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SCHUSTER, D. H. (Department of Psychology, Iowa State University, Ames, Iowa 50011). Construction and Evaluation of a Small Solar-Heated Building. Proc. Iowa Acad. Sci. 83(2): 77-80, 1976. A small (16' X 18') solar-heated building has been built in Ames and data have been collected to evaluate it in several ways. The first objective was to evaluate the effectiveness of solar heating in maintaining specified building temperatures. The second objective was to compare the cost of adding solar heating to the building with the cost of heating it electrically over many years to a break-even point. The plan of the evaluation used the building as its own control in a time series design. For one week, the building was operated with electrical nighttime heating. For the next alternate week, the building was operated with nighttime heat energy stored from daytime collection of solar energy. Preliminary indications are that solar heating of existing homes and of new houses in Iowa may be a practical way of helping to solve current energy demands.

The purpose of this research project was to build and evaluate a small solar-heated building. The writer felt a personal need for empirical data on a solar-heated building approximately two years ago. The energy crisis of the 1973-74 winter prompted the decision to go ahead with constructing a small building to be used as a greenhouse to gather experience as cheaply as possible. Depending on a satisfactory outcome, thought has been given to applying the knowledge gained from this study to the solar heating of existing homes as a second step. The technical information can be extrapolated to supplemental solar heating of houses readily. No one in the Ames area currently has local and up-to-date information on the technical and financial aspects of solar heating for small buildings. Data from this project should help fill this lack. Data from the contemplated add-on solar heating project would help definitively; a separate proposal to an agency such as Housing and Urban Development is envisioned as one possibility.

Literature review. The scientific community is concerned with the energy problem; one entire issue of *Science* (4-19-74) was devoted to energy. Hammond (1974) discussed solar heating in houses as part of the trend toward energy self-sufficiency. Metz (1974) pointed out that the academic community can train badly needed researchers and do the research required to solve the energy problem. Wolf (1974) pointed out that solar energy could make a significant input to US energy consumption by 1980, but that careful R & D needs doing first. Moss (1974) chaired the committee that led to the US Solar heating and cooling demonstration act.

Several national workshops on energy have been held . . . Donovan et al. (1972) chaired such a workshop on solar energy. Allen (1973) edited the proceeding of a solar energy workshop devoted to US building applications.

The article that triggered the writer's decision and design was the article by Chahroudi (1971). The present building design is a modification and extension of his that incorporates various features gleaned from the previous references.

Description of solar-heated building. Fig. 1 gives a side view of the present structure, looking west. The floor plan is 16 X 18 feet. The theory of operation for this structure is as follows. The sun's rays enter the warm room through the solar panel, or double storm window of vinyl plastic. The blackened walls and floor, and plants absorb this radiant energy (insolation), heating the air in this room. A fan circulates this warmed air through a concrete end channel down 3 to 4 feet under the floor. Heat energy transfers through the hollow concrete forms into moist dirt which serves as the heat storage medium.

At night the energy transfer changes. When the sun sets or on cloudy days with insufficient insolation, an overhead door moves down over the rear of the solar panels, acting as an insulating shutter to reduce losses due to back radiation to a minimum. The fan continues to circulate air through the warm room and the subterranean air ducts. However, heat flow now is from the heated moist dirt into the flowing air then into the warm room.

There are several methods of controlling temperature. While daytime temperatures in the warm room are expected to range from 65°F. to 75°F., nighttime temperatures should be about 60°F to 65°F. Dual thermostats are used to regulate air flow to maintain specified temperatures, such as 70°F. daytime and 65°F. nighttime. If the daytime temperature rises appreciably over this set temperature (75°F.) and the heat reservoir is fully charged, the exhaust fan dumps the undesired extra heat energy from insolation to the outside air automatically. Conversely, at night if the warm room temperature starts to drop below the present limit (65°F.) and the heat reservoir is nearly depleted, an auxiliary space heater (not shown) prevents further lowering of temperature.

The building is better-than-usually well insulated. The roof is insulated with an 8'' air space filled with fiberglass insulation. The exterior walls have 6'' of the same insulation. Underground, heat is prevented from leaking away laterally by 1'' thick slabs of foamed polyurethane plastic insulation. There is no concern for heat energy's transferring vertically through the concrete floor or down into the ground below the air ducts, as this can be recovered.

A small cool room is provided for storage of tools, research instrumentation and general storage. This room is separated by a 4'' thick wall from the warm room. A separate thermostat and circulating fan maintain cool room temperature at about 55°F.

Details of the theoretical thermal analysis (after Chahroudi, 1971) are given in Table 1. Anticipated insolation provides 70,000 BTU input per day on the average, to be offset by comparable losses including charging the heat battery. While the heat battery can store 500,000 BTU, only the first 5/8ths of this is available for heating. This means that once the heat reservoir is fully charged after many sunny days consecutively, that the heat reservoir alone should keep the warm room temperature at or above the minimum temperature of 65°F. for five cloudy days in a row. Then the electric space heater would kick in to maintain the set temperature. This five day figure ignores any daytime infrared heating on partially cloudy days; this heating extends the five day figure.

Next, a financial analysis of actual expenses to construct the solar-heated building is shown in Table 2. Total estimated cost was $4300. Assume that approximately $1000 of this is for making the building solar heated.

The amortization of this solar heating capital cost can be figured as follows. At present electric utility rates, $30 per year would heat a similar well-insulated building of 300 square feet of floor space. (This

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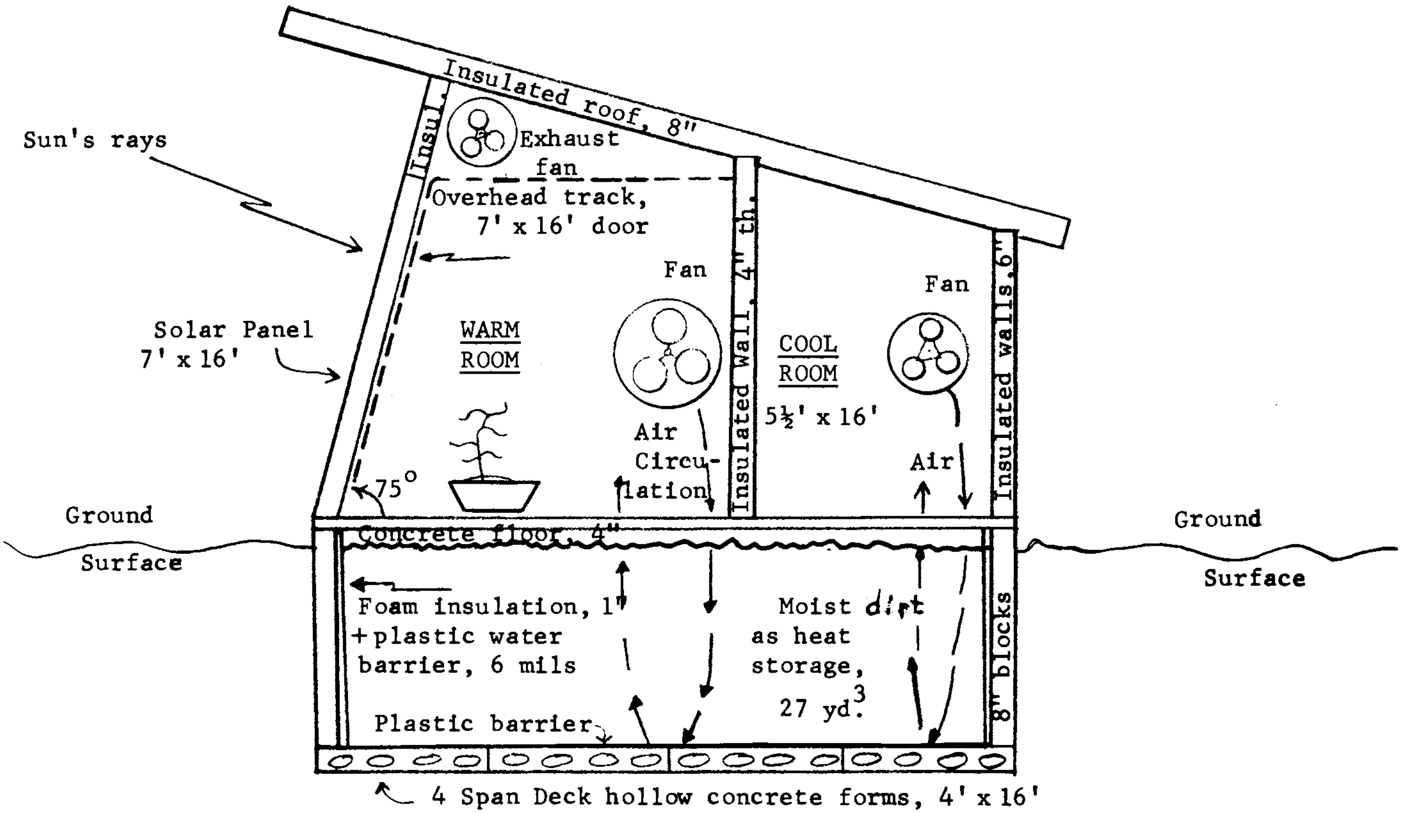

Fig. 1. Solar heated building, vertical cross-section, side view 4-3-74

figure is felt to be quite conservative.) Thus the solar heating component of the edifice would be amortized in 33 years at today's electric rates. However, electric utility rates are expected to quintuple in the next five years. This would lower the payoff period to seven years; this would make solar heating very attractive for homes!

The previous figures are estimates and actual data from this research will be used to refine these calculations.

Research design. Temperature and electric heating data were collected this winter (Jan. to Apr. 1975) to evaluate the effectiveness of solar heating in this building. The basic plan used the experimental edifice as its own control in a time series design. A time period of 14 days was used. For one week, the building was operated with solar heating during the day but with the heat reservoir shut off so that nighttime and cloudy day heating was done electrically. For the next week, the building operated with daytime solar heating plus nighttime heating from the subterreanean heat battery and supplemented as needed by electric heating. This cycle repeated every two weeks. The solar battery had its air flow blocked off during the week of non-use; its temperature at the start of the following week was about where it was when the previous charging-discharging cycle stopped.

The research objectives of this project were, 1. to evaluate the effectiveness of solar heating in keeping specified day and night temperatures in the building, and 2. to compare the cost of adding solar heating to the building with the cost of electrically heating it over many years to a break-even point.

Two basic and related questions concerning effectiveness were: when operating with heat storage, is solar heating alone adequate to maintain the desired day-night temperatures? What is the ratio of electric heating required in the two time periods, that is, electric heating used as a supplement to solar heating vs. electricity is the primary heat source? Several thermometers are required for measuring temperatures of the outside air, warm and cool rooms, and heat battery. The temperatures were recorded manually at the same times each day at about 7 AM and 6 PM. A watt-hour meter was used to record electric power consumed daily by the space heater in the warm room. An integrating and recording solar radiometer would have been desirable to record insolation; one was not available for loan. Instead a visual rating was made daily on a 1-9 scale of the amount of sunshine during the day.

Results and Discussion. The results for the two separate phases in the evaluation of the solar-heated building are presented separately. First, data are presented for the survival solar heating experiment where the building was kept at a low temperature, but well above freezing, and secondly where the building was maintained near room temperatures desirable for human dwelling.

Phase I. The statistical data for the first experiment to see how well solar heating would keep the building just barely above freezing during February, 1975, are presented in Table 3. A number of not too surprising characteristics are obvious in the table, the dirt mass for solar heat storage heated up significantly approximately one degree from morning to each evening, in spite of the fact that February 1975, had appreciably more cloudy days than average. The outside air temperature also increased significantly from morning to evening. Room wall temperature increased significantly from morning to evening which does indirectly indicate the influence of solar heating during the day.

Considerable interest centers around the fact that the total nighttime number of supplemental electric heater hours was significantly greater than the total daytime average heater hours (0.72 average per night vs. 0.30 hours per day). This is obviously attributable to the direct solar heating or insolation during the daytime. The last major datum of interest is that when stored solar heat was used at night, significantly less supplemental electric heat was used than when the stored solar heat was blocked. The averages were 0.33 hours of heater time each night when solar heat was used vs. 1.12 hours when it was blocked.

The two empirical regression equations that relate the amount of supplemental electric heat required in this solar-heated building are also shown in Table 1. The number of supplemental heater hours during the daytime was inversely related first to the morning dirt storage mass temperature and secondly to the rating of the amount of sunshine received that day. This was only a low-level correlation; probably measurement error in the setting of the heater thermostat and in the author's rating or measurement of the amount of sunshine contributed to the relatively low predictability of only 8% of the variability of the daytime heater hours.

Table 1. *Thermal analysis of solar-heated building*

Heat inputs

Angle of solar panel: 27° (Sun's seasonal dec) + lat. 42° = 69° optimum.

Sun is lower at 10 A.M. & 2 P.M., therefore use 75°.

Assume 50% cloud cover, this corresponds to 770 BTU/ft² day.

Transmission factor of 1.8, panels are ⊥ to sun, not flat.

Vinyl transmission of 0.75, 1-15 mil layer + 4-4 mils = 30 mils PVC.

Wall absorption factor = 0.7.

Panel area, excluding sides & stretchers = 98 ft².

Heat input = 770 BTU/day - ft² X 1.8 X 0.75 X 0.7 X 98 ft² = **71,300** BTU/day

Heat losses

Assume panels open 8h./day, 85°F. inside & 30°F. outside:

0.5 BTU/hr. ft² °F X 8ʰ X 55°F. X 98 ft² = *21,500* BTU loss

At night, (65°F.) panels are insulated with 6'' rock wool fiberglass:

0.06 BTU/hr. ft² °F. X 16h. X 98 ft² X 35°F. = *3,290* BTU loss

Walls & roof loss, 6'' fiberglass insulation:

0.06 BTU/hr. - ft² °F. X 24h. X 646 ft² X 40°F. Ave. = *37,100* BTU loss

Assume air leak & storage loss of *9,410* BTU/day

Total daily heat loss = **71,300** BTU

Heat storage

Assume △ T = 85°F. stored - 65° F. used = 20°F.

Wet compact dirt capacity = 30 BTU/ft³ °F.

Volume = 16' x 16' x 3.5' = 900 ft³

Capacity = 30 BTU/ft³ °F. x 900 ft³ x 20°F. = *560,000* BTU (8 day supply)

Conductivity, wet dirt = 1.5 BTU/ft² °F.h.

Contact area = 256 ft², ignoring ends.

If ⅜ capacity, △ T = 7.5°F.

Heat output = 1.5 BTU/ft² °F.h. x 256 ft² x 7.5°F. x 24 h. = 69,100 BTU/day

Table 2. *Construction expenses for solar heated building*

Description	Cost
Electrical	328.92
Foundation & underground	1374.23
Lumber	1323.00
Labor*	850.00
Tools	140.09
Plumbing	104.21
Panels, solar	177.50
Combined Total:	$4297.95

*None of the writer's time is included.

Table 3. *Data for Survival Solar Heating Experiment, Feb., 1975 (N=30 Days)*

General Characteristics

Datum	Average	Stan. Deviation	t
Temperature, dirt mass, 7 a.m.	45.97	2.21	
Temperature, dirt mass, 6 p.m.	47.20	2.50	4.16**
Temperature, outside air, 7 a.m.	15.97	11.20	
Temperature, outside air, 6 p.m.	23.80	9.14	4.48**
Temperature, room wall, 7 a.m.	47.87	2.86	
Temperature, room wall, 6 p.m.	57.10	7.34	6.22**
Heater hours, nighttime, solar heat used	0.33	0.68	
solar heat blocked	1.12	0.76	2.91**
Heater hours, total nighttime	0.72	0.82	
total daytime	0.30	0.38	3.30**
Sunshine amount, 1-9 rating	5.00	2.57	

**p ∠ .01

Regression Equations

Heater hours, daytime =
-0.028 Dirt temperature, 7 a.m. +
-0.036 Sunshine amount +
1.748 Hours

($R=0.283$, $R^2=.081$)

Heater hours, nighttime =
-0.211 Dirt temperature, 6 p.m. +
-0.682 Night solar heating, if used +
11.681 Hours

($R=0.775$, $R^2=0.601$)

The amount of nighttime supplemental heater hours was inversely related first to the dirt storage mass temperature at the start of the evening and secondly to whether nighttime stored solar heating was used or not. In this case, 60% of the variability of the nighttime supplemental heating was predicted by these two variables, showing very good predictability indeed.

Phase II. The statistical data for the second experiment to see how well solar heating would keep the building at normal "home" tempera-

Table 4. *Data for Home Solar Heating Experiment, March, 1975 (N=28 Days)*

General Characteristics

Datum	**Average**	**Stan. Deviation**	**t**
Temperature, dirt mass, 7 a.m.	65.36	0.67	
Temperature, dirt mass, 6 p.m.	65.79	1.01	2.36*
Temperature, outside air, 7 a.m.	26.18	9.69	
Temperature, outside air, 6 p.m.	33.57	11.01	5.62**
Temperature, room wall, 7 a.m.	64.82	1.39	
Temperature, room wall, 6 p.m.	67.86	2.91	4.31**
Heater hours, nighttime,			
shutter used	7.32	4.23	
shutter not used	7.35	3.89	0.02
Heater hours,			
total nighttime	7.34	4.07	
total daytime	3.45	2.90	6.57**
Sunshine amount, 1-9 rating	4.89	2.73	—

*p < .05, **P < .01.

Regression Equations

Heater hours, daytime =
-0.79 Amount sunshine +
-0.08 External air temperature, AM +
-0.06 External air temperature, PM +
-0.61 Dirt mass temperature, AM +
51.46 Hours.
($R = 0.820$, $R^2 = 0.672$)

Heater hours, nighttime =
-0.20 External air temperature, PM +
-2.06 Dirt mass temperature, PM +
149.14 Hours.
($R = 0.776$, $R^2 = 0.603$)

tures are presented in Table 4. The heat storage thermostat was set to put heat into the dirt mass when the room temperature exceeded 70°F. The room heating thermostat was set to extract heat from the dirt storage mass when the room temperature dropped to 65°F. or below. These two temperatures were on approximation to "normal" human dwelling temperatures.

Many results shown in Table 4 are not surprising. The evening temperatures exceeded morning temperatures for the dirt mass, outside air and wall thermometers. The amount of nighttime supplemental heating was about double that for daytime.

One unanticipated result from Table 4 is that the use of the shutter at night to block the infrared radiation heat loss showed no significant effect: the number of nighttime heater hours was independent of whether the shutter was used or not. The shutter had been included in the design to cut nighttime radiation losses. For instance, Telkes (1949) reported that expanses of glass in houses lost much heat at night and on cloudy days. There are several possible explanations for the result here. First and most likely, the shutter was yet a good infrared radiator in spite of its white outer surface. Second was a ramdom error in the supplemental heater hours. The thermostat on the supplemental heater could not be set repeatably to 64°F.; it drifted randomly. (This has been corrected since this report by using a two stage thermostat to ensure that stored solar heat will always be utilized first if sufficient. If not, then supplemental electric heating will be used.)

The regression equations to predict hours of heater usage are shown at the bottom of Table 4. Variables are listed in order of their contributing to supplemental heating hours. The number of daytime heater hours was inversely related, in order, to the amount of sunshine, the external air temperature and least to the morning storage mass temperature. The amount of prediction is quite significant practically, as over 67% of the variance in heater hours was accounted for.

The second equation shows that the number of nighttime heater hours was predicted inversely first by the evening outside air temperature and the evening dirt mass storage temperature. It should be noted that the use or not of the radiation shutter did not enter into this equation; the shutter usage variable was included in the correlation matrix used by the stepwise multiple regression program. Again, the number of electric heater hours at night could be predicted quite well; its shared variance was 60%.

Summary. A small solar heated building was designed, constructed and data collected for its operation from January 1975 to April 1975. These points are made:

1. A thermal heat balance analysis was calculated.
2. Cost data for construction, ignoring the author's time, are presented.
3. Data on daytime solar heating are presented.
4. The use of stored solar energy for nighttime heating reduced the need for supplemental heat.
5. Using a shutter at night to block infrared radiation loss was not beneficial.
6. Based on the above, solar heating of new or existing homes in Iowa appears to have considerable potential and should be researched further.

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