SOLAR DOMESTIC AND SERVICE HOT WATER MANUAL

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FOREWORD

This manual is intended to stimulate solar utilization by providing system designers and installers with the information necessary to design solar domestic and service hot water heating systems that are technologically correct and cost-effective. These solar systems are the most frequently installed, readily available, and easily understood of today's solar applications. This manual will demonstrate that stand-alone solar domestic and service water-heating systems, systems that do not provide space heating, are practical today for most parts of this country. Domestic water is primarily for human use, i.e., food preparation, personal hygiene, and washing (clothing, dishes, etc.). Service water is primarily for industrial uses. This manual is limited to applications that require a water temperature no higher than 180°F (82°C).

This manual is intended to (1) provide a concise how-to approach to making systems work and (2) to be used as a comprehensive design/installation tool. Additionally, it will enhance the reader's knowledge of the design, cost estimation, installation, and operation of various solar water-heating systems. Several system types and related components will be discussed, along with ways of combining them in the most economical manner based on hot water (load) requirements, climate, and building configuration. Methods will be introduced for load determination, equipment selection, and system performance estimation. Discussion of system start-up, operation, and maintenance procedures will be included, with the intention of improving system performance and dependability. The reader will be informed of common pitfalls and problems, along with suggested ways to eliminate or minimize them.

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NOMENCLATURE

A	Total gross area of collectors
CRF	Capital recovery factor
C_c	Fluid capacity rate of cold fluid
C_h	Fluid capacity rate of hot fluid
C_{min}	The lesser value of C_h and C_c
C_p	Specific gravity
E	Overall system efficiency
E_r	Energy rate
F	Annual solar fraction
$F_R'U_L$	Collector parameter (considers system heat losses)
$F_R'(\overline{\tau\alpha})$	Collector parameter (considers transmittance and absorbance properties)
i	Interest
I	Average solar radiation intensity
I	Solar radiation striking the collector
j	Cost escalation
K	A correction factor that is used with the Δt_{la} that would be computed for an equivalent counterflow heat exchanger
K	Location factor
l	Daily load, energy required to supply hot water
L	Annual load
m	Mass flow rate
n	Mortgage term
O_w	Owning cost
P	Pump
PB	Payback
PW	Present worth
PWEF	Present worth escalation factor

q	Actual heat-transfer rate
q	Daily hot water usage
q_{max}	Maximum possible heat-transfer rate
Q	Estimated daily hot water consumption
Q_a	Annual energy usage
s	Salvage value
S	Sensor
S	Storage capacity
t_a	Ambient temperature
t_{ci}	Cold fluid inlet temperature
t_{co}	Cold fluid outlet temperature
t_{hi}	Hot fluid inlet temperature
t_{ho}	Hot fluid outlet temperature
t_i	Temperature of the fluid at the collector inlet
Δt_m	Log mean temperature difference
Δt	Temperature differential
T	Controller
T_C	Cold water temperature
T_H	Hot water temperature
T_i	Cold water supply temperature at system inlet
T_s	Hot water supply temperature at system outlet
U	Overall heat-transfer coefficient of heat exchanger
V	Valve

α	Absorptance
ε_{cs}	Collector/storage heat exchanger effectiveness
ϵ	Heat exchanger effectiveness
η	Collector efficiency
τ	Transmittance
θ	Incident angle

SYMBOLS


Shut-off valve


Automatic valve


Balancing valve


Check valve


Pump



Running-time meter


Air vent


Pressure-relief valve


Temperature and pressure-relief valve


Tempering valve


Pressure gauge


Vacuum breaker


Finned coil


Sensor


Thermometer



Differential temperature controller


Drain


Expansion tank with air eliminator

INTRODUCTION

One of the oldest and simplest domestic uses of solar energy is the heating of water. This manual has been compiled to disseminate information regarding the design and operation of solar domestic and service hot water heating systems. This manual is intended (1) to provide the reader with technologically correct methodologies for designing solar systems, specifically for heating domestic and service water, and (2) to provide methods for determining the economic merits of these systems.

Solar hot water heating systems have been in use in the United States for more than 75 years, first in southern California and then in southern Florida. Prior to the rural electrification programs of the 1940s, thousands of systems were in use. In 1951 it was estimated there were 50,000 solar water heaters in the city of Miami. The use of solar water-heating systems in the United States has declined during the last 40 years because of the availability of inexpensive electricity and fossil fuel.

Use of solar water-heating systems was often limited to areas with infrequent freezing and with greater solar radiation available. However, solar water-heating systems are becoming attractive alternatives to conventional systems in many regions of this country, primarily because of increased fuel costs and technological advances involving more efficient system components and more effective controls and freeze protection.

In 1973 the total gross energy consumption of the United States was 74.7 quadrillion Btu (see Fig. 1.1).

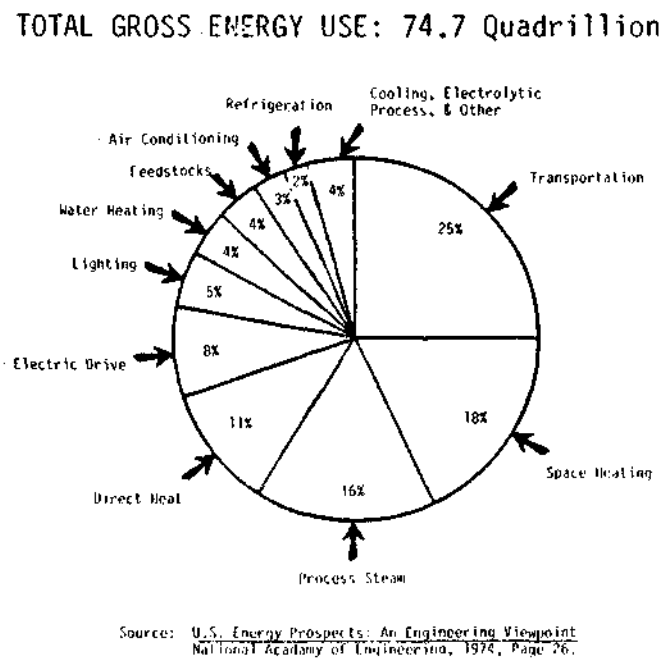


Figure 1.1. U.S. Gross Energy End Uses, 1973

It was estimated that four percent, or three quadrillion Btu, of this energy was used for water heating. This is roughly equivalent to 1.5 million barrels of petroleum per day for a year. A large portion of the indicated consumption involved heating water to 180°F (82°C) or less. Even a reduction of one percent in the energy used for water heating would result in a substantial fuel savings.

Objectives

Utilization of solar energy involves some considerations that are unique to solar water-heating systems, but the majority of design factors are the same as for conventional systems. The primary difference between solar and conventional water-heating systems is that solar systems exaggerate the limits of certain operational parameters, such as the size of storage tanks and the temperature of water. As a result, solar systems generally require greater attention to detail during the design, installation, and operational phases. Determining the feasibility of a solar domestic and service hot water system requires close examination of user needs, site requirements, climatic and solar conditions, system performance characteristics, and economic factors.

1. The user's needs must first be determined so that all system components can be sized to handle anticipated requirements, i.e., the amount of water at the desired temperature. Systems with a water temperature upper limit of 180°F (82°C) are addressed specifically in this manual.

2. Site characteristics, including building orientation, collector location, and activities or objects on adjacent sites that may block sunlight, must be considered. These matters are discussed and recommendations made.

3. Climate is discussed, as it relates to freezing conditions and the availability of solar radiation, along with ways to calculate the quantity of energy that can feasibly be used.

4. Various solar water-heating systems are described, along with their advantages and disadvantages. System components are discussed and methods introduced for integrating them with other parts of the system.

Methodologies for determining the economics of solar water-heating systems are presented. A short method predicts a simple payback, which is that point in time when annual savings will offset the increased capital expenditure of a solar system as compared to a nonsolar system. Another more detailed method considers interest rates and energy escalation rates and determines the present value of savings when calculating the payback period. A procedure for determining the additional monthly payment required when the cost of the solar system is financed by a loan or a mortgage is also included.

SYSTEMS

Solar water heaters are basically only slightly different from the conventional residential water heaters with which most design engineers are familiar. It is the heat source that makes them unique: a solar collector array that absorbs solar radiation (insolation) and converts it to usable heat. This heat is then absorbed by a heat-transfer fluid (water, a nonfreezing liquid, or air) that passes through the collector. The heat-transfer fluid's heat can be stored for later use or may be used directly. Since portions of the solar system are exposed to the weather, they must be protected from freezing; freeze protection is discussed for each type of system in the following sections. The systems must also be protected from overheating due to high insolation levels during periods of low energy demand, and overtemperature protection also is discussed.

In solar water-heating systems, water is heated directly or indirectly. In direct water-heating systems, the heat-transfer fluid (potable water) that is used for domestic and service hot water needs is heated directly in the collector. In indirect water-heating systems, the heat-transfer fluid heated in the collector passes through a heat exchanger and transfers its heat to the domestic or service water.

The heat-transfer fluid is transported by either natural or forced circulation. Natural circulation occurs by natural convection and gravity, or thermosiphoning, discussed in the next section. Forced circulation is accomplished by the use of pumps (to circulate liquid) or fans (to circulate air), which is also explained.

The most common system types are described, and the various system components are introduced in this chapter and discussed in the next chapter.

THERMOSIPHON SYSTEM

System Description

Thermosiphon systems are direct water-heating systems. Domestic or service water is heated directly in the collector, and water is circulated by means of natural convection and gravity; mechanical energy is not required. Thermosiphon systems are simple, relatively inexpensive, and applicable in climates where freezing is infrequent or for summer-only use. They are impractical in freezing climates and are not recommended.

Aside from the freezing problem, the greatest disadvantage of this type of system is that the storage tank must be elevated above the collectors. This sometimes requires placing a heavy water tank on an upper floor or in an attic space, and upper-level floor joists and ceiling joists may not be designed to bear such weight.

Another disadvantage of this type of system is scale deposits. In areas where water is extremely hard or acidic, scale deposits may quickly clog the absorber fluid passages, and/or corrosion may render a system inoperable.

Since this type of system is exposed to city water pressures, it must be assembled to withstand test pressures as required by local code. Pressure-reducing valves and pressure-relief valves are required when city