

THE SOLAR HOUSE
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by

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Abstract

Due to the dwindling of present day fuel resources, it is inevitable that the solar heated house becomes a reality. Present day solar heating methods are still in the experimental stages. And although there have been many successful experiments, solar heating has still not reached the stage where it can compete with conventional heating systems, on a large scale, in all parts of the country.

The solar energy heating system places many limitations on design. The house must be properly oriented with the sun, and large amounts of space must be provided for the purpose of trapping and storing solar energy. Thus the challenge in designing a solar house, is combining usefully, tastefully and economically, the large amount of mechanical equipment with the function of the family.

TABLE OF CONTENTS

	Page
I. INTRODUCTION	1
II. CLIMATIC CONSIDERATIONS.	2
III. DESCRIPTION OF THE SOLAR HEATING SYSTEM.	8
IV. THE FLAT-PLATE SOLAR ENERGY COLLECTOR.	9
V. THE STORAGE SYSTEM	13
VI. THE AUXILIARY HEAT SYSTEM.	14
VII. THE DOMESTIC HOT WATER SYSTEM.	15
VIII. REFRIGERATION BY SOLAR ENERGY.	15
IX. SOLAR HEATING AND THE FUTURE	18
X. THE EFFECTS OF SOLAR HEATING ON DESIGN	21

I. INTRODUCTION

One of the strongest desires of the present day creative architect is to ponder over and attempt to predict building designs for the future. But in order to speculate over future design it is pertinent, but seldom possible, to know what stipulations will be entailed in such design. Certainly, because of the introduction of new materials and methods of construction, the design of today was undreamed of 50 years ago. And, as certain, the design fifty years from now is undreamed of today. However, it is not the intention of this paper to predict future design, but rather to consider one of the facets that will have to be taken into consideration, and how it will affect future building design. This particular facet is solar heating and cooling as applied to architecture.

The earth receives from the sun: 1.94 calories per square centimeter; the energy equivalent of 6,000,000 tons of coal per second; the equivalent in five minutes of the United States annual energy consumption of 1/4 billion tons of coal; and on each square mile the equivalent of about two atom bombs per day.¹ Because of our rapidly dwindling fuel reserves it is

¹"Introductory Lecture" by Hoyt C. Hotter, Space Heating With Solar Energy, August, 1954, M.I.T.

necessary that we find a means to utilize this great source of energy from the sun.

The first attempts to harness solar energy took place in France and America during the last quarter of the 19th Century. The names of Mocquot, Pifre, Ericson, Eneas, and Schumann are associated with steam engines run from boilers that were heated by solar energy. The most successful of these pioneers was Schumann who established a plant in Egypt containing 13,000 square feet of cylindrical parabolic reflectors.

In 1937, Dr. Godfrey L. Cabot established an endowment for solar research at Harvard University, and in 1938 made a similar grant to M.I.T.¹ Since then, much time has been devoted to the problem of space-heating with solar energy. M.I.T. has so far produced four Solar Houses, the first being completed in 1940 and the last being completed in 1960.² The idea of harnessing the sun's energy is as old as man, but only recently has the solar power been put to a practical use.

II. CLIMATIC CONSIDERATIONS

In most areas of the United States enough solar heat is

¹"Performance of the M.I.T. Solar House" by August L. Hesselslhwerdt, Jr., Space Heating With Solar Energy, p. 99.

²"Solar House" by John Peter, Look, October, 1960, p. 59.

received during the year to provide adequate thermal comfort over the cool season. Unfortunately, in some areas of the country there is an excess of solar heat in the summer season and a deficiency in the amount of solar heat received during the winter season. Therefore, it becomes obvious that in certain areas of the country, thermal comfort from solar heat is out of the question. The ratio of direct solar radiation to the thermal requirements is just too unfavorable. But even in these regions certain solar design applications can be used to supplement standard heating systems.

Figure 1 shows a map of the United States divided into three distinct areas:

(a) Region of Maximum Feasibility, made up of Florida, the gulf and southeastern coastal plains, Texas, New Mexico, Arizona, southern California and bordering areas. In this area heat requirements for evenings and the entire cool season can be supplied by solar radiation collection devices without elaborate or expensive engineering.

(b) Region of Engineering Feasibility, made up of central Atlantic coastal plains and piedmont, central Mississippi basin, north central midwest and western states, and northern California. In these areas solar

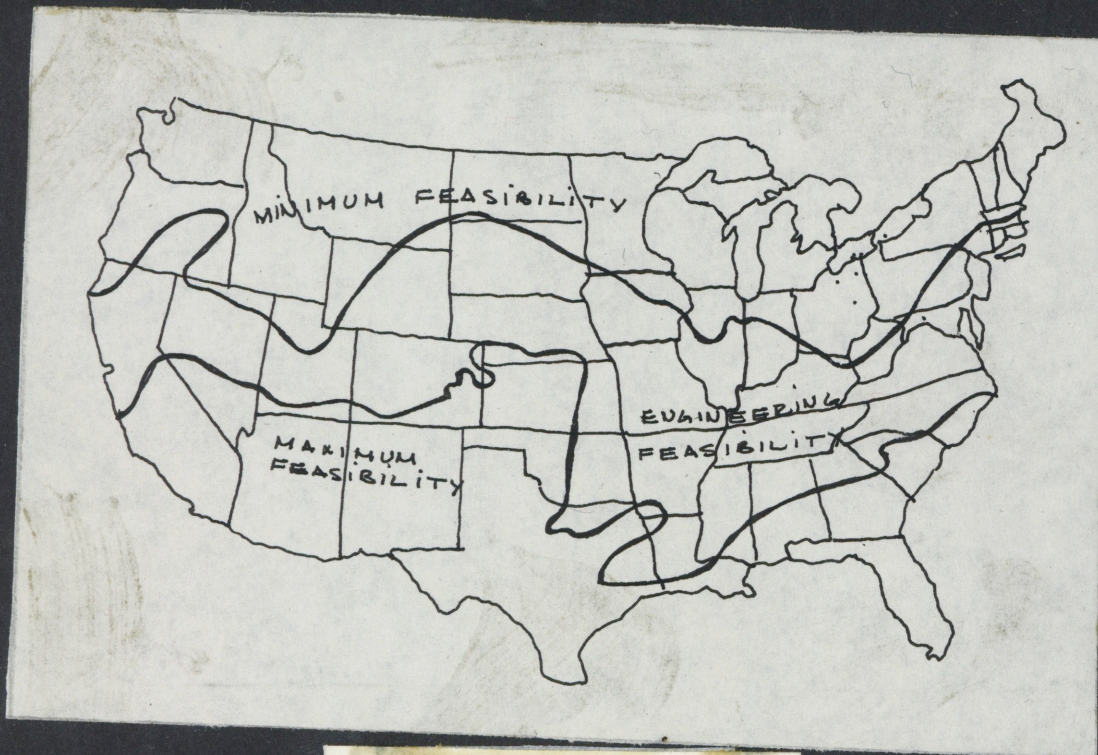


Figure 1
From: Ref. 1, p. 4

radiation can supply most of the heating needs throughout the year but supplementary, conventional heating will be required as a precautionary matter.

(c) Included in the Region of Minimum Feasibility are northern New England, New York, Pennsylvania, Wisconsin, Minnesota, North Dakota, Montana, Idaho, Washington, and Oregon. In these states, due to prolonged periods of intense cold, heavy cloud cover, and low angle of the sun, solar radiation, by itself, is entirely inadequate for winter space heating with present engineering methods. However, a solar heating system may be used to great advantage in these areas as a supplementary heating device.¹

As is indicated in this map (Figure 1), latitude determines the amount of heat received from the sun. For every latitude there is a constantly recurring annual of cycle different from that of every other latitude. Also, the seasonal variations in length of day is effected by the latitude. At the equator, days are always twelve hours long. At San Juan, Puerto Rico, latitude 18° 28' N. the length of day varies from about thirteen hours in summer to eleven hours in winter,

¹"Climatic Considerations of Solar Energy for Space Heating", Abstract Talk by Paul Seple, Space Heating With Solar Energy, August, 1954, p. 14.

while at Fairbanks, Alaska, latitude $69^{\circ} 52'$ N. the variation is from twenty-two hours maximum to four hours minimum.

In order to understand the geometry of polar radiation we must visualize the daily rotation of the earth on its axis in relation to its annual movement around the sun. These two movements occur in planes that are at an angle of $23^{\circ} 27'$ with each other. The declination of the sun (its angle away from zenith at noon on the equator) is identical with the latitude of the point on the earth's surface where the rays are vertical. The declination is considered to be positive when the north latitudes are getting more than half the total incident radiation, from March 21 to September 21, and negative during the other half of the year when the south latitudes have the advantage. At the equinoxes, declination equals 0 and each hemisphere gets half the radiation distributed over equal areas.

The angle of the sun is most commonly designated as the zenith angle (θZ) or angular distance from the zenith line. At sunrise and sunset $\theta Z = 90^{\circ}$. θZ can be computed for any place at any time knowing the latitude, the declination or time of year, and the time of day (expressed as hours before or after solar noon). The minimum zenith angle occurs at noon and equals latitude minus declination. For example, in Boston

the zenith angle at noon on December 21 is $42^{\circ} - (-23 \frac{1}{2}^{\circ}) = 65 \frac{1}{2}^{\circ}$. During that day θZ varies from this amount to 90° .¹

It is apparent that the mean zenith angle during a day or a month and the mean length of the day during such a period are the chief factors responsible for determining the amount of sunshine per square mile and thus are to a large extent the determinants of climate. The amount of sunshine received in different seasons in different parts of the world is primarily determined by latitude.

However, latitude is not the only determining factor in the amount of sunshine received. Gas molecules in the air and water vapor absorb some of the radiation and are warmed by it. Another portion is scattered in all directions, so that even on a perfectly clear day, the total radiation is appreciably depleted before arrival at the earth's surface. In clear weather, the amount of depletion depends on the air mass traversed. Other factors that effect the radiation received are: water vapor, dust, altitude, terrain and cloudiness.

It would be convenient if the use of solar heating calculations of weather data were available in terms of average transmissivity of the atmosphere for many different localities

¹"Variables Affecting Solar Incidence" by Lawrence B. Anderson, Space Heating With Solar Energy, p. 17, 1954.

during the critical months of the heating season. Combining such information with latitude factors one could calculate local incidence in an orderly fashion. But at present, the best procedure is to work with horizontal incidence records. This data is recorded continuously at some 34 well-distributed pyrheliometric stations, reporting regularly to the United States Weather Bureau. After obtaining a record from the station which has the most nearly comparable conditions, it is possible to apply corrections due to local dust and cloudiness conditions differing from those of the station.

These records are usually made with an Eppley thermoelectric pyrheliometer whose sensitive element has two concentric rings of equal area, one black and one white, forming the hot and cold junctions respectively of a thermopile. The difference in electromotive force between the two rings gives the measure of radiation received. Diffuse radiation can be measured at any time by means of an occulting screen held so as to intercept direct radiation. The reading then taken is the value of diffuse radiation which can be subtracted from total radiation to obtain the value for direct radiation.

III. DESCRIPTION OF THE SOLAR HEATING SYSTEM

The solar-house heating system is primarily concerned with the collection and storage of solar energy. The two primary parts of the solar-heating system being the solar collector, which is mounted in a position that is exposed to the sun, and the insulated thermal-storage unit in which energy is stored during the day for use at night.

IV. THE FLAT-PLATE SOLAR ENERGY COLLECTOR

The solar collector consists essentially of a flat copper or aluminum plate painted black on the side facing the sun to increase its absorption (see Figure 2). On the opposite side the plate is insulated to reduce the backward heat loss.¹ Above the blackened copper or aluminum plate are mounted 1, 2 or 3 glass plates about 1/2 inch apart.² The glass transmits the short wave solar radiation but is opaque to the long wave radiation from the collector plate. Energy that is absorbed by the blackened plate is then transported by the carrier stream either to the rooms of the house or to the storage unit.

¹"Solar House Design", Progressive Architecture, May 1955, pp. 122-126.

²"Performance of the Flat-Plate Solar Collector" by Hoyt C. Hotter, Space Heating With Solar Energy, p. 71.

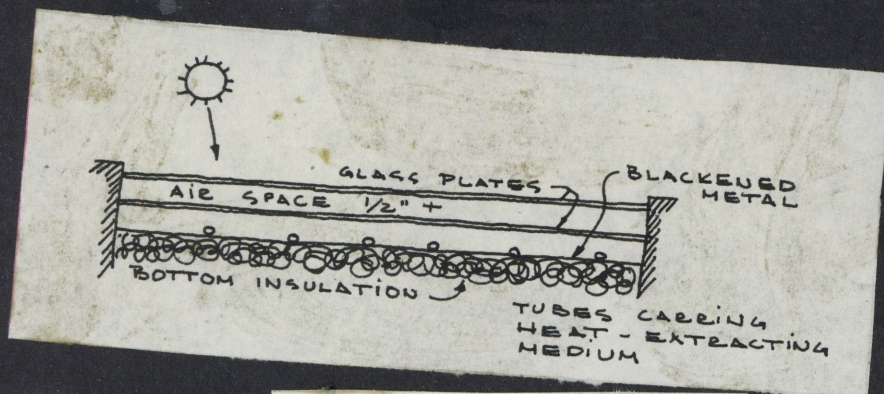


Figure 2
From: Ref. 1, p. 9

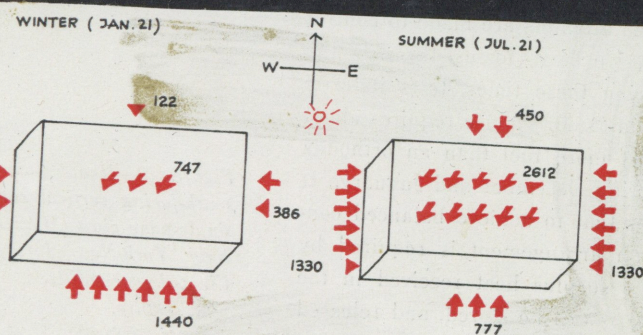


Figure 3
From: Ref. 1, p. 12

The collector, as previously mentioned, should be located in a southern exposure. Air is circulated up the collector between and beneath its glass surfaces. It then enters a manifold at the collector exit, passes to a fan, and then either passes to the rooms of the house or to the storage unit. If the air is being directed to the rooms of the house by the thermostatic controls, it would finally leave them via the cold air return ducts and return to the collector unit to be recirculated. However, if heat is to be stored, the air, after delivering its sensible heat to the gravel bed, leaves the storage unit and returns through a duct to the collector inlet. Then, when the house requires heat at night, air would be drawn from the rooms through the cold air return ducts to the storage bin. It is heated by passing through the gravel, and then it is forced by fan through the heating ducts to the rooms.

The number of glass cover plates needed depends upon the temperature level of operation above atmospheric temperature. As a rule of thumb, one cover glass is needed when the difference in temperature between the incoming fluid and the outdoor air is less than approximately 60° F.; when it is between 60° F. and 140° F. two glass cover plates are needed and when the temperature difference is over 140° F., three cover plates

are needed.¹ In general, then, the temperatures increase^s with each glass plate that is added.

The solar collector is always mounted in a position where it may best intercept the rays of the sun. Figure 3 shows the amount of total radiation for clear sky conditions on the various sides of a building in the New York-New Jersey area. Each arrow represents 250 BTU/sq. ft./ day.² As is seen in Figure 2, the south side receives the largest amount of heat in winter and the least amount of heat in summer. Thus it is evident that a heat collector surface should have a southern orientation.

For maximum performance during the winter season the solar heat collector should be tilted towards the sun. The actual angle of the tilt will depend on the time of year when the most energy is required. For year-round performance when the winter energy requirement is greater than that during the summer a tilt of 10 to 20 degrees greater than latitude is sufficient. At latitudes between 40 and 45 degrees the collector should be tilted towards the equator at approximately 15

¹"Solar House Design", Progressive Architecture, May 1955, pp. 122-126.

²"Solar Heating for Houses" by Olgyay and Felkes, Progressive Arch, March 1959, p. 195.

degrees greater than latitude. This would give approximately 15% more energy during the critical winter months than a south facing vertical collector.¹

V. THE STORAGE SYSTEM

In designing a storage system for thermal energy (heat) the architect is confronted with three major problems:

1. Where should the system be located?
2. What should be used for a storage medium?
3. How large should the storage area be?

The storage system should be located in the least expensive part of the house to build, such as the attic or the basement. Several problems arise if the storage system is in the attic. A large storage area in the attic would mean that special structural supports would have to be introduced. Also, any heat that leaked out of an attic storage system would be lost to the outdoors; whereas, if the storage system were more centrally located in the basement of the house, escaped heat would be used.

In choosing a type of storage system, there is no great

¹"Performance of the M.I.T. Solar House" by August L. Hesselshwerdt, Jr., Space Heating with Solar Energy, p. 99.

difference, performance wise, between a water system and a hot air system. The materials that are being used at present for storage are water and crushed solids, which store the energy as sensible heat.

Reliability and cost are a good basis for choosing any medium for storage. The cost of a medium should be evaluated on the basis of volume and should include allowance for space occupied in the house, for the cost of the material itself, and for the cost of necessary containers and fittings. Water in most situations is probably the less expensive of the two methods in both cost and volume.

The size of the storage system¹ is about 5 to 50 pounds of water per square foot of collector, with about 20 pounds being close to optimum for house heating.

VI. THE AUXILIARY HEAT SYSTEM

As previously mentioned, auxiliary heating is needed when there is an extended period of no sunshine. Thus, in practically all cases, especially in the more northern climates, auxiliary heating should be considered. The choice of an auxiliary heating

¹"Solar House Design", Progressive Architecture, May 1955, p. 122.

system depends mostly on the amount of extra heat needed and also upon the cost of various fuels in the particular area. If the quantity of auxiliary heat is small, a low efficiency oil burner or possibly direct electrical heating would be sufficient.

The auxiliary heating unit should not heat the solar storage system but should be distributed directly to the house through the existing solar heat distributing system.

VII. THE DOMESTIC HOT WATER SYSTEM

The energy or heat required for the domestic hot water supply is constant or almost constant year-round as compared with the other heating demands for the house. The peak-demand rate of solar energy for house heating and water heating are of somewhat the same magnitude. Because of this it is possible to use a single auxiliary heater for both purposes, thus avoiding duplication of equipment.

VIII. REFRIGERATION BY SOLAR ENERGY

As of yet, the use of summer solar heat for the operation of absorption type refrigerators (dehumidifiers) is possible but not competitive on a cost basis with other types of mechanical

refrigeration. Therefore, in the long run, it is much more practical to use standard type cooling systems.

However, the use of the solar heating system may be used for cooling in the following way:

The large storage system may be used in conjunction with a small mechanical-refrigeration unit to provide complete summer air conditioning. The advantage of this arrangement lies in the fact that a $3/4$ -ton compressor may be used in place of a conventional 3-ton unit to give complete air conditioning; the $3/4$ -ton unit would run 24 hours a day, cooling the large storage system when no house cooling is needed.

Figure 4 shows a schematic layout for a solar-heated, summer air-conditioned house. The following features should be noted.

1. The large tank is solar heated in winter and mechanically cooled in summer. The small tank is heated by the furnace in winter and is solar heated in summer.

2. In winter, both tanks are used for heating; in summer the large tank is used for cooling and the small tank for heating.

3. In winter, the domestic water is preheated in the large tank before passing through the small tank for final heating. In summer, it is by-passed around the

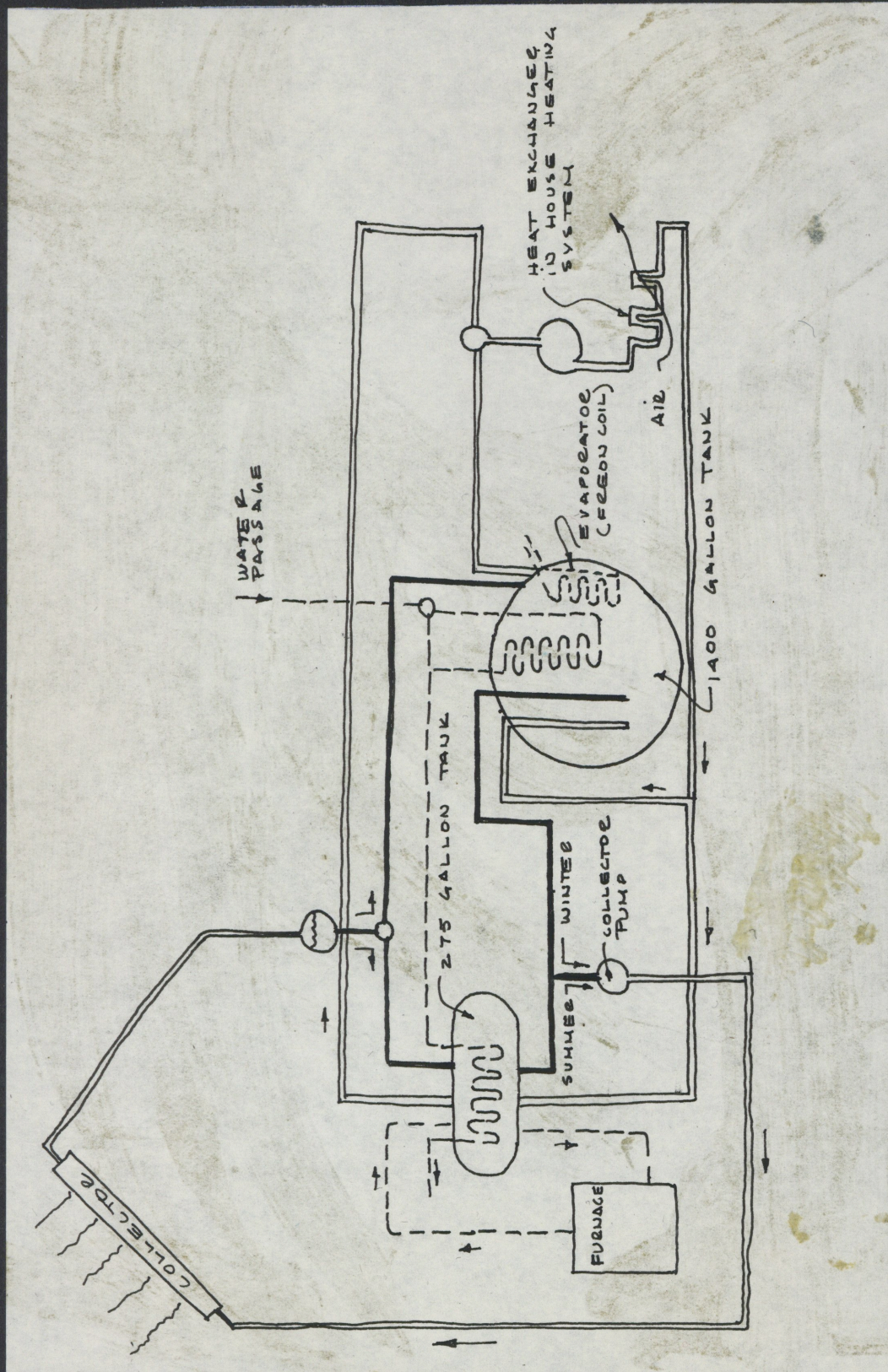


Figure 4
From: Ref. 1, p. 12

(mechanically cooled) large tank and is heated only in the small, solar-heated tank.

4. The heat exchanger and pump are used for solar heating, auxiliary heating, and summer cooling with complete automatic control.

5. The switch-over from winter to summer and back again each year requires manual switching of only two water valves (in the collector circuit and in the domestic-water circuit); all electrical controls may be made automatic.

IX. SOLAR HEATING AND THE FUTURE

Probably the largest determining factor in the future success of solar heating is whether or not it can compete economically with conventional heating systems. Two years ago solar heat collectors cost nearly \$2 per square foot for most applications, and their fixed charges usually exceeded the value of the fuel which they could save. Today, thanks to the improved design of the solar system the cost is well below \$1 per square foot.¹

¹"Solar Energy Today and Tomorrow", Journal of American Institute of Architects, April 1958, p. 198.

There are already many parts of the world where the solar collection system, including auxiliary heating and summer cooling, is already competing with conventional fuel burning systems. Figure 5 shows a perspective of a development of solar houses that will be built in the very near future at Spring Valley, New York. Sixteen solar houses are included in this project.¹

The Materials Policy Commission in 1952 predicted that by 1975 there will be thirteen million solar houses in the United States.² But in order to have the prophecy come true, there are still two major problems to be solved. The problems are:

1. improving the heat storage devices;
2. improving the heat operated refrigeration system.

The water tanks or rock piles which have been used successfully in the pioneering buildings in Albuquerque and Denver are too expensive and space consuming to be the ultimate goal in heat storage problems. They eventually must be replaced by

¹"Solar Heating For Houses", Progressive Architecture, March 1959, p. 202.

²"Solar Space Heating for Houses", Architectural Record, November, 1955, pp. 227-230.



Figure 5
From: Ref. 1, p. 12

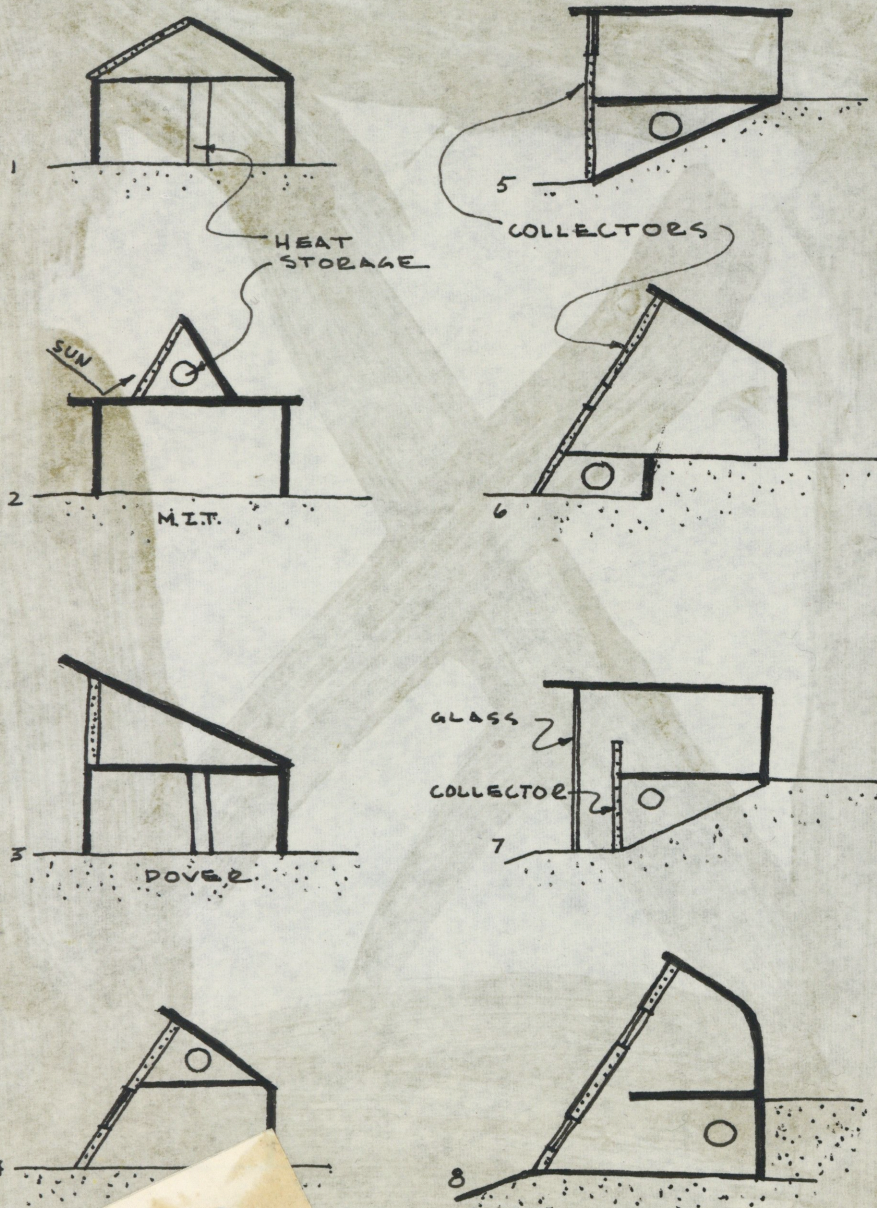


Figure 6
From: Ref. 1, p. 13

some other means which will store much more energy in less space and at a lower cost.

Throughout the south, winter heat is relatively inexpensive; but summer air conditioning is costly. The ultimate goal, then, is to have both the summer cooling needs and the winter heating needs met by the same system.

X. THE EFFECTS OF SOLAR HEATING ON DESIGN

Now that we have decided that there is a future for solar heating, and have studied the system to some extent, let us study what effect this new heating system will have on future design and whether or not the effect is good or bad. In our analysis of this system we have already become aware of many factors that would limit the freedom in architectural design.

Figure 6 shows sections through various designs of solar houses. It should be noted from these sections that the storage area is usually located in the central part of the house. This is done so that any heat loss from the storage area would contribute toward the heat load of the house.

In Figure 6, Number 1 shows a conventional house with one-half the sloping roof used as a collector. Unless the roof is made abnormally steep, the tilt of this collector would be

optimum in some latitudes, being more in need of cooling than heating. Number 2 shows the first M.I.T. house where an attempt was made to get a slight increment of incidence reflected from the aluminum roof. Number 3 is the Dover house with a slightly less favorable tilt but perhaps with better maintenance characteristics. In Number 4 the entire south wall has been tilted to a more advantageous angle and the roof and end wall areas have been slightly reduced. In Number 5 advantage has been taken of south-sloping terrain to increase the collector area. Number 6 has combined the advantages of Number 4 and Number 5 with two stories devoted to a sloping collector and window. In Number 7 the collector has been brought inside the house, the south window serving as one of the protective glass layers. Finally, Number 8 is a two story house that takes advantage of the insulation value of the soil wherever possible.¹

The degree of involvement of the house designer with solar considerations will vary according to whether his design objectives permit the use or avoidance of the available energy in contributing to comfortable conditions.

¹"Architectural Problems", by L. B. Anderson, Space Heating With Solar Energy, 1954, p. 113.

In designing the solar house all of the exposed surfaces have to be designed ~~and~~ from the point of view of its individual relation to solar incidence. In temperate climates the exclusion of unwanted radiation may be more of a problem than the absorption or transmission of radiation. In tropical latitudes the east and west walls, and the roof bear the brunt of solar incidence; the south and north walls can be open, with a certain amount of shading. In the southern United States because of the incidence increase and long summers, the north wall may be the only suitable one for large windows. And even in this area shading may be necessary for morning and afternoons of the longest days.

Still further northward, winter extremes begin to control; north wall glazing becomes a thermal liability and south wall glazing a great advantage.

In designing a solar house, the roof is always a very special problem. One of the most important controls in roof design is shading. The double roof enclosure or aerated attic, is itself a form of shading, but the most useful method of outdoor shading is by trees. Thus the designer should seek to place his building close to the north side of several large trees, whose lower branches can be pruned so that view, summer breeze and winter sun are not blocked, and so that the upper

portion of the trees will shade as much as possible, the roof and south, east and west walls during the hot summer months.

In Figures 7, 8, and 9 there are presented solar houses now operating in three different parts of the country. The purpose of showing these three buildings is to illustrate the progress that has been made to this date and to stimulate the imagination as to what might follow.

LÖF HOUSE, DENVER

Figure 7 shows pictures of the Löf House and a diagram of its heating system. The house has been planned to permit a southfacing patio to trap and control volumes of air. Also on the north side of the house an attempt has been made to hold warm air of midday as long as possible.

Air from the house can be made to enter the duct at its low point (68° F. to 70° F.) and gathered again at its high point after having absorbed heat directly from the sun. The super heated air is then forced through storage beds of hard granite gravel, where it deposits heat in direct proportion to the specific gravity of the storage material. The air is then recirculated through the system again to build up heat at those times when the house does not need heating.¹

¹"Solar Heating for Houses", Progressive Architecture, 1959, p. 204.

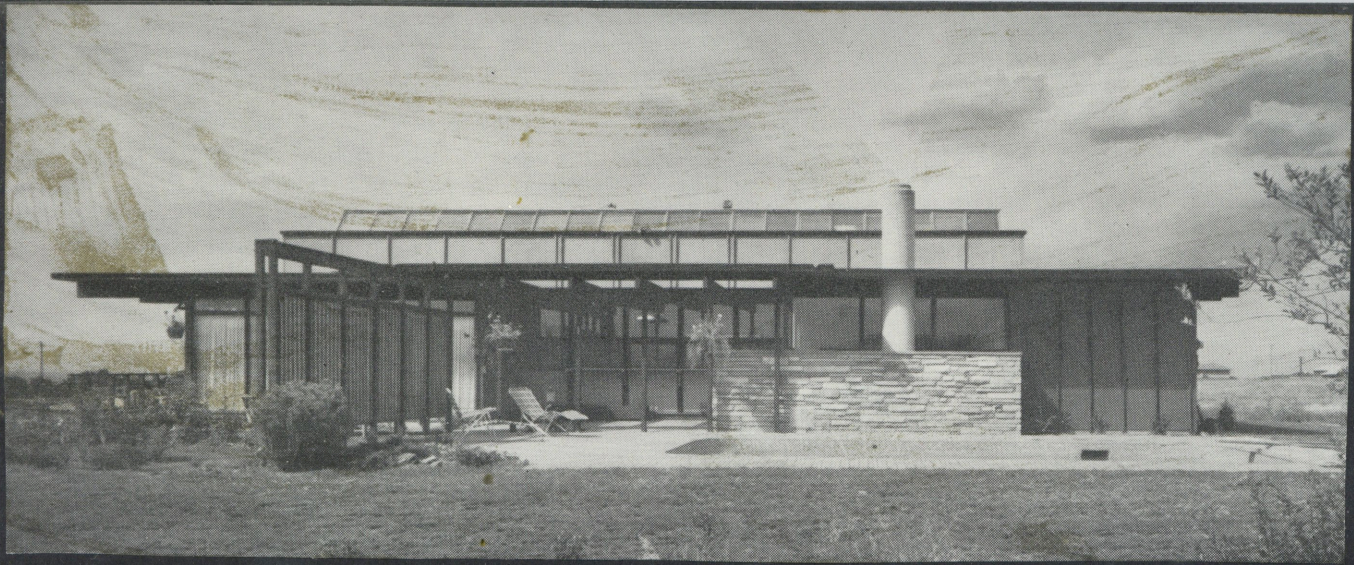
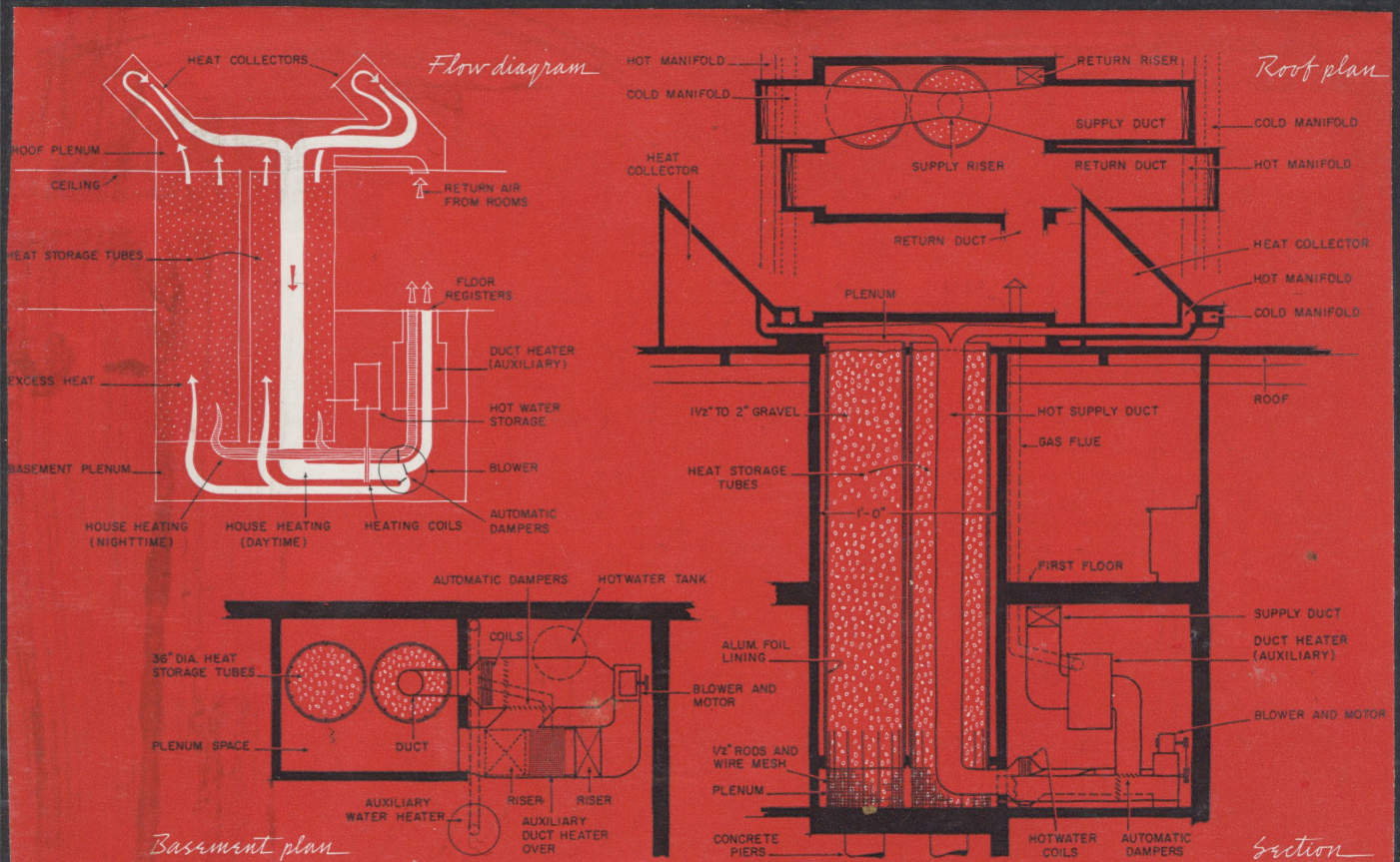


Figure 7
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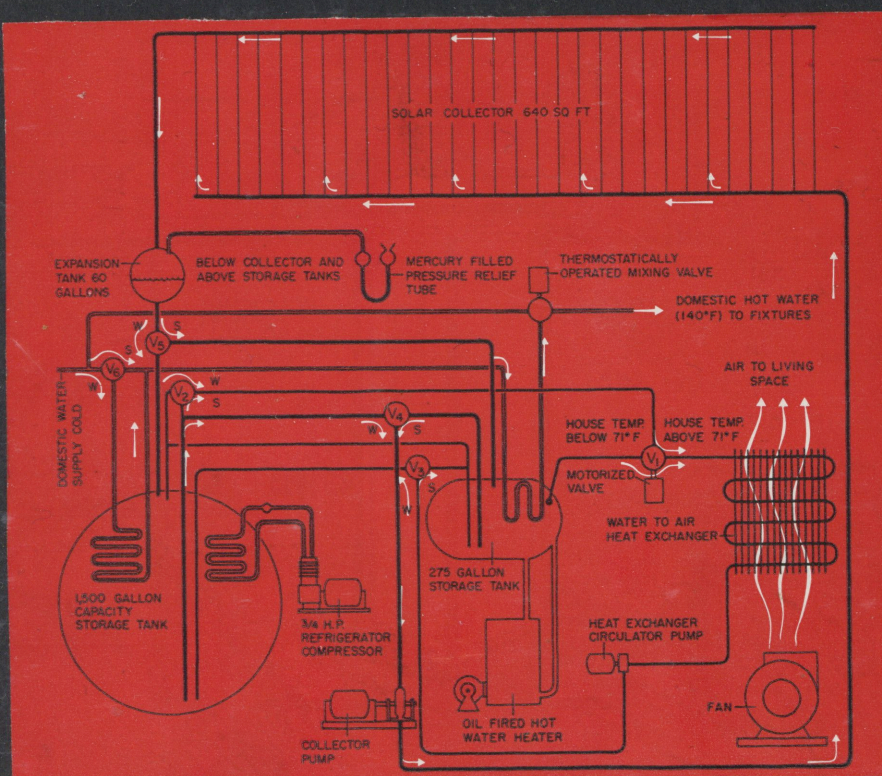
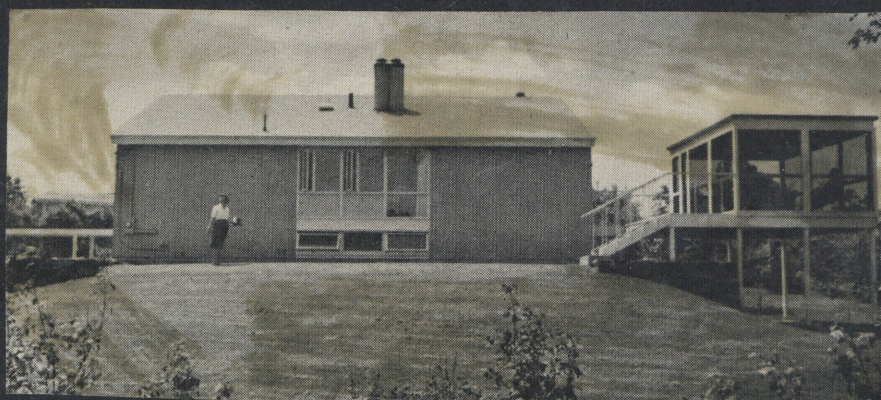
M.I.T. SOLAR HOUSE IV, LEXINGTON, MASSACHUSETTS

Figure 8 shows pictures of the M.I.T. solar house and a diagram of its heating system. This is the fourth house completed by M.I.T. researchers who have pioneered solar heating for twenty years. Located in suburban Boston, this two-story house has been sold to a private family but maintains a separate access for research personnel. The house has a total usable area of 1450 square feet. Its 60 degree tilt-collector consists of 640 square feet of glass, two layers thick, over a similar area of .025 inch thick aluminum sheet painted black. Water is circulated through copper tubes attached to the aluminum sheet and captured solar energy is transferred from the sheet to the water. To heat the house, the hot water is pumped through a heat exchanger which transfers heat to an air stream passing through ducts and registers.¹

¹"Solar Heating for Houses", Progressive Architecture, 1959, p. 206.



Figure 8
From: Ref. 1, p. 12



A.F.A.S.E. HOUSE, PHOENIX

Figure 9 shows a picture of the A.F.A.S.E. (Association for Applied Solar Energy) house and a diagram of its heating system. The house is an experiment in which the cost of a conventional heating system is being compared to a solar heating system. As of yet test results have not been completed.

At the heart of the system is a 2,000 gallon insulated water tank buried in the earth. Water tank temperature is raised by passing it through flat-plate solar collectors constituting the louvers over the central court, and the north and south patios. When the water temperature is higher than the house air, heat will be transferred directly from the water to the air through an exchanger. When the water temperature is lower than that of the house air, thermal energy will be transferred from the water to the house by a pump.¹

¹"Solar Heating for Houses", Progressive Architecture, 1959, p. 207.

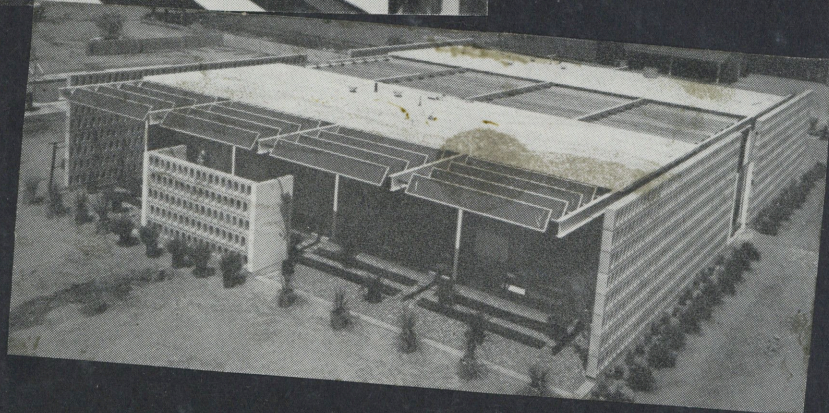
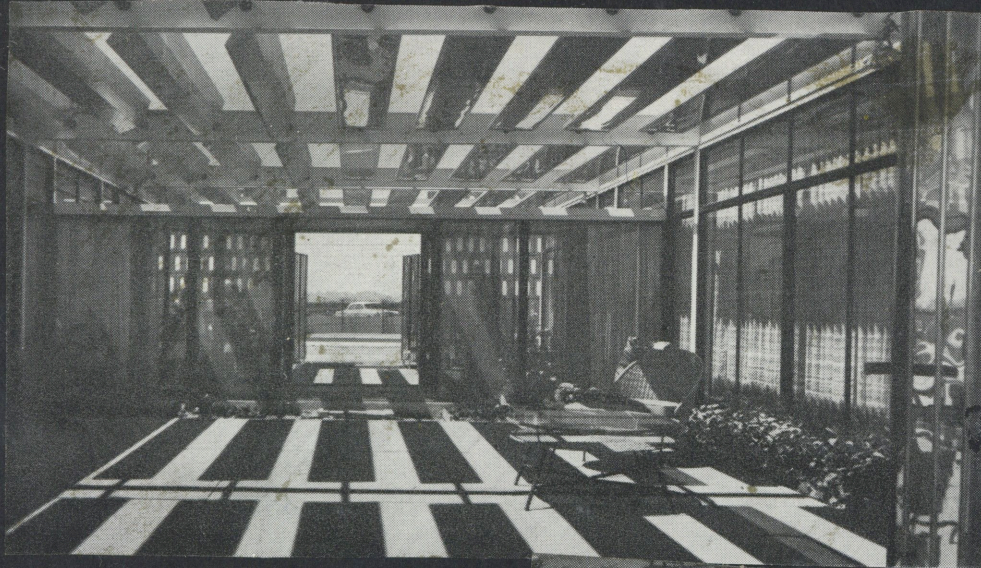
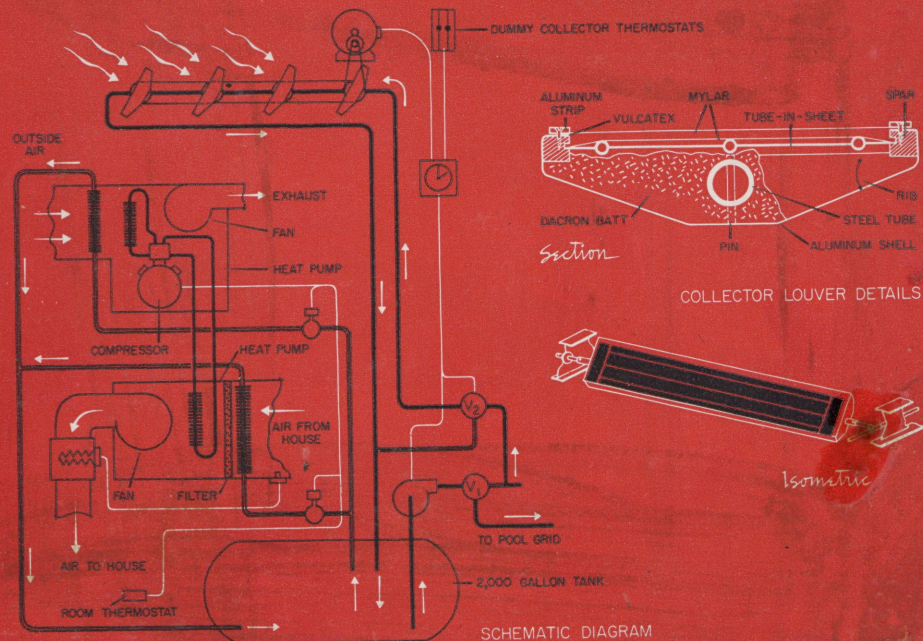
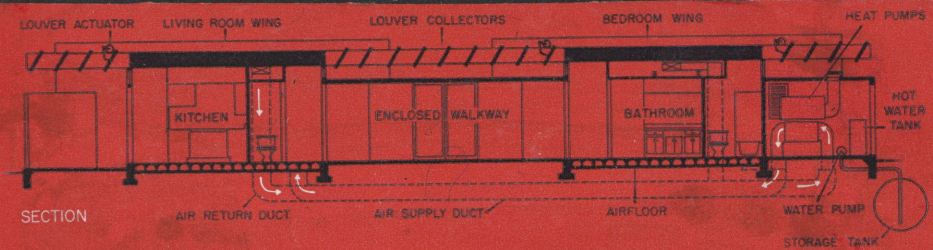


Figure 9
From: Ref. 1, p. 12



CONCLUSION

The use of energy from the sun for the purpose of space heating has long been an unfulfilled dream. And with the growth of a new architecture, it has become the subject of much trial and error experimentation of the architectural and engineering professions.

Because solar heating is still in the experimental stages it would be unjust to conclude presently, whether it is good or bad for architecture. However since the solar heated house is inevitable, in the near future, we must be aware of its advantages and disadvantages, so that we may realistically face the challenge that is before us.

The solar house, because it is designed to admit generous quantities of sunshine is a cheerful, healthful, relaxing and comfortable place to live. And from the sociological point of view this enhances and benefits family life. These factors alone are enough to give inestimable value to the solar heated house.

From an economic point of view, as previously mentioned, in many areas of the country, the solar house is already competing with conventional type heating systems. In two years of research the cost of a solar collector dropped from \$2

per square foot to \$1 to square foot. This certainly is an encouraging factor but because of the size of the collector and the amount of space it requires within the building it is still considered an uneconomical solution.

Now let us consider the solar house from a design standpoint or better still, an appearance standpoint.

What the final form of the solar house will be, of course, no one can say. However it can be seen thru the previous illustrations, the stereo-type design associated with the solar house.

And indeed how is it possible to have a variation in design when it is a necessity that certain large areas be located in certain positions in order to function properly. For instance, as previously mentioned, all solar houses have their heat storage area located in the center of the building. Also as previously mentioned, all solar houses must be designed to absorb as much sunshine in winter as possible. This necessitates that the most used rooms have a southern exposure. Secondary rooms, garages, storage and utility areas must face the north to act as buffers for the cold north winds. In the final analysis we find that in order to obtain a comparatively large portion of southerly exposed wall, a typical solar house will have to be long and narrow, closed to the north and open

to the south.

Another objection that might be noted from the previous illustrations is the factory-like appearance of the solar house. This, of course, is a result of the large amount of mechanical equipment placed in the envelope of a small building. Thus one of the big problems in designing a solar house is how to effectively conceal all the mechanical equipment in order to keep the house looking like a house.

In essence then, the challenge of the solar house is twofold: a challenge to the architect for new and better solar design possibilities, and a challenge to the mechanical engineer for new, more efficient media for the solar heating system.

As this challenge is answered and these problems solved, architecture will enter a new phase -- the age of the solar heated building.

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