



*ACTIVE SOLAR
HEATING
SYSTEMS
DESIGN MANUAL*



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**American Society of Heating, Refrigerating,
and Air-Conditioning Engineers, Inc.**

in cooperation with

Solar Energy Industries Association

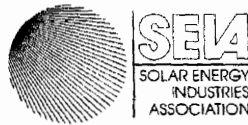
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PREFACE

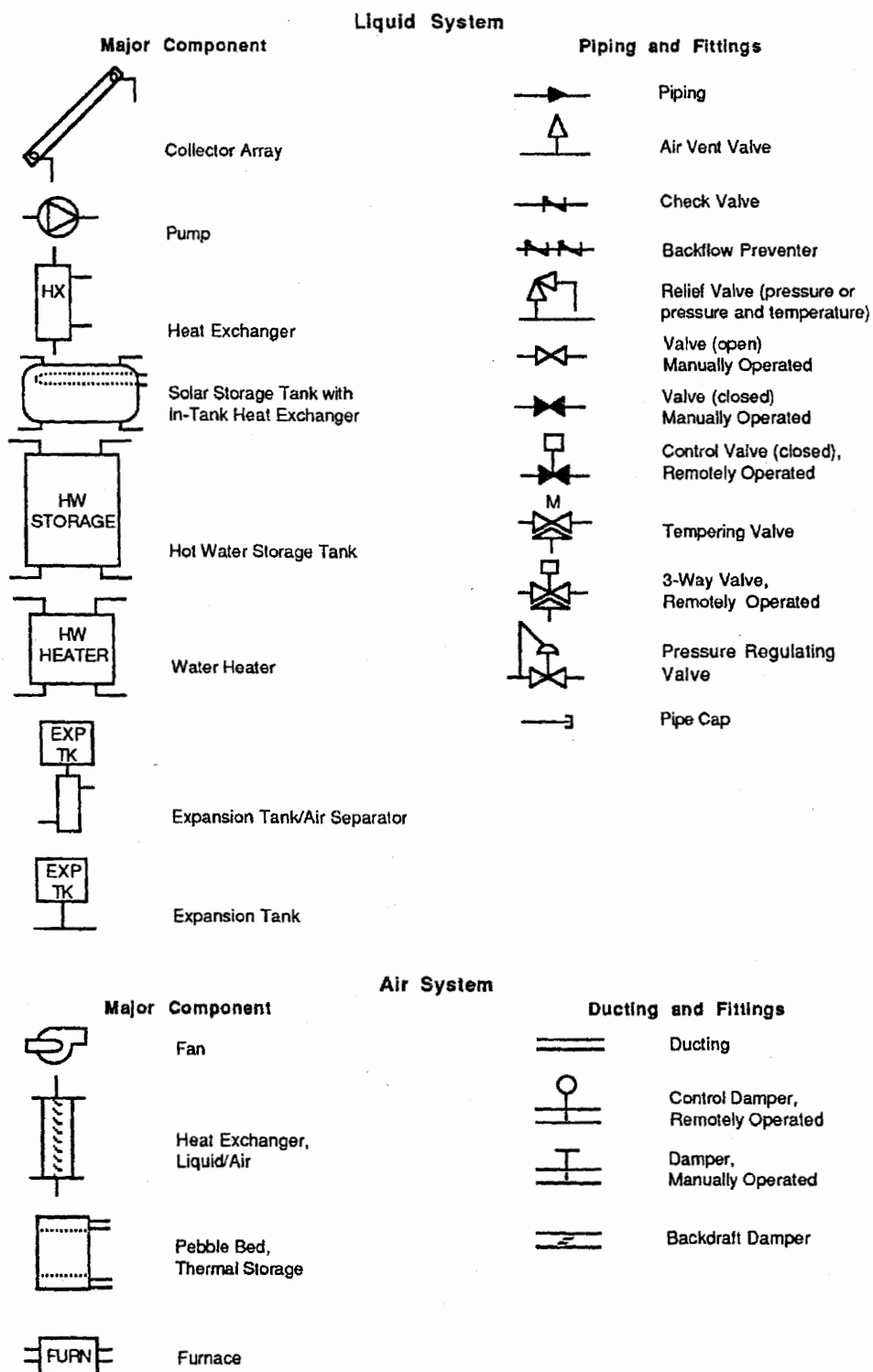
This Active Solar Heating Systems Design Manual for large commercial-scale service hot water and space heating solar energy systems represents two years of cooperative effort by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the Solar Energy Industries Association (SEIA), the American Consulting Engineers Council (ACEC), academia and Department of Energy (DOE) contractors. The challenge of creating a single design manual to satisfy the specific needs of solar designers for a variety of locations, applications and system types called on the talent and experience of specialists in many different areas.

It is Industry's responsibility to design, build and maintain state-of-the-art solar energy systems that satisfy a wide variety of markets and requirements. The Department of Energy has assumed the role of supporting Industry in the development of the technology base for advancement of solar energy systems that would accelerate their acceptance in the marketplace. During preparation of this manual, great effort was spent to distill information from sources with widely varied experiences and to translate it into a usable format that represents this collective knowledge base.

This manual is more than design information in another form. It is a design process which together with the companion Installation, Operation and Maintenance Manual represents a comprehensive coverage of the major elements that will significantly enhance the success of solar applications in buildings.
























The Active Solar Heating Systems Design Manual was developed to give solar designers an effective means to use the collective knowledge of government and industry to better select options, from among the many now available, for improving the quality and energy efficiency of solar systems they design and build.

Legend for Design Manual Figures



Legend for Design Manual Figures (continued)

Controls and Instrumentation

	Differential Temperature Controller		Thermostat Switch (normally closed, open on temperature rise/fall)
	Control Relay Coil		Thermostat Switch (normally open, closes on temperature rise/fall)
	Time Delay Relay Coil		Delay ON Relay (normally closed; timing starts after coil is energized and contact opens at end of period)
	Valve Control Relay Coil		Delay OFF Relay (normally closed; opens when energized timing starts after coil is de-energized and contact closes at end of period)
	Damper Control Relay Coil		Flow Switch (normally open, closes when required flow is established)
	Motor Control Relay Coil		Double Acting Thermostat Switch
	Heater Control Relay Coil		Control Relay Contact (normally open; closes when energized)
	Temperature Gauge		Motor Control Relay Contact (normally open; closes when energized)
	Pressure Gauge		Control Relay Contact (normally closed; opens when energized)
	Pressure/Temperature Port (P/T Plug or "Pete's Plug")		Motor Control Relay Contact (normally closed; opens when energized)
	Flowmeter		Overload Contact (normally closed)
			Pilot Light, Light ON signifies output

Abbreviations and Acronyms for Design Manual

°C	Degree Celsius	U	Overall Heat Transfer Coefficient
°F	Degree Fahrenheit	UA	Overall Heat Transfer Coefficient (for specific area or device)
I-P	Inch-Pound	R	Thermal Resistance Rating (for thermal insulation)
SI	Systeme International	UV	Ultra Violet
Btu	British Thermal Unit	Vac	Voltage-Alternating Current
hp	Horsepower	elev	Elevation
k	Kilo	horiz	Horizontal
M	Mega	FC	Fail Close (close on loss of power)
J	Joule	FO	Fail Open (open on loss of power)
W	Watt	ETC	Evacuated Tube Collector
h	Hour	HX	Heat Exchanger
s	Second	Max	Maximum
yr	Year	Min	Minimum
ft	Foot	NC	Normally Closed
in.	Inch	NO	Normally Open
mm	Millimeter	DP	Double Pole
m	Meter	ST	Single Throw
mph	Miles Per Hour	DT	Double Throw
Pa	Pascal	DHW	Domestic Hot Water
g	Gram	SHW	Service Hot Water
lb	Pound	IPH	Industrial Process Heat
psig	Pounds Per Square Inch Gauge	TC	Cold Temperature Sensor
psi	Pound Per Square Inch	TH	Hot Temperature Sensor
WG	Water Gauge	RTD	Resistance Temperature Detector
cfm	Cubic Feet Per Minute	T Stat	Thermostat
gal	Gallon	DAS	Data Acquisition System
gpm	Gallons Per Minute	PRV	Pressure Relief Valve
L	Liter	NPSH	Net Pump Suction Head
Dia	Diameter	P & ID	Piping and Instrumentation Diagram
ppm	Parts Per Million	SDD	System Design Description
TDS	Total Dissolved Solids	SH	Space Heat
% RH	Percent Relative Humidity	EPDM	Ethylene Propylene Diene Monomer
N/S or N-S	North/South	PVC	Polyvinyl Chloride
E/W or E-W	East/West		
A/E	Architect/Engineer		

Abbreviations and Acronyms for Design Manual
(continued)

Organizations

ACEC	American Consulting Engineers' Council
ACI	American Concrete Institute
ANSI	American National Standards Institute, Inc.
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
AWS	American Welding Society
BOCAI	Building Officials and Code Administrators International
DOE	U.S. Department of Energy
ETEC	Energy Technology Engineering Center
IAPMO	International Association of Plumbing and Mechanical Officials
MSS	Manufacturers Standardization Society of the Valve and Fittings Industry
NBS	U.S. Bureau of Standards
NWS	National Weather Service
SEIA	Solar Energy Industries Association
SFBP	Solar In Federal Buildings Program
SMACNA	Sheet Metal and Air-Conditioning Contractors' National Association
SRCC	Solar Rating and Certification Corporation
TVA	Tennessee Valley Authority

EXECUTIVE SUMMARY

PURPOSE

This manual was prepared to provide architects/engineers (A/Es) of large active solar heating systems with the best available design information for large commercial-scale solar service water and space heating systems. It incorporates experience from the solar industry and from government-sponsored programs that have demonstrated and advanced the technology of active solar heating systems.

The manual is not a “stand-alone” document. The manual draws on information from both industry and government sources. It requires the use of referenced documents to address basic engineering and design practices. Addition or removal of information to adapt the manual to the individual needs of the architect/engineer is left for the user to do.

The manual is to be used by the A/Es of active solar heating systems from concept development through final design. Solar insolation calculations and system configurations are included for experienced A/Es of conventional heating systems who may not have a working knowledge of solar energy systems. The manual may also be used by a prospective owner to follow the progress of solar energy system design, from concept through final design. After the system is built, the manual’s design package will provide a record of how and why certain design decisions were made, for reference during future repair or modification.

Finally, the manual provides information for preparation of system installation, operation and maintenance procedures. The companion volume to this design manual, Installation, Operation and Maintenance (IOM) Manual, should be used during preparation of the IOM procedures for the as-built solar energy system.

SCOPE

The manual is for use in designing commercial and industrial solar energy systems for service water heating and space heating. The systems described in this manual have been demonstrated to be dependable and efficient to operate. The systems are limited to those using flat plate or evacuated tube collectors, liquid or air cooled, and requiring solar storage of at least 1000 gal (3,800 L) of water or equivalent or a collector field of at least 700 ft² (65 m²). The systems’ highest operating temperature is that temperature recommended by the collector manufacturer.

The systems may also be considered for future use in seasonal storage projects when this concept has been proven for use. The high temperature range of these systems will be suitable for solar space cooling applications when the cost-effectiveness of this application has been improved. The stored solar energy of these systems can be used in existing heat pump systems. The integration of these solar energy systems with heat pump systems is not covered in this manual. All of these systems will add to the overall energy efficiency of a building that has used passive solar design techniques to reduce the base energy level needed for space and water heating.

SYSTEM CONFIGURATION

The manual presents optimized liquid collector system configurations for three freeze protection modes and an optimized air collector system configuration. The drainback design using water in the solar collector loop is suitable for heating service water at any site where the collectors can be mounted high enough above the drainback tank to ensure positive, complete draining. When drainback is not possible, a design using antifreeze in the solar collector loop (typically, 50/50 propylene glycol/water) can be used. Finally, for mild climates with minimum freeze potential, the simple recirculation design is recommended. Space heating projects that require a large percentage of fresh air for ventilation are served by the air collector system design.

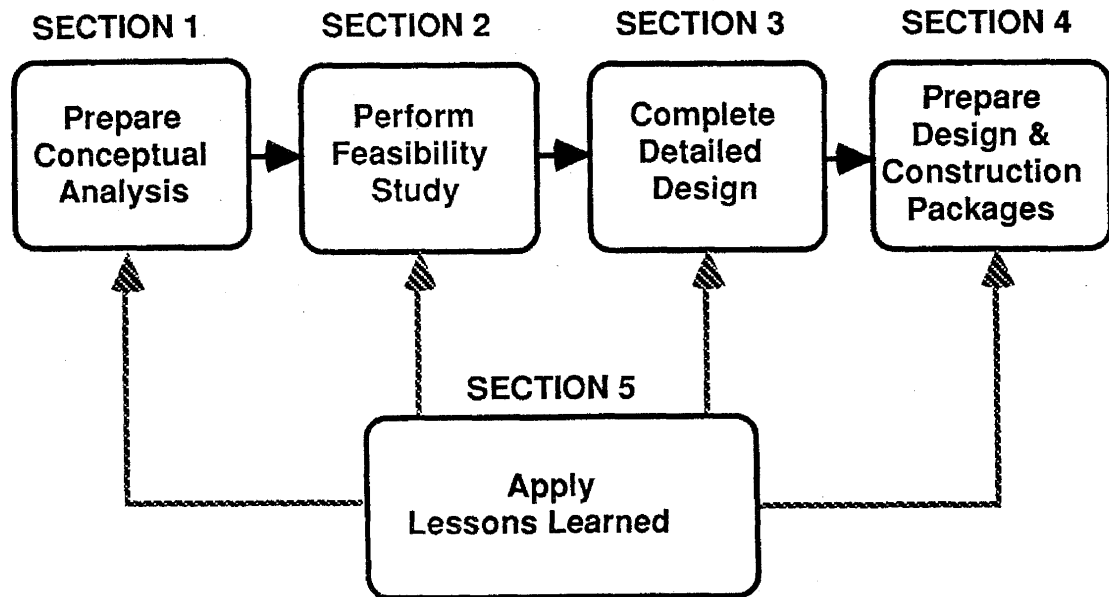
The systems to be designed by following this manual are most effective when used for low temperature heating of water or air; i.e., heating service water for large volume residential use, for commercial buildings, or for industrial processes that can use water up to 180°F (82°C). Preheating of fresh air for space heating a large building is also an efficient use of solar energy.

These systems are also most effective for loads that use the collected solar energy steadily during the day as it is collected so that little solar heat has to be stored for later use, minimizing or eliminating the need for storage.

DESIGN PROCESS

The manual consists of four interrelated sections that encompass the design process; i.e., Conceptual Analysis, Feasibility Study, Detailed Design, and Design and Construction Packages, and a fifth section, Lessons Learned, that lists common problems and solutions for solar energy system designs.

A\Es may use all sections in designing a project or may select only those specific sections needed, depending on their experience, and size and complexity of the proposed solar energy system.



Conceptual Analysis — This is a simple analysis to determine whether a full feasibility study is warranted. This analysis involves simple evaluations based on rules of thumb, charts, and typical performance results from existing systems. This analysis allows for the determination of the type of solar energy system to be used, a rough estimate of the load, and where the collectors could be placed; size of collector field and system cost are estimated. The results are summarized in a conceptual analysis summary.

If this study shows reasonable cost-effectiveness, the design process proceeds to the feasibility study.

Feasibility Study — This study estimates the cost-effectiveness of the proposed project. The first subsection presents procedures for determining the site data needed to design the system: energy conservation measures, sizing and timing of the heating loads to be satisfied, site and building characteristics, interface with existing heating systems, and selection of system configuration.

The second subsection presents procedures for sizing the collector field, estimating the system cost, and determining system cost-effectiveness. The results of this section are summarized in a solar energy system design description.

If this study shows that the solar energy system will be cost-effective, the design process proceeds to detailed system design. At this point, a contractual commitment for the design effort may be made.

Detailed Design — The first step in detailed design is to verify the design requirements and collector field sizing from the feasibility study. A system schematic (or piping/instrumentation drawing) is prepared to establish the optimum system configuration. Collector and storage subsystems design can then proceed in parallel with the electrical, instrumentation, and control design. Design review at 40% of the task completion confirms that the system configuration is still optimum or directs an iteration to improve the fit with the project's goals. A final design review at 90 to 100% of task completion confirms that the design details are correct and complete. A final check of collector performance calculations is made to account for any design changes that were made, and a firm final cost estimate is prepared.

Output from the detailed design includes system performance calculations; economic evaluation; piping, structural, mechanical, thermal, and other design analyses; subsystem drawings; and component requirements.

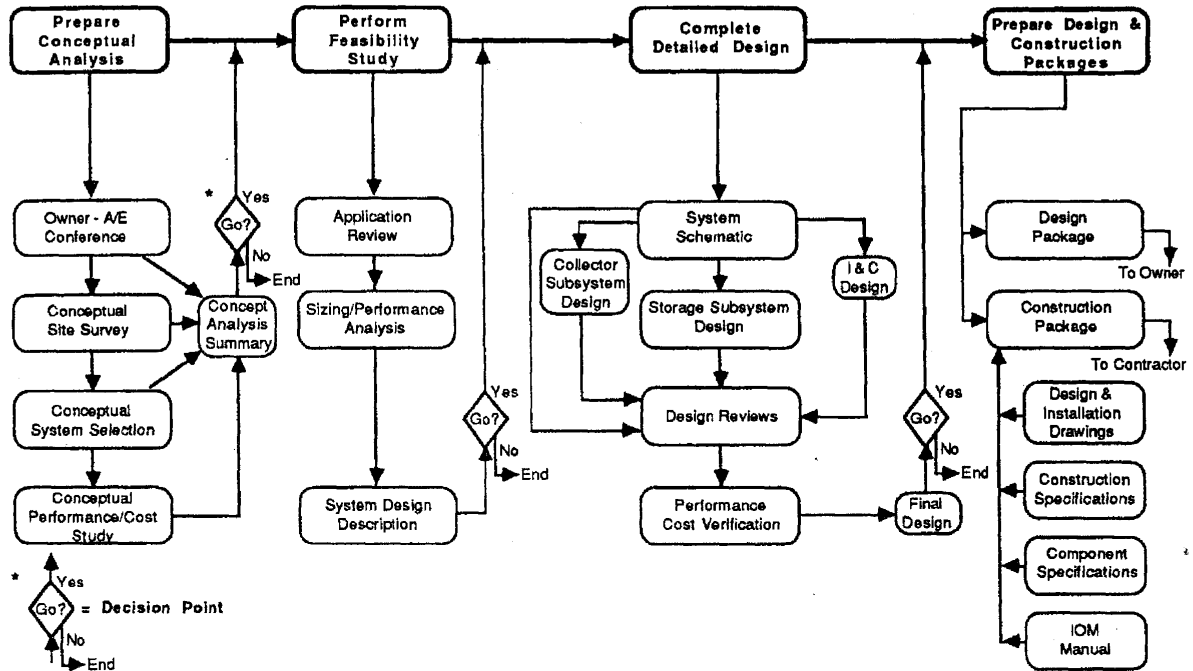
Design and Construction Packages — The design analyses, design and installation drawings, cost estimate, economic evaluation, and the solar energy system design description generated in Section 3 are compiled into a design package. The construction package includes all design and installation drawings, component specifications, and construction specifications. It is ready for construction bids when bidding procedures are added.

Lessons Learned — Problems commonly found in solar energy system design, potential effects of these problems, and ways to avoid them are presented. Problems found in construction and operation, caused by design mistakes, are described and solutions explained.

This section provides a quick reference by specific component for design problems commonly found that must be avoided; these lessons have been incorporated in the manual's design procedures. Review of this section can prevent the inadvertent inclusion of a design procedure that has been shown by accumulated field experience to be dysfunctional.

The sketch that follows illustrates the flow of work in the design process, as it is presented in the manual, with the major work packages and decision points identified.

SOLAR SYSTEM DESIGN PROCESS



An example of the design of a solar energy service water heating system following this design process is included as "Example System Design" and follows Section 5 of this manual.