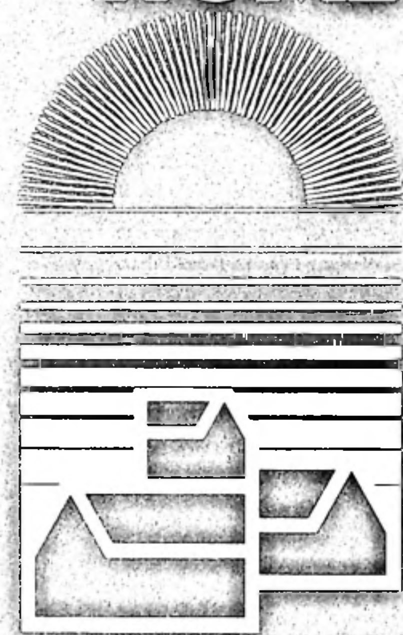
BUILDING THE SOLAR HOME



Some early lessons learned.

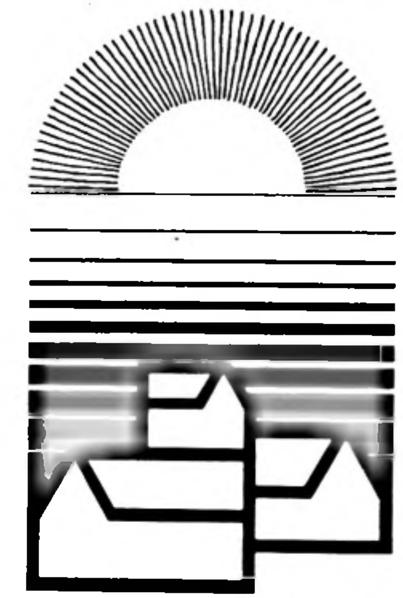
#2

Residential Solar Program Report

Published by the U.S. Department of Housing and Urban Development, Solar Demonstration Program, in cooperation with the U.S. Department of Energy.

U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

BUILDING THE SOLAR HOME



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Published by the U.S. Department of Housing and Urban Development, Solar Demonstration Program, in cooperation with the U.S. Department of Energy.

Prepared for Division of Energy, Building Technology and Standards, Office of Policy Development & Research, Department of Housing and Urban Development.

This report was prepared under contract to the U.S. Department of Housing and Urban Development by Dubin-Bloome Associates. The findings and conclusions are those of the contractor, and do not necessarily reflect the policy or views of the U.S. Department of Housing and Urban Development.

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OFFICE OF THE ASSISTANT SECRETARY
FOR POLICY DEVELOPMENT AND RESEARCH

IN REPLY REFER TO:

To the Solar Community:

The HUD Residential Solar Demonstration Program is an integral part of the national solar heating and cooling program under the direction of the Department of Energy. One of the key elements of the HUD program is the collection and dissemination of information on all aspects of residential solar applications.

Therefore, I am pleased to present the second technical report based on the demonstration program data: Building the Solar Home: Some Early Lessons Learned. Like the first report, Selling the Solar Home: Some Preliminary Findings, this report is the result of a limited number of demonstration projects in the first two cycles of HUD's five-cycle demonstration program.

A third report, Living in the Solar Home, will cover the experiences of some of the purchasers of demonstration homes. Each of the three reports in the series will be revised as additional units are constructed and more data become available.

While performance data from these projects are still quite limited, we have found that many builders, solar installers, and their individual workers have not really understood the problems that can occur due to the faulty installation of a solar system. I hope that the ideas and recommendations in this report will be very useful to the residential builder, the local installation contractor, and others in the building industry who are participating in the growing solar community.

Donna E. Shalala
Assistant Secretary

CONTENTS

Foreword

The U.S. Department of Housing and Urban Development, in cooperation with the U.S. Department of Energy, is administering the residential solar heating and cooling demonstration portion of the national program for solar heating and cooling of buildings. An important aspect of the program is HUD's continuing involvement with the demonstration projects. Once grants have been awarded, a number of contractors assist HUD in monitoring and supervising a wide range of technical and non-technical activities and in the collection and dissemination of information on the issues associated with the use of solar energy in residences.

Dubin-Bloome Associates (DBA), an energy engineering firm, and the American Institute of Architects Research Corporation (AIA/RC) are supplying technical assistance to HUD under the terms of their subcontracts with the Boeing Aerospace Company, HUD's Program Management Support Contractor. DBA and AIA/RC have reviewed the design of each project, have inspected the projects during installation and start-up, and have followed up with investigations of problems which were encountered.

Building the Solar Home reports their preliminary, subjective findings from the first two cycles of demonstration projects. These are not the results of rigorous scientific studies, but represent experiences in and inferences drawn from a limited number of solar applications. (See TABLE ONE for a summary of projects in Cycles 1 and 2.) They are based largely on the observations of technical field representatives and the review of final project designs.

As a result of these "on-site" analyses and discussions with the grantees, HUD's support contractors have targeted areas where problems have—or may—occur. In addition, they have identified positive steps which may be taken to overcome or avoid these problems altogether. Many of the problems, such as those related to system installation, are not unique to solar construction; others, such as those related to the manufacture and installation of collectors, represent new concerns for the industry. Finally, some are one of a kind and are included to illustrate the range of difficulties which were encountered.

Building the Solar Home is designed to provide practical guidelines for residential builders and developers who are considering solar energy projects and for the solar manufacturers, installers and distributors who service them. We hope these guidelines will assist the process of solar applications in future development.

A

Overview

Building the Solar Home: Some Early Lessons Learned examines, from the perspective of DBA and AIA/RC, the experiences of the first three years of the HUD Residential Solar Heating and Cooling Demonstration Program. This document summarizes common problems and highlights some unique experiences, but does not report in detail on individual projects.

With each cycle of HUD demonstrations there has been a marked decrease in difficulties encountered at all stages of residential solar utilization and a marked increase in proficiency. Calculations have been better prepared; system components have been redesigned and improved; and materials have undergone more thorough testing. The HUD program supports this advance in the state-of-the-industry by providing the opportunity to demonstrate new ideas, by the widespread dissemination of information, and by helping to identify the areas where additional technical effort and experience are required.

Still, significant areas remain in need of improvement. Three of these, which influence most solar applications, are a lack of information from manufacturers to builders and users, insufficient product quality control, and a need for skilled, experienced system installers. These are probably the most critical issues in good system performance; uncertainty about them has undoubtedly deterred potential users from entering the solar market.

As this is a new industry, actual experience with solar installations has demonstrated both good and bad procedures. **Building the Solar Home** documents a large number of critical points at which problems may occur and decisions must be made. An understanding of these points will go a long way to ensuring a successful solar experience.

The issues discussed in this report cover solar system calculations, design, components, and installation as well as the special concerns of passive systems. In addition, the roles of other housing industry participants are discussed to assist builders and developers in their relationships with them. **Building the Solar Home** is organized under the following headings:

CALCULATIONS

This section stresses the importance of accurate calculations based on good data on loads, weather conditions and equipment performance. Increasingly, computer models are being used in the design of solar energy systems.

THE MANUFACTURER'S ROLE

The relationship between a builder and his manufacturer takes on a special significance at this stage of solar application. Often manufacturers, designers, and builders are new to this segment of the housing industry and their cooperation can result in better products, better installation, and better system performance.

COLLECTORS

Many details are involved in the design and installation of collection systems: from the materials used, shipping procedures, connections, and servicing, among others. These details all require careful attention.

STORAGE

The importance of storage details such as size, placement, and expansion cannot be minimized. If energy is inefficiently or insufficiently stored, there may be little or none available on days when solar energy collection cannot take place.

HEAT TRANSFER FLUIDS

The properties of these fluids, such as toxicity and expansion, must be understood and analyzed to determine their effect on other system components and building materials.

OTHER SOLAR SYSTEM COMPONENTS

Piping, ductwork, pumps, valves, expansion tanks, heat exchangers and controls must be carefully selected and installed according to the special requirements and problems of residential solar energy systems.

PASSIVE SYSTEMS

In a passive system the structural elements of the dwelling are employed in the collection and storage of solar energy. They must provide details for dealing with internal and external temperature and climate variations. These details can range from complex insulating devices to relatively simple choices of interior surface materials.

RELATING THE COMPONENTS

An understanding of the interdependence of the components to each other and to the dwelling design is essential to the overall success of the solar system.

MAINTENANCE

The maintenance of the solar energy system is necessary to protect up-front costs associated with solar and to keep the system running efficiently.

GLOSSARY

The glossary is not intended to serve as a comprehensive guide to solar terminology. It does, however, define the terms used in this report in an effort to make it most useful to the reader.

A summary of grants can be found in the Appendix along with a table of operational problems encountered during system testing and early system use.

B

Calculations

A typical conventional residential heating system may often be sized by rule-of-thumb methods, but the design of a solar heating and cooling system requires complex calculations and considerable design time. Unlike the sizing of the conventional HVAC system, the sizing of a solar energy system is a major expense item with costs that are directly related to system capacity. Therefore, the design time spent on calculations represents a wise investment.

Thorough and accurate calculations of the residential load and system output enable the designer to select the appropriate system for the individual project. In the demonstration program, most builders received assistance from solar manufacturers and distributors in carrying out calculations. A number of architectural and engineering firms have developed or are developing expertise in solar system design.

An evaluation of the design reports filed with HUD's technical advisors shows that 53% of the designs for Cycle 1 paid inadequate attention to building load calculations. However, this percentage dropped to 21% in Cycle 2. As the chart below indicates, similar drops have also been noted on most other calculations:

SURVEY OF MAJOR TECHNICAL CONCERNS: CALCULATIONS

	CYCLE I*	CYCLE II*
Building Load Calculations	53%	21%
DHW Load Calculations	40%	11%
Weather (Solar) Data	2%	14%
Collector Efficiency	56%	9%
Collector Area	40%	5%
Collector Tilt and Orientation	26%	20%
Solar Calculations	52%	23%
Collector Shading	58%	12%

*Percentage of projects with insufficient building load calculations.

BUILDING LOAD CALCULATIONS

The calculation procedure begins with an analysis of the energy conservation capability of the building and some understanding of the life-style and comfort requirements of the probable occupants. (Frequent door openings, for example, definitely increase energy demands during the heating season. Will little children be running in and out? Will an elderly couple spend their time quietly indoors? Will a business be run from the home?) Other building load factors to account for include weather information, collector performance expectations, and system operational procedures.

WEATHER DATA

Several grantees found that local weather station data were not strictly applicable to their projects. One site, 40 miles from the nearest government weather monitoring station, recorded temperature variations of as much as 10°F from the station levels. As a result, the system design did not represent actual conditions.

All weather data should be examined critically. Officials in one city are re-evaluating their weather data because a significant difference in insolation was found as air quality **improved** and the amount of smog **decreased** from one area of the city to another.

COLLECTOR PERFORMANCE INFORMATION

Collector performance information has not been presented in a consistent format. Until approval of ASHRAE 93-77*, there was no standard procedure for testing collector performance, nor for reporting the results. Collector testing activities are becoming more rigorous and information is now being provided in the ASHRAE 93-77 format. However, solar system designers should still seek assurance that information from the manufacturer or distributor is accurate and is presented in a useful format.

The National Bureau of Standards' "round robin" test program has shown that small instrument calibration variations can have a significant impact on final test results. Because of this, designers should be concerned with testing procedures as well as final test results. With the advent of a new federally supported collector testing program and an industry operated collector certification program, more precise performance information will become available.

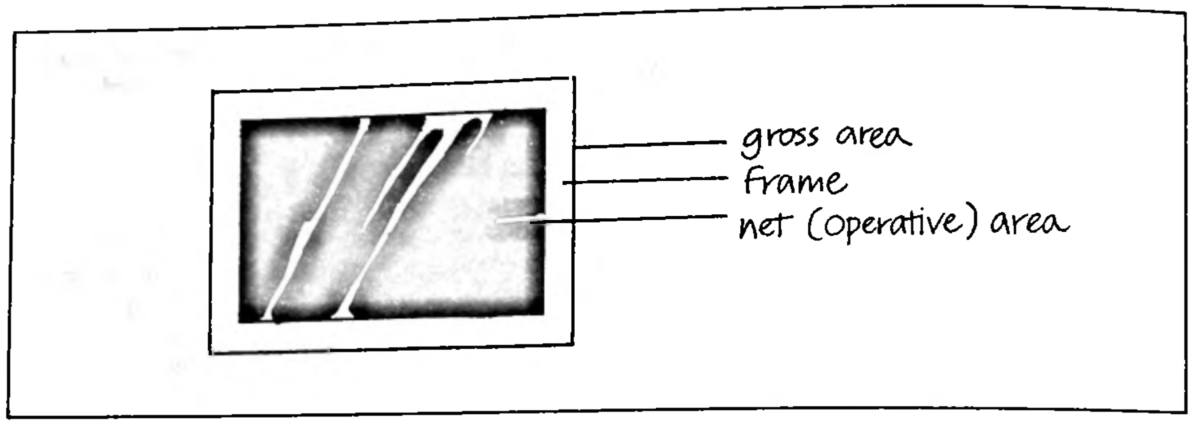
* The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has established the standard "Method Of Testing the Thermal Performance of Solar Collectors". These voluntary standards are the most widely accepted and are required by the U.S. Department of Housing and Urban Development for all collectors used in HUD grant projects. Copies may be obtained by writing to ASHRAE, 345 East 47th Street, New York, N.Y. 10017.

SYSTEM DESIGN CONSIDERATIONS

Prior to completing final system performance calculations, the designer must verify other information on collector design and structure, develop diagrams of system arrangement and flow, and establish a system control logic. Experience in the first two HUD demonstration cycles has identified several areas where these have influenced the final design:

COLLECTOR AREA

Since the amount of sunlight reaching the absorber plate is limited to the collector aperture, the designer needs to know the "net" or "operative" area. Many catalogs list only the "gross" collector area including the frame.



COLLECTOR ORIENTATION

Deviations of a few degrees from true South have a minimal effect on collector performance. Some demonstration project designers oriented homes on magnetic South, failing to take account of the magnetic deviation in their calculations. A solar system will work in an off-South orientation, but at the expense of reduced output based on the amount of deviation from true South. This may also result in additional expense for additional collectors.

COLLECTOR TILT

Similarly, collector tilt angles can differ from the optimum angles specified in design manuals only at the expense of reduced performance. Nevertheless, one Cycle 2 grantee determined that the additional collector cost was less than modifying his roof design to support the collector at an optimum tilt.

COLLECTOR SHADING

Site designs should allow only minimum shading of collectors. However, if shading is accepted as a result of specific site conditions, its impact on collector efficiency must be calculated. Remember that only the amount of direct insolation is affected in corrections for shading; the diffuse component of sunlight is not included in shading calculations.

STAGNATION TEMPERATURES

In the future, collector test results will provide results of stagnation tests with the collector exposed to direct sunlight without the flow of cooling transfer fluids. The designer must be sure that the collector can withstand the stagnation conditions expected at the site.

SYSTEM CONFIGURATIONS

Solar system performance is a function not only of the individual components and available sunshine, but also of the interaction between components. For example, the size and type of storage systems depend on the temperature at which they are expected to operate, collector area and output, and other system factors. Preliminary analyses should be made of several alternative configurations and sizes to select the one that is best for the specific project.

> **OPTIMUM SIZE**
>
> In conventional climate-control systems, an increase in system size and capacity does not increase the cost of the system at the same rate. As the size of a solar system increases, on the other hand, the energy collected increases proportionately, and, more important, the cost of the system also increases proportionately. Sizing a solar system to take care of the "worst case" situations can mean that the system is oversized for most of the year. *There is a theoretical "optimum" size for a solar system; a point where it does not pay to invest in another increment.*

CALCULATION PROCEDURES

After a decision is reached about the best system for the project it is necessary to carry out complete calculations. Most current solar system designs are being calculated using computer simulation models, backed up by the judgment of the designer. Rules of thumb for designing residential solar systems are inadequate.

RULES-OF-THUMB

In the past solar literature has provided rules-of-thumb for system sizing. Typically, it recommended that the collector area should be about 25% to 50% of the heated floor area and that one to two gallons of storage should be provided for each square foot of collector. In the first two HUD demonstration cycles, the actual designs varied widely from these specifications:

> **DESIGN RATIOS**
>
> **COLLECTOR AREA**
> RANGE: 0.11 sq. ft. collector/1 sq. ft. floor area to 0.42 sq. ft. collector/1 sq. ft. floor area.
> AVERAGE: 0.28 sq. ft./1 sq. ft. floor area.
>
> **LIQUID STORAGE CAPACITY**
> RANGE: 0.9 gal./1 sq. ft. collector to 6.2 gal./1 sq. ft. collector.
> AVERAGE: 2.0 gal/1 sq. ft. collector.
>
> **ROCK BIN CAPACITIES**
> RANGE: 0.41 cu. ft./1 sq. ft. collector to 1.9 cu. ft./1 sq. ft. collector.
> AVERAGE: 0.9 cu. ft./1 sq. ft. collector.

Variations in building design, energy demand, installation, use and climate interact dramatically to affect these figures. Given these variations, **rules-of-thumb should be used only in evaluating whether a system design is within reasonable limits.**

COMPUTER MODELS

The computer simulation models currently available have some limitations. Most are designed around specific system configurations, with limited flexibility for alternative applications. In using these models to design other system configurations, designers should perform sufficient manual calculations to ensure that the computer results are applicable to their project.

In addition, no current models effectively account for the operation of a solar-assisted heat pump. Projects involving such heat pumps or other non-standard system configurations require individual consideration and good judgment on the part of the designers.

Demonstration program data are expected to provide information to validate design procedures now being developed for heat pumps and similar non-standard systems. In the meantime, the builder or developer should review the design approach being used with the system designer to be certain that the resulting design is appropriate for the project.

C

The Manufacturer's Role

Historically, a builder looks to his manufacturer's representative for technical assistance in using or deciding to use the manufacturer's product. The representative is expected to know the good points and the limitations of the product and to advise the builder of installation requirements. A good representative can also provide the designer and builder with a channel for communicating their needs to the manufacturer.

There is some evidence from the solar demonstration program that this relationship has not yet taken shape within the solar industry. In some cases, factories have sent over-qualified engineers who did not speak the language of the "mechanic," or sales-oriented field representatives who did not have the necessary technical training or interest.

The following points are useful to keep in mind when dealing with a manufacturer or his representative:

Manufacturers should be requested to provide all the technical documentation and information necessary for a successful design. Insufficient construction and installation details are detrimental to the design and frustrating to the contractor who needs to know how a product relates to other components of the solar system and how it may affect other building systems and materials.

Manufacturers may offer little assistance with installation. This can be due either to the lack of an extensive field organization or to a low level of capitalization.

Nevertheless, some solar manufacturers have provided free engineering services to builders. Experience indicates, however, that once they and the solar industry are established, they will begin to charge for these services. Relying on the manufacturer for engineering assistance may restrict the designer in using non-standard variations in a system design.

A number of manufacturers are both small and new to the HVAC (and solar) market. They are still learning industry procedures and contractual requirements. Often they are interested in becoming actively involved with a project which incorporates their product.

D

Collectors

The collector is the major new component used in solar energy systems. Much effort has gone into the study of collection systems and many earlier pitfalls can now be avoided. Of course, problems may still occur when materials are subjected to conditions for which they were not designed.

In this section the reader is alerted to four major problem areas: packing, shipping and delivery; construction (materials and design) and installation; summer overheat; and collector support structure. The extent to which builders faced problems in the latter three areas is shown in the table below:

SURVEY OF MAJOR TECHNICAL CONCERNS: COLLECTORS

	CYCLE I*	CYCLE II*
Collector Construction and Installation	21%	18%
Summer Overheat	95%	12%
Collector Support Structure	16%	20%

*Percentage of projects which had inadequate information

PACKING, SHIPPING, AND DELIVERY

PACKING AND SHIPPING PROCEDURES

Check with the manufacturer to find out what precautions his firm takes with its product. Great care must be taken in packing and shipping collectors. Although the situation is improving, breakage has been a problem.

In one incident a manufacturer shipped his collectors, immediately after testing, with the fluid still in them. Because he was behind in his delivery, the collectors were air freighted to their destination. At an altitude of 40,000 feet the fluid froze, breaking the collectors.

In another case, a manufacturer of glass tube collectors discovered that the glass tubes were vibrating and cracking in shipment. As a short-term solution, foam padding was placed behind each tube. As removal of the padding would have required disassembling the collectors, it was left in. At the high temperatures involved in operation this padding "outgassed." The collectors have since been redesigned to employ a thicker, heavier tube which resists breaking in shipment.

These examples point out the need for care in the production, testing, and transportation process.

DELIVERY TIME

Allow adequate time in your schedule for delivery as delivery guarantees are not always reliable and construction delays are costly. On the other hand, when collectors arrive too early, the contractor must solve the problem of where to store them to avoid breakage. Storing the collectors at the site can also lead to overheating and collector deterioration.

CONDITION ON ARRIVAL

Inspect each collector carefully upon delivery; on occasion parts have been missing or damaged. For example, the tubes manufactured for one evacuated tube collector had hair-line scratches that were almost invisible. These scratches, along with pressure and high operating temperature, caused some of the tubes to break.

CONSTRUCTION (MATERIALS AND DESIGN) AND INSTALLATION

DRAINAGE

Make sure that the design of liquid type collectors allows for them to be completely drained when necessary. Failure to do so may cause freeze-ups in the winter and boil-outs at stagnation temperatures. In one collector, flow was obstructed because the copper tubes were penetrating the header manifold too far.

The present design of some evacuated tube collectors can cause the collectors to become air-bound in the upper tubes, trapping liquid below. At stagnation, this liquid will turn to steam and might rupture some collector tubes.

VENTING

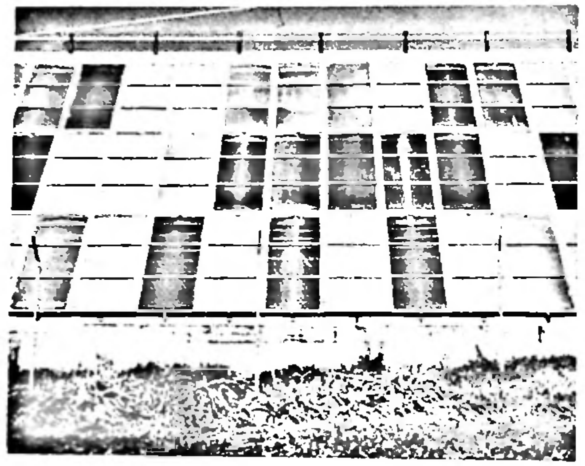
To prevent pressure build up and to permit condensation to escape, some collectors require venting devices, such as weep holes at the top and bottom. These weep holes caused problems for one installation when they became plugged by snow and ice during a serious winter storm. When the sun came out, enormous pressure built up inside the collector, actually blowing off the collector cover plate.

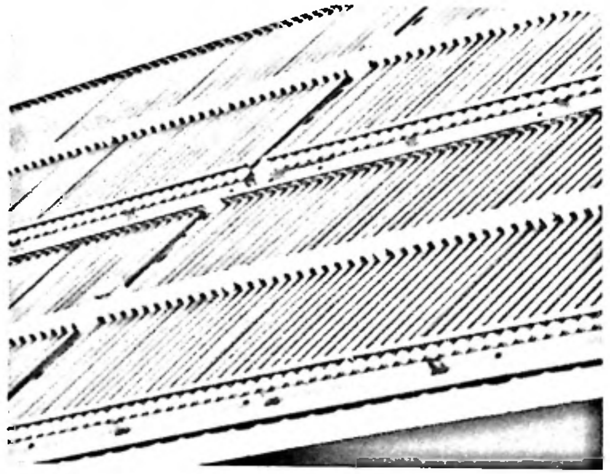
In areas with high winds airborne dust can enter through weep holes and accumulate inside the collector making it necessary to design a filter system or a procedure to clean the inside of the cover plate.

SELECTIVE SURFACES

Use selective surfaces with proven performance. One manufacturer was purchasing the ingredients for the absorptive coating separately and mixing them at his plant. Minute variations in the mixtures were later found to cause differences in efficiency from one collector to another of as much as 10% to 15%. A reevaluation of the collector led to the use of a black chrome surface. This resulted in a far superior and stable product. The increase in cost was minimal relative to achieving consistent performance.

Several problems related to selective coatings concern the stability of the surfaces themselves. Some have discolored, often after as short a time as three months. Others have peeled, pitted, and cracked after expanding and contracting repeatedly. How this effects collector efficiency has not been adequately determined.





Selective surfaces are not worth the expense when used exclusively with a domestic hot water system. A less expensive coating can provide comparable effectiveness in the range of domestic hot water operating temperatures.

LEAKAGE

Collector malfunction caused by leaking, cracking, or breaking affected 10% of the systems in the first two cycles of the HUD Demonstration Program. Most of these problems were caused by poor workmanship and faulty parts.

ANTIFREEZE

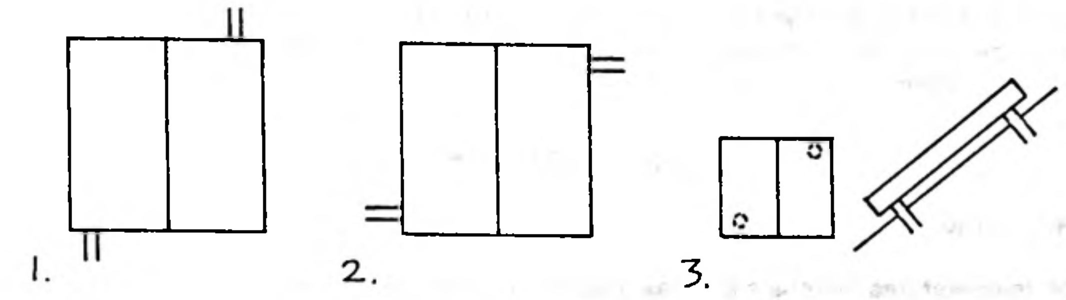
Care must be taken when using glycol solutions because the oil base may dissolve some seals and gaskets. The use of glycols may require double-wall heat exchangers to protect the potable water.

CONNECTIONS

Specify to the manufacturer where the connections to the collector are to be made. Increasingly, manufacturers are designing in flexibility so that the hook-ups can be made through the back, side or top of the collector. In addition, header piping is being included in the collector itself. This eliminates the number of joints that must be made in the field, since the installer has only to connect the headers together, rather than the collector to the header and the headers to each other. Joints made in the field are more costly and more prone to leak than factory-made joints.

Automotive hoses should not be used to connect collectors. Although they can withstand relatively high temperatures and are impervious to most antifreeze solutions, they usually are not designed for exposure to ultra-violet radiation or to temperatures as high as those reached in a solar collector. **In some cases, synthetic rubber paints can be applied to provide adequate ultra-violet resistance.**

COLLECTOR HOOK-UP OPTIONS



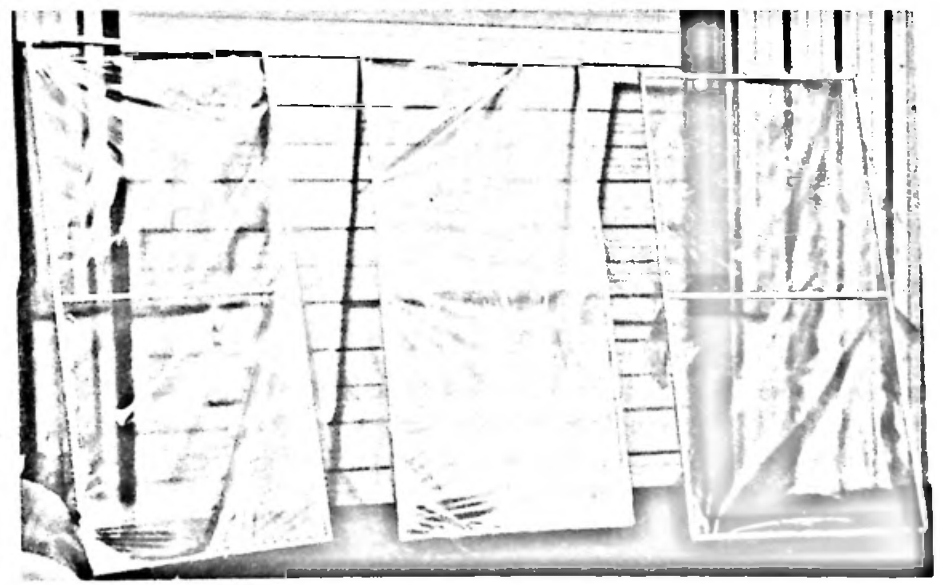
ABSORBER PLATES

Examine the collector to make sure the absorber plate is not in direct contact with a metal exterior wall. This direct contact, or thermal bridge, can cause a tremendous heat loss.

PLASTIC COVER PLATES

Due to continual expansion and contraction, plastics which are used for collector glazing may eventually sag and in time tend to flutter in high winds. The resultant noise can be quite loud and annoying. Two possible solutions to this problem are bracing or contouring the plastic for additional stiffness and strength.

In long term use, plastic films are also subject to degradation from ultra-violet radiation, ozone, and high temperatures. They should be designed to allow for easy replacement.



SERVICE ACCESS

The arrangement of solar panels should take into account the need for easy accessibility for future maintenance and servicing. Non-integral collectors and collectors with easy to remove glazing are most accessible.

When multiple arrays of collectors are used it is advisable to provide a means of isolating each one so that it can be worked on (and possibly removed) without disturbing the entire array and causing a shut down of the system.

SUMMER OVERHEAT

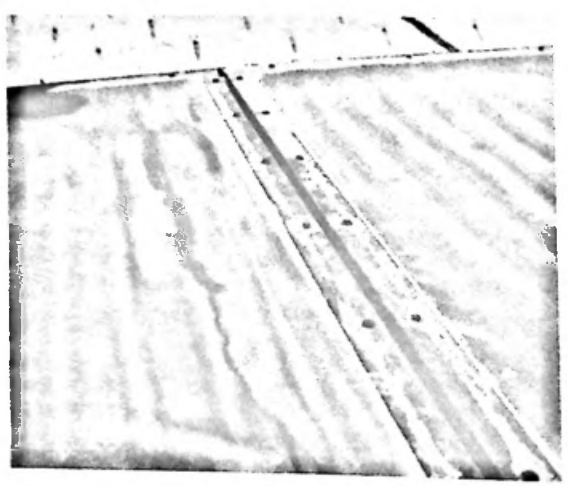
OVERHEATING

At high temperatures materials such as insulation, absorber plate coatings, and sealants may break down and structural components of the collector may undergo dimensional changes. When the collector is not being cooled by the transfer fluid, stagnation temperatures can be as high as 300°F to 400°F.

> 95% of the Cycle 1 demonstration projects did not take into consideration the special problems encountered because of overheating.

OUTGASSING

One common overheat problem is outgassing, which occurs as volatile materials "boil off" depositing a film on the inside of the collector cover plate. It is not always simple to isolate the cause of this serious problem.



In one instance, a manufacturer ran into problems when the binder in the fiberglass insulation appeared to be outgassing. Replacement of the insulation did not solve the problem. Research into the coating manufacturer's literature showed that it was not recommended for use above 300°F (and probably not over 150°F). A new coating was applied but did not prevent outgassing.

This time the problem was poor quality control. After the new selective surfaces were baked on, a well-meaning employee took it upon himself to touch up the collectors with ordinary black paint that subsequently outgassed.

EXCESS HEAT DISPOSAL

In summer, an array designed for heating space and hot water will be under-utilized and a means to prevent or dispose of excess heat must be incorporated. One method of handling this is a heat dump—a component designed to lose heat. However, more manufacturers are now designing collectors to withstand the effects of stagnation.

COLLECTOR SUPPORT STRUCTURE

Only a few manufacturers now provide good details for attaching the collector to the roof. This is a significant deficiency which manufacturers and contractors will have to remedy.

INSTALLATION TOLERANCES

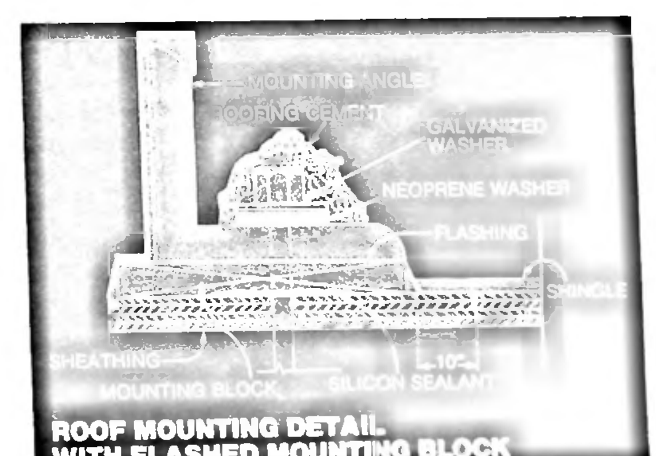
Insist upon design tolerances that are within the parameters of good building practice. Some of the more sophisticated collectors require tolerances of as little as 3/32" over a short span. As most conventional roofs will not conform to that tolerance, they require—at additional expense—an adjustable mounting system.

Make sure that the collectors are manufactured to specified tolerances. In one installation, the builder predrilled the roof sheathing, only to find that the collector piping was not located as shown on the manufacturer's drawings.

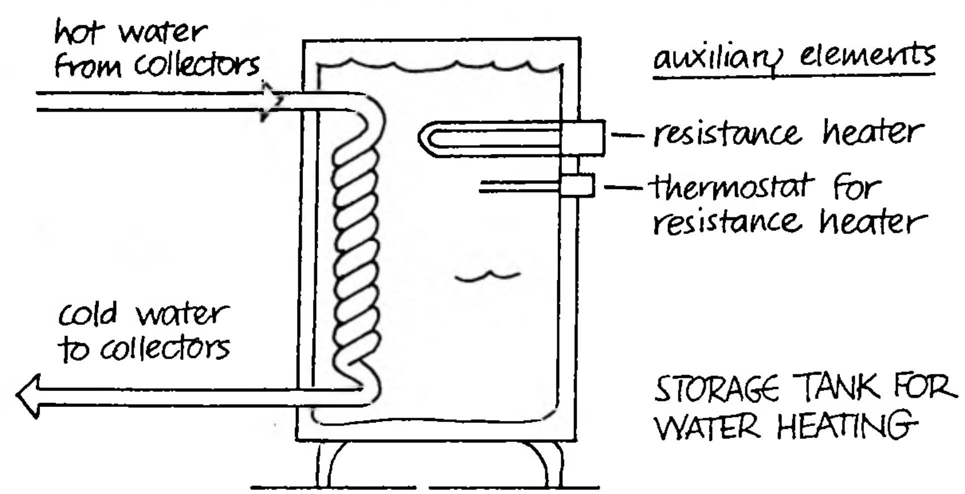
SUPPORTS

Raising collectors off the roof is preferable to mounting them directly on the roofing surface and reduces the potential of moisture retention, dry rot, and even carpenter ants. The supports must be of sufficient strength to counteract wind loading forces, especially in areas of high wind, such as Colorado, Texas, and Wyoming. Other environmental factors such as rain and snow also influence the design of collector supports.

(When collectors must be mounted directly on the roof it is best to mount them on the roofing paper rather than on a finished roof surface. They can then be flashed and sealed as part of the weather surface).



ROOF MOUNTING DETAIL WITH FLASHED MOUNTING BLOCK



The principles of this temperature stratification are often poorly understood or misused. The importance of stratification is relative to the size of the system. In current computer design programs, only TRNSYS takes stratification into account.

DRAIN DOWN

There must be room in storage to accommodate the transfer fluids when they are drained from the collectors. This was a problem for 14% of the projects in Cycle 1 and 6% in Cycle 2.

THERMAL EXPANSION

Do not underestimate the importance or the extent of the thermal expansion of the fluid in the storage tank, where temperatures can range from 32°F-210°F or higher. Some system designs failed to take into account that large volumes of fluids undergoing such temperature changes require expansion tanks larger than those of conventional heating systems.

As evidence of this lack of understanding, one contractor, who tried to solve the problem of a popping relief valve, compounded his problem by increasing the size of the **storage** tank. The correct procedure would have been to check the valve for malfunction and then install a larger **expansion** tank able to handle the maximum temperature and pressure differential.

F

Heat Transfer Fluids

PROPERTIES

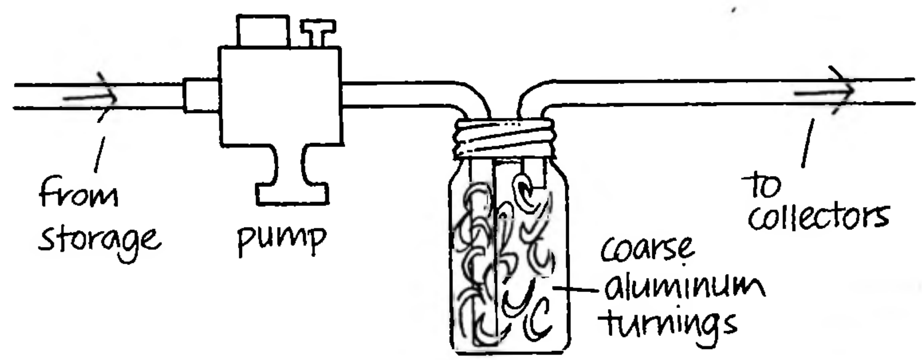
The coefficient of expansion, the viscosity, and the specific heat of various transfer fluids differ widely. These variations necessarily have effects on the head flow rates and thermal capacity of the system. In simpler systems, such as those designed to preheat domestic hot water, this is not so critical; in larger, more complex systems these factors are of major importance.

> Remember that the thermal coefficient of expansion of glycol solutions is 1.25 times that of water.

INHIBITORS

The use of inhibitors for water treatment can greatly increase the life expectancy of a system and requires little, low-cost maintenance. Inhibitors, and even the use of getter columns, slow down corrosion and can open the way to the use of previously problematic materials such as aluminum.

GETTER COLUMN



Fluid levels must be maintained and flow rates adjusted according to fluid specifications. In a pressurized system using a glycol solution in a closed loop, a leak can be a very serious problem. If unchecked, the system will take up tap water, diluting the solutions, and freeze-ups or corrosion may eventually occur.

TOXICITY

The distinction between the terms toxicity and potability is ill defined by today's standards. When choosing a transfer fluid, ascertain these properties as accurately as possible, being sure to consider all the additives and check them with local and state public health officials. Remember that a leak could contaminate the supply of drinking water.

GLYCOLS

Glycols ultimately break down into glycolic acid at high temperatures. The customer must be informed when, how, how much, and with what to test and replace the transfer fluid.

LEAKAGE

As there will probably be some leakage, at least during installation, check what effect the leaking fluid has on the building materials it may come in contact with, such as asphalt shingles.

FLUSHING

Provide a means of thoroughly flushing the system. Certain fluids, when drained, leave a film. Additives may also leave a residue which could reduce the efficiency of heat transfer.

DRAINING

Check local public health regulations to determine whether used transfer fluids can be drained to public sanitary or storm sewer systems. In some areas it may be necessary to contract for system draining and disposal.

G

Other Solar Components

In addition to collectors, storage and transfer fluids, several other components are crucial to the workings of a solar energy system. Most are familiar elements encountered in conventional mechanical systems, but their application in solar energy systems creates some new concerns. As a solar energy system will most likely have more components than a conventional mechanical system, there will be more potential failure points and attention to each will be more critical.

PIPING AND DUCTWORK

VENTING AND PITCHING

Take care to vent and pitch pipes correctly. Air blocks prevent effective drain down and can result in freeze-ups.

FLUSHING

Flush the piping to ensure fluid flow before hooking up the collectors and charging the system. Then, when charging the system, take care not to blow copper filings into it, especially if aluminum absorber plates are used.

INSULATION

Be sure to tape and insulate all ductwork. Leaks from faulty connections are a problem not unique to solar applications. Air leaks and inadequate insulation will severely penalize solar system efficiency. Ductwork installed within a wall that is roughed in and covered prevents adequate inspection.

WORKMANSHIP

Poor workmanship is the most serious installation problem. In one case, when a mechanic was running pipe from outside through concrete foundations, he drilled oversized holes which he later failed to pack with insulation. In other cases, crawl spaces, foundation walls, and sills were not insulated. Uninsulated pipes in uninsulated crawl spaces can significantly reduce system efficiency.

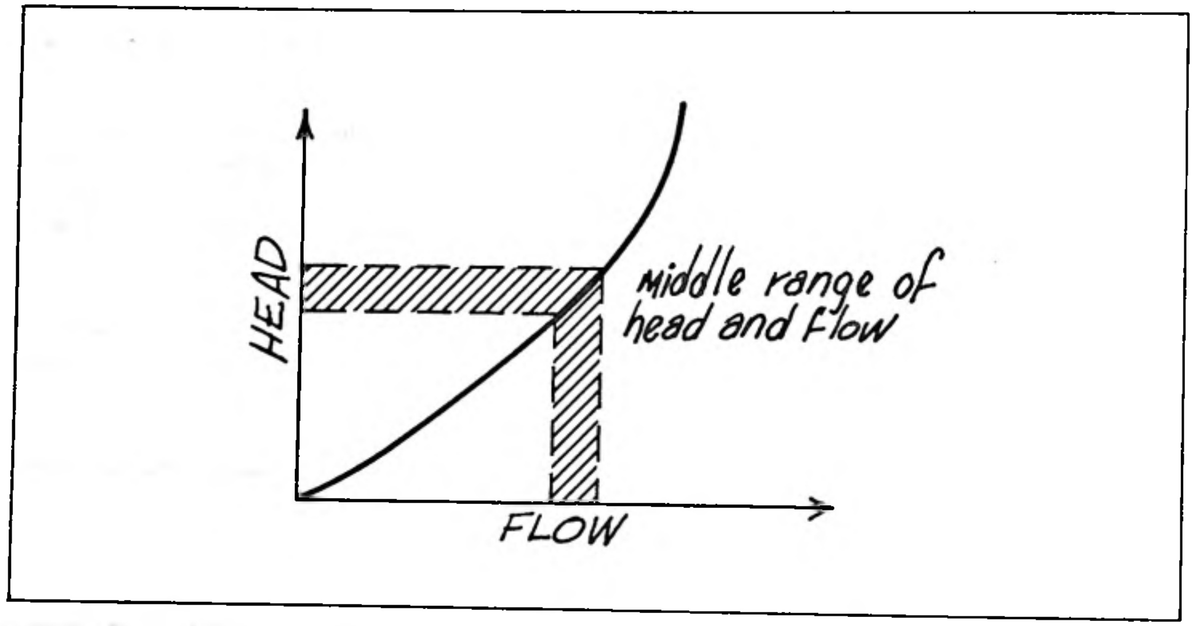
PUMPS

COST

Don't try to save money by using the cheapest pumps available. Failures can cause leaks and freeze-ups which are a greater problem and more costly than the simple replacement of a part. A better quality pump of proper selection also offers the option to change impellor size.

SIZE

Pumps in the middle range of impellor size and pump curve are most efficient. They have an additional advantage of affording the option to go up or down in flow rate by changing the impellor. In most demonstration program projects, the head was either greater or less than expected, resulting in a loss of efficiency.



LOCATION

Locate pumps so that the suction side will receive a net positive head. Storage located below the pumps has created problems.

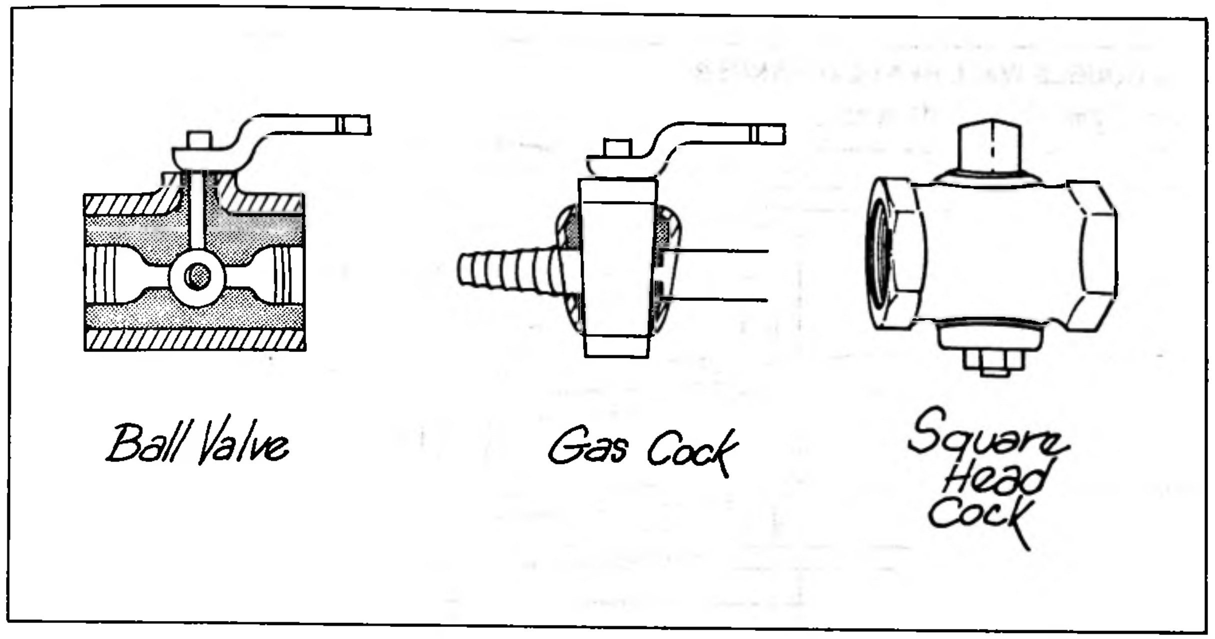
VALVES

COST

Don't compromise on valves. One grantee ignored the warning to replace a 3-way valve with two one-function valves. The valve failed, causing incomplete drain down and a freeze-up in the collectors.

BALANCING FLOW RATES

Provide a means for balancing the flow rates. One method is to add a balancing valve, such as a ball valve, a gas cock, or a square head cock. These are cheaper than gate valves and do not require packing which may deteriorate with some transfer fluids. Balance cocks should be located on the discharge side of the pump to control the flow rate and head pressure. Another method provides a self-balancing reverse return system for the collector array.



ISOLATION VALVES

The use of isolation valves permits work on one part of the system while the rest remains operational.

EXPANSION TANKS

SIZE

Remember to account for the various properties of transfer fluids in sizing expansion tanks. The thermal coefficient of expansion of glycols is 1.25 times that of water and necessitates a larger tank.

LOCATION

To maintain positive pressure in the pump, the expansion tank must be placed, as in conventional systems, on the suction side.

NUMBER

If there are several separate closed circulation systems, each requires a separate expansion tank.

H

Passive Systems

Passive solar energy systems rely on natural, non-mechanical means to collect, store, and deliver energy. There have been a limited number of passive systems in the demonstration program.

COLLECTION-DISTRIBUTION

Passive approaches offer the advantage of collecting heat close to the dwelling's delivery temperature requirements, thereby minimizing thermal losses in distribution. Because they have fewer points of heat exchange than active systems, they experience less energy degradation.

HEATING CONTROLS

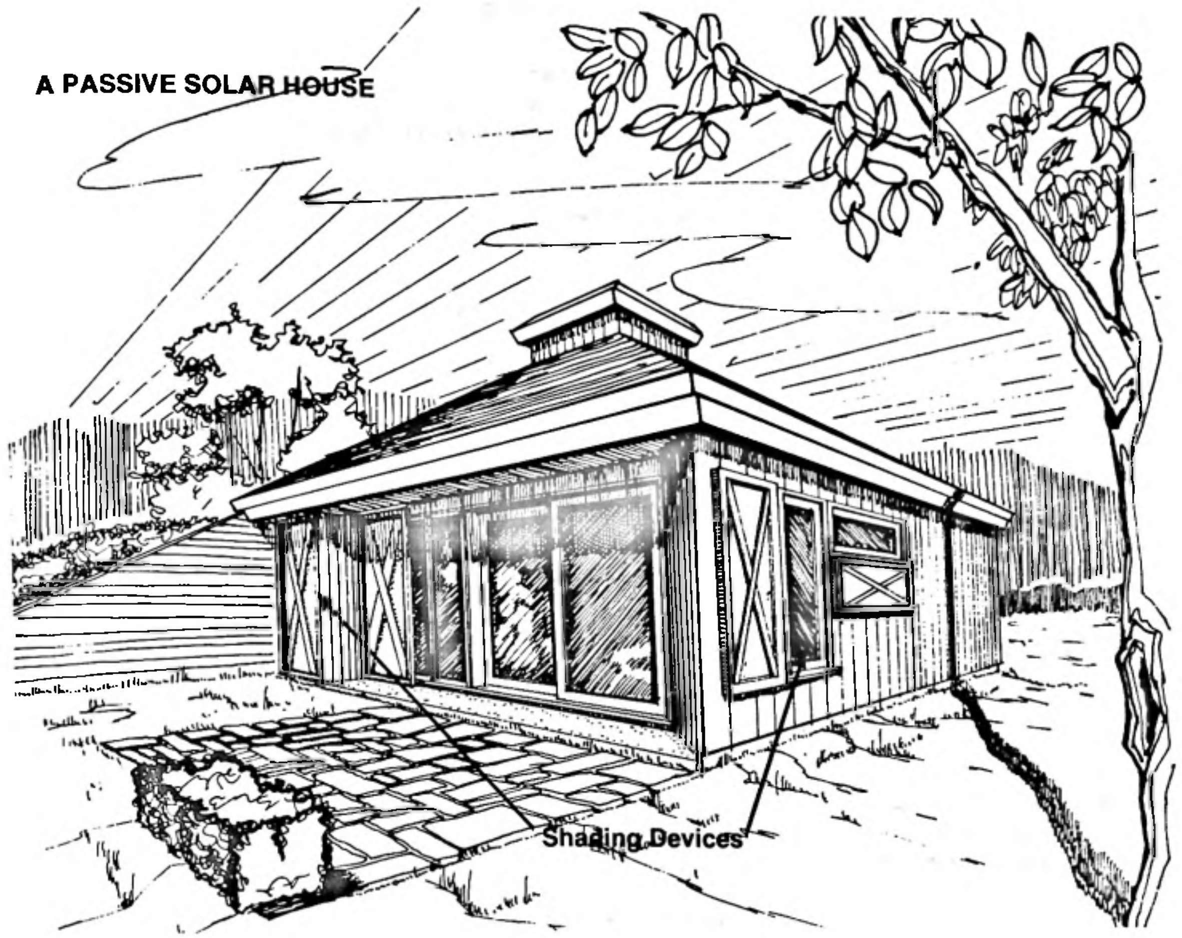
In designing a passive system, it is important to provide a way to control the heat distribution and to circulate the room air (from overheated space to underheated space or overheated space to ambient air). When the living space becomes underheated, an auxiliary system is activated to bring the area back to the comfort zone.

The control of energy flow is a problem because homeowners usually demand constant comfort conditions. Many passive designs call for temperature swings of 10°-15°, instead of the usual 3°-5° for a conventional heating system.

INSULATING DEVICES

COLLECTOR SHIELDING

A passive approach requires that the collector surface be physically shielded from unwanted gains or losses. This can be accomplished with movable insulation and/or shading devices. A good design may also use vegetation to provide shading. The design of insulation devices should account for the accumulation of debris and weathering.



Don't make unrealistic assumptions about the owner's participation in operating the movable insulation or shading devices. The operation of one system depended on the owner to lift out and store twelve separate insulating panels in the morning and to replace them again at night. This is one area where mechanical controls could have been used.

Intricate track assemblies may require tolerances too small for site assembled, residential construction techniques.

SEALING

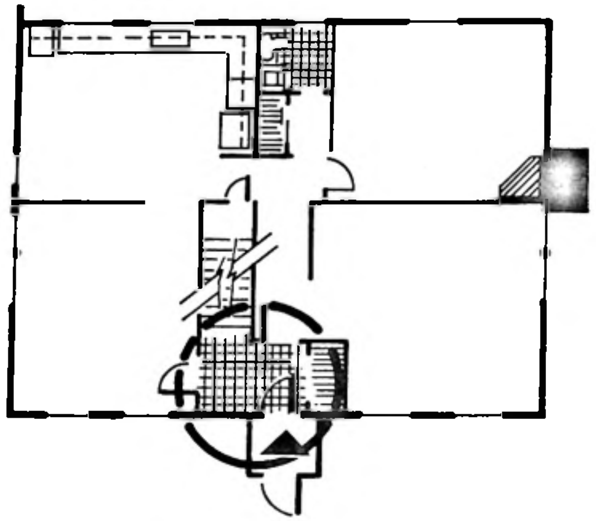
Seal the insulating system to minimize convective thermal losses. In using insulating curtains, it is important that as much of a dead air space as possible be created through the use of valances.

VENTILATION

Be sure to allow for cross ventilation in the summer. This is an essential provision as passive houses are sealed tightly in order to operate efficiently during the heating season. With careful design of ventilation details, the dwelling can be comfortable in the non-heating season.

AIR LOCK ENTRIES

Air-lock type entries on high-traffic doors help to reduce infiltration losses and allow the solar energy system to operate efficiently during the heating season. A standard entry can negate all anti-infiltration measures when used frequently. Few designs in the demonstration program provided this feature.



INTERIOR SURFACES

Do not carpet or otherwise cover floors when they are to be used as the storage mass. Ideally, masonry floors should be dark and non-reflective and should be well-insulated underneath. If you anticipate floor temperatures above a comfortable range, consider making the floor a lighter color, even though this will reduce storage effectiveness. Watch what types of materials are used on interior surfaces as well as on furnishings inside the passive gain area. Remember that they may be subject to a large degree of direct sunlight.

COST

Passive systems are more expensive in terms of dollars/BTU than originally expected. This can be attributed to the fact that each system must be individually designed. Also, construction of passive systems frequently involves techniques unfamiliar to small home builders. This can result in increased labor costs. However, passive systems have been as cost effective as active systems and offer a greater building life expectancy.

I

Relating the Components

The sensitive consideration of all component relationships is as important to efficient solar system design as thorough calculations, informed component specifications and proper installation. A complete solar house design should account for interior heat gains from occupants, hot water tanks, light, major appliances, and mechanical equipment. It should also balance the effects of shading and ventilation against solar gain.

In new construction, the cost effective way to reduce the size and therefore the cost of the solar energy system is to significantly reduce the building load. Reducing the size of the system also makes it easier to integrate it into the building design. Passive design techniques incorporate the whole house as collector, storage, and distribution system. **The emphasis here is that the house and the solar energy system must be compatible and should be designed together.**

J

Maintenance

Proper maintenance of a solar energy system is essential in order to protect the initial investment. While it is still too early to talk about maintenance with the authority of wide experience, some trends and concerns have emerged.

DIFFICULTY

It is no more difficult to maintain solar energy systems than it is to maintain conventional HVAC systems. However, good user manuals are not always available.

REPLACEMENT PARTS

Check on the availability of replacement parts. One grantee had problems with a broken pulley sheave. The manufacturer had no available replacement and the grantee finally resorted to having one especially machined at a very high cost.

SYSTEM TESTS

It is important to inform the consumer about start-up, tuning and initial testing. No publication currently addresses this concern. For now, at least, the installer usually performs these tasks. The customer is often not aware of the operational characteristics of the system, nor of the need for these procedures.

SERVICE

Make sure the customer knows whom to call for service. Whereas an oil burner man may be counted on to continue to service a fuel oil system after installation, it may not be clear who is responsible for servicing the solar energy system.

K

Conclusion

Building the Solar Home: Some Early Lessons Learned has shown that problems CAN and DO arise at any stage of solar energy use (design, installation, construction and operation). This can be attributed in part to the lack of experience of those involved in solar applications and to the experimental nature of the technology. However, watchfulness and careful attention to detail can lead to early detection of problems or can help to avoid them altogether.

The following list of experiences illustrates the range of problems which a builder should anticipate. It also indicates an additional problem: that it may not always be clear where responsibility for error rests. Problems can arise not only in components, but from improper or careless actions by any person at any point from initial design to final use.

SAMPLE LISTING OF FUNCTIONAL PROBLEMS ENCOUNTERED IN THE DEMONSTRATION PROGRAM*

1. Absorber plate lost half its coating.
2. Absorber coating of some collectors is peeling.
3. Collector tubing ruptured due to freezing.
4. Film appeared on inside of collector cover—probable outgassing due to high temperature of glass fiber binder; **manufacturer** seems unwilling to fix.
5. Collector tubes are too far in header—flow blocked.
6. Evacuated tube manifold is leaking.
7. Collector pump is running 24 hours a day; incorrectly wired by **installer.**
8. System requires two additional dampers.
9. Insulation is incorrectly installed—**poor workmanship.**
10. Hot water flow rate is below design.
11. Domestic hot water heat exchanger froze due to damper leakage or **improper installation.**
12. Tracking motors need replacing—**manufacturer** says **installer** caused the problem. Installer claims he did his work correctly and that it must be a **maintenance problem.** The **grantee** is fixing it himself.
13. **Occupant** has lifted cover on his rock storage box, probably to heat basement space. This has totally disrupted flow in the solar energy system. **Occupant** has been asked to put the cover back on the storage box.
14. Air handler blower circulates return air through rock storage from bottom to top when furnace is on, as per design. Air cools to 60°F or below through storage and then is reheated. Heat lost is buried in rock storage not recoverable in house. **Poor design.**

*Based on a Boeing Aerospace Company summary of problems, December, 1977. See Table II for a categorized list of operational problems encountered in the first two HUD demonstration cycles.

The overall impression of the technical advisors to the HUD Solar Residential Demonstration Program is one of success and progress. According to Dubin Bloome Associates, Cycle 2 projects showed, "a marked improvement in technical presentation over those received for Cycle 1 indicating that the experiences gained had been put to good practical use and had the positive effect of training professionals to deal with them, resulting in improved and more economical solar energy systems. By requiring adequate warranties and documentation of performance claims, the program has forced the solar hardware industry to substantiate advertising claims, building confidence in the availability of clean, efficient, and energy conserving systems."

TABLE 1
SUMMARY OF CYCLE 1 and 2 GRANTS

	CYCLE 1	CYCLE 2
ORIGINAL GRANTS	$1,038,083	$3,913,724
ADJUSTED GRANTS	$ 864,168	$3,863,543
NUMBER OF GRANTS	55	102
ADJUSTED NUMBER	42	91
NUMBER OF UNITS	141	1,411
ADJUSTED NUMBER	126	1,396
LIQUID (UNITS)	110	1,328
AIR (UNITS)	16	68
ACTIVE	124	1,370
PASSIVE	1	10
HYBRID	1	16
HOT WATER (ONLY)	28	773
HEAT (ONLY)	7	2
HEAT & HOT WATER	68	497
HEAT & COOLING	5	4
HEAT, HOT WATER, & COOLING	18	120
NEW CONSTRUCTION	93	743
RETROFIT	33	653
COMPLETED	88	864
SOLD OR RENTED	68	264
INSTRUMENTED	1	17
MANUFACTURERS REPRESENTED	25	

Figures as of December, 1977

TABLE II
OPERATIONAL PROBLEMS*

PROBLEM	CYCLE 1	CYCLE 2
	(number of installations)	
Performance below design for:		
Heating	2	1
Cooling	1	—
Hot water	1	—
Thermal storage	—	2
Comfort range exceeded for:		
Thermal storage	1	—
Energy required for transport exceeded:		
Electrical design	1	—
Efficiency of system reduced by:		
Corrosion	3	1
Leakage	2	—
Orientation and tilt	1	2
Shadowing	—	1
Inadequate freeze protection	5	—
Air lock	1	—
Unnecessary interference	—	3
System impaired by:		
Dimensional changes of structure	1	1
Structural element failure	1	—
Weight overload	—	2
Environmental extremes	1	—
Workmanship not in accord with accepted practice:		
Collectors	2	1
Storage	1	1
Installation	3	4
Fail safe controls failed to prevent:		
Overheating	3	—
Excessive pressure build-up	3	4
Contamination of potable water	1	2
Environment adversely affected components by:		
Moisture	—	3
Airborne pollutants	—	1
Deterioration due to material incompatability	1	1
Losses due to leakage	5	3
Losses due to outgassing	4	2
Inadequate:		
Accessibility for maintenance	1	1
Accessibility for monitoring	1	2
Replacement parts	1	1
Care in shipment	5	7

*Based on National Bureau of Standards report.

GLOSSARY

ABSORBER PLATE—The surface in a collector that absorbs solar radiation and converts it to heat energy; generally, matte black surfaces are good absorbers and emitters of thermal radiation while white and metallic surfaces are not (see Selective Surface).

AIR-TYPE COLLECTOR—A collector that uses air as the heat transfer fluid.

ASHRAE—American Society of Heating, Refrigerating and Air-Conditioning Engineers.

AUXILIARY HEAT—The extra heat provided by a conventional heating system for periods of cloudiness or intense cold when a solar heating system cannot provide enough.

BACKFLOW—The unintentional reversal of flow in a potable water distribution system which may result in the transport of foreign materials or substances into the other branches of the distribution system.

BACKFLOW PREVENTER—A device or means to prevent backflow.

COEFFICIENT OF HEAT TRANSMISSION—The rate of heat loss in BTU per hour through a square foot of wall or other building surface when the difference between indoor and outdoor air temperatures is one degree Fahrenheit.

COLLECTOR EFFICIENCY—The ratio of usable heat energy extracted from a collector to the solar energy striking the cover.

COLLECTOR TILT—The angle between the horizontal plane and the solar collector plane.

COMPONENTS—An individually distinguishable product that forms part of a more complex product (i.e., subsystem or system).

CONTROL SUBSYSTEM—The assembly of devices and their electrical, pneumatic or hydraulic auxiliaries used to regulate the processes of collecting, transporting, storing, and utilizing energy in response to the thermal, safety, and health requirements of the building occupants.

COVER PLATE—A sheet of glass or transparent plastic placed above the absorber plate in a flat-plate collector (see Absorber Plate and Collector).

DIFFUSE RADIATION—Indirect sunlight that is scattered from air molecules, dust, and water vapor.

DIRECT RADIATION—Solar radiation that comes straight from the sun, casting shadows on a clear day.

FLOW CONDITION—The condition obtained when the heat transfer fluid is flowing through the collector array under normal operating conditions.

GETTER COLUMN—A form of corrosion control in mixed piping systems for piping systems for which a canister of a sacrificial metal (usually aluminum or magnesium) in the form of screening is inserted in the flow loop head of the collectors.

HEADER—The pipe that runs across the edge of an array of solar collectors, gathering (or distributing) the heat transfer fluid from (or to) the risers in the individual collectors. This insures that equal flow rates and pressure are maintained.

HEAT EXCHANGER—A device, such as a coiled copper tube immersed in a tank of water, that is used to transfer heat from one fluid to another through a separating wall.

HEATING LOAD—The total heat loss from a house under the most severe winter conditions likely to occur; a concept used in the design of buildings and their heating systems.

HEATING SEASON—The period from early fall to late spring (in the Northern Hemisphere) during which additional heat is needed to keep a house comfortable for its occupants.

HEAT TRANSFER MEDIUM—A medium, liquid, or air or solid, which is used to transport thermal energy.

INSOLATION—The total amount of solar radiation—direct, diffused and reflected—striking a surface exposed to the sky.

INSULATION—A material with high resistance to (R-value) heat flow.

LIQUID-TYPE COLLECTOR—A collector using a liquid as the heat transfer fluid.

NO-FLOW CONDITION—That condition obtained when the heat transfer fluid is not flowing through the collector array due to shut-down or malfunction and the collector is exposed to the amount of solar radiation that it would receive under normal operating conditions.

OUTGASSING—The emission of gases by materials and components usually during exposure to elevated temperature or reduced pressure.

PASSIVE SOLAR SYSTEM—An assembly of natural and architectural components including collectors, thermal storage devices and transfer fluid which converts solar energy into thermal energy in a controlled manner and in which no fans or pumps are used to accomplish the transfer of thermal energy. The prime elements in a passive solar system are usually some form of thermal capacitance and solar energy control. An assembly of natural and architectural components which converts solar energy into usable or storable thermal energy without mechanical power.

PITTING—The process by which localized material loss is caused in materials or components by erosion or chemical decomposition.

POTABLE WATER—Water free from impurities present in amounts sufficient to cause disease or harmful physiological effects and conforming in its bacteriological and chemical quality to the requirements of the Public Health Service Drinking Water Standards or the regulations of the public health authority having jurisdiction.

SELECTIVE SURFACE—A surface that absorbs radiation of one wavelength (i.e. sunlight) but emits little radiation of another wavelength (i.e. infrared); used as coating for absorber plates.

SOLAR DEGRADATION—The process by which exposure to sunlight deteriorates the properties of materials and components.

STAGNATION—The condition of high collector temperature obtained when the heat transfer fluid is not flowing through the collector. The collector must be able to endure this condition (400°F. for double glazed, 350°F. for single glazed panels) without degraded performance when operation is resumed.

SUBSYSTEM—A major, separable, functional assembly of a system such as complete collector, or storage assembly, etc.

SYSTEM—The complete assembly necessary to supply heat and/or domestic hot water to the dwelling.

TUBE-IN-PLATE ABSORBER—A metal absorber plate in which the heat transfer fluid flows through passages formed in the plate itself.

TUBE-TYPE COLLECTOR—A collector in which the heat transfer liquid flows through metal tubes that are fastened to the absorber plate by solder, clamps or other means.

Sources: Federal Energy Administration, *Buying Solar* (Washington, DC: Government Printing Office, June 1976, GPO Stock #041-018-00120-4)

B. Anderson and M. Riordan, *Solar Home Book* (Harrisville, NH: Cheshire Books, 1976)

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☆ U.S. GOVERNMENT PRINTING OFFICE : 1978 O—268-054

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