cons
Mono-Crystalline Silicon	Crystalline silicon is more widely-used, proven technology. Highest conversion efficiency. Non-toxic to the environment.	Considerably more expensive than poly-crystalline at only marginally higher conversion efficiency.
Poly-Crystalline Silicon	Crystalline silicon is more widely-used, proven technology. More affordable than mono-crystalline. Non-toxic to the environment.	Lower conversion efficiency than mono-crystalline due to overall lower-quality silicon.
Ribbon Sheet Silicon	Manufacturing process yields less waste, more environmentally-friendly. Conversion efficiency similar to poly-crystalline.	Few vendors. Manufacturing method yields inconsistent thickness, yields conversion efficiency similar or worse than poly-crystalline.
Thin Film	Lower weight than crystalline silicon. Better wind resistance. Durable to foot traffic. Versatile. Affordable modules. Withstands high heat. Can use indirect light.	Much worse conversion efficiency and quicker performance degradation than crystalline silicon. Contains toxic materials.

Amorphous Silicon Film	Affordable modules. Flexible. Withstands high heat and partial shading.	Much worse conversion efficiency and quicker performance degradation than crystalline silicon.
Cadmium Telluride Film	Layered design allows module to capture more of the sunlight spectrum for more energy generation.	Cadmium is an exotic metal and toxic substance that may pose problems at the end of the life-cycle for disposal. Few vendors. Less efficient and more expensive than crystalline-silicon.
Copper Indium (Gallium) (di)Selenide Film	Layered design allows module to capture more of the sunlight spectrum for more energy generation.	Cadmium is an exotic metal and toxic substance that may pose problems at the end of the life-cycle for disposal. More difficult to manufacture than Cadmium Telluride. Few vendors. Less efficient and more expensive than crystalline-silicon.
BIPV [roof (i.e. solar shingles), façade]	Architecturally blends into structure, more aesthetically pleasing. Covers maximum surface area for more energy generation. Building itself is support structure.	Much worse conversion efficiency and quicker performance degradation than crystalline silicon. Difficult to repair and replace due to components beneath roof membrane.
BAPV	Architecturally blends into structure, more aesthetically pleasing. Covers more surface area for more energy generation. Building itself is support structure.	Much worse conversion efficiency and quicker performance degradation than crystalline silicon. Difficult to repair and replace.

E-6 PROS-CONS: PV TRACKING ARRAYS

E-6.1 PV Tracking Array Pros:

- Captures more solar irradiance energy than fixed-tilt arrays, increasing system output by up to 50% in the summer and 20% in the winter.

- Passive designs do not consume additional energy.

E-6.2 PV Tracking Array Cons:

- More expensive upfront than fixed-tilt arrays by up to 25%.
- Motorized designs consume energy for tracking mechanism to operate.
- Moving parts and more complicated design than fixed-tilt arrays.
- Heavier than fixed-tilt arrays.
- Higher maintenance costs than fixed-tilt arrays.
- A failed tracking mechanism can leave the array at an angle where it collects almost no sun.

APPENDIX F EXAMPLE SOLAR PV DRAWINGS AND SCHEDULE CHECKLIST

F-1 PURPOSE.

The drawings and schedule checklist provides the solar PV system designer, project manager, and quality assurance personnel with a list of those items that are called out by the guide specification to appear on the drawings, or are strongly suggested based on experience with solar PV system design problems. The designer is encouraged to annotate the drawings to ensure that design changes are properly accounted for, to provide a record of system settings and performance criteria, and to ensure that important details are not overlooked during construction. The following items should be included as part of the system drawings and schedule.

F-2 SUGGESTED DRAWINGS AND SCHEDULE.

F-2.1 PV Array Layout (No Scale).

The PV array layout will be in accordance with the guidance defined in Chapter 3. As a minimum define the layout, number of modules, string sizes, rows (if applicable), and required balance of system components. Coordinate with site plan to anticipate any future structures or vegetation (trees) that could block future solar access.

F-2.2 System Schedule.

The job specific system schedule includes the following:

- Note the module parameters around which the system was designed:
  - Module technology.
  - Module tilt and azimuth angle.
  - Racking type.
- Note the following system parameters:
  - System wattage and voltage.

F-2.3 Roof Plan (To Scale).

- Module groupings in strings and rows as designed.
- Minimum row spacing shown and noted.
- Orientation with respect to due south shown and noted.
- Tilt angle.
- Combiner boxes shown and noted.
- Rooftop mounted equipment, vents, and system penetrations shown and noted.
- Rooftop conduit shown and noted.
- Walkway, catwalk, or other array access shown and noted.

F-2.4 System Elevation.

- Required module tilt angle shown and noted.
- Conduit run shown between equipment room and roof.
- Array support structure shown.
    - Collector mounting to support detail at tilt shown.
    - Support mounting to roof detail shown.
    - Structure with hardware noted.
    - Design loads noted.
- Walkway, catwalk, or other array access shown and noted.

F-2.5 Equipment Area Layout.

- Inverters, disconnects, conduits, meters, main panel, and any subpanels shown.
- Access is available to all equipment by maintenance personnel for repair, replacement, or monitoring.
- Adequate working and personnel safety clearance distances must be indicated on the plans.

F-2.6 Additional Schedules and Instructions.

- Schedule of operation. The operating characteristics of the system should be indicated.
- Schedule of labels.