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DESIGN METHODOLOGIES FOR ENERGY CONSERVATION AND PASSIVE HEATING OF BUILDINGS UTILIZING IMPROVED BUILDING COMPONENTS

Progress Report

January 15, 1978 to April 15, 1978

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PROGRESS REPORT

January 15, 1978 to April 15, 1978

This contract is concerned with gaining data on the performance and marketing of lightweight ceiling thermal storage materials, transparent insulation assemblies, and specialized louvers to direct light to the ceiling. A 900 square foot building (called Solar 5) has been constructed with separate monies to test these materials.

The enclosed paper (presented at the DOE Passive Heating Conference) shows the first month's performance of the MIT Solar Building 5. The additional single sheet details preliminary performance for the subsequent month of March. The monthly solar heating fraction has been about 8% below expectations. This is due to a building skin thermal loss that is slightly higher than predicted. The cause of the extra skin losses is not known at this point, but the results of a thermograph study conducted on April 14 are being used to track down the difficulties.

The updated economic analysis included in this report reflects the latest price projections of the various component manufacturers and performance predictions that have been projected from the Solar Building 5 data. Payback periods are in the 10 year range. This period would be reduced to 7 years if the louvers were charged off to window dressing rather than the solar heating function.

The marketing study for the various components is under way and will be reported on in the project's final report.

PRELIMINARY PERFORMANCE OF THE
MIT SOLAR BUILDING 5†

by

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ABSTRACT

The recently completed MIT Solar Building 5 demonstrates direct gain solar space heating through the use of new architectural finish materials. February 1978 measurements are summarized in this report. Results indicate the building performed nearly as expected.

INTRODUCTION

MIT Solar Building 5 was completed for monitoring purposes on January 27, 1978. The 866 ft^2 building (Fig. 1) is a single, one story space that is used as a studio-classroom (Fig. 2) by the MIT Department of Architecture. Solar heating is accomplished by directing insolation to dark colored ceiling tiles containing a phase change material for storage and temperature regulation. Window losses are minimized by inserting a 'heat mirror' between two layers of glass.

Building Description

The 866 ft^2 building has 817 ft^2 of heated space with a 10 foot high ceiling. Solar hea is provided by 180 ft of special south facing glazing. Additional natural light is provided by 30 ft^2 of northern double glazing and 15 ft^2 of east facing glazing. Heat is stored in 88 ft^2 of special tiles placed on the window settees and 400 ft^2 of ceiling tiles. Although the entire 817 ft^2 ceiling is tiled with the new storage tile, only the front half participates in the storage function. The building is insulated with 6 inches of fiberglass batt in the walls, and 11 inches in the ceiling. The floor is a 4 inch slab on a grade with 4 inch styrofoam perimeter insulation extending down an equivalent of 4 feet. Air exchange rates are kept low through the use of a vestibule. Measured thermal losses due to infiltration and conduction are 280 BTU/hr°F.

† Work reported in this paper has been supported in part by the Department of Energy Solar Heating and Cooling Research and Development branch, Office of Conservation and Solar Applications.

Material Descriptions

The southern windows are a composite of several materials. The assembly, working from the outside in, is Float Glass (furnished by PPG Industries), 3/4 inch air gap, double sided Heat Mirror (developed and fabricated by Suntek Research Assoc.), modified louvers (fabricated by Rolscreen Co.) in a 3/4 inch air gap, and Float Glass. The overall calculated heat conductance for the glazing assembly is 0.15 BTU/hrft^2°F.

The major contribution to this low heat conductance is the Heat Mirror, a transparent insulation composed of a polymer substrate coated on both sides with a vacuum deposited transparent selective surface. The coating exhibits an emissivity of 20% to long wave thermal radiation and a 70% transparency to solar radiation. Overall solar transmission of the southern glazing is 59%. The view through the window assembly is clear and undistorted. At the time of this writing, only one of the south windows has Heat Mirror installed due to slipping delivery dates. The presence of missing Heat Mirror is simulated by a 750 watt base board heater that supplies energy that would not be normally lost through the remaining 7 windows during sunless hours.

Insolation is directed to the dark colored ceiling by reflecting louvers [1] placed in the southern windows. The movable louvers are designed to minimize interferance with views while offering the occupant control over the visual environment. Figure 3 shows the louver cross section for accepting a wide range of solar profile angles while remaining fixed. This particular design requires

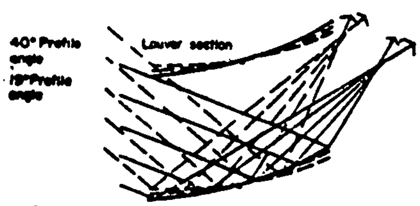


Fig. 3 Louver section accommodating 19–40° profile angle range.

only six adjustments during the heating season to keep all reflected solar energy on the ceiling. Large area source glare and glare due to high light intensity ratios is eliminated by the louvers since sunlight is reflected harmlessly over the occupants' heads.

The polymer concrete ceiling tiles, two feet square and only one inch thick, are the storage component of the system (Figure 4). Their chemical core - a

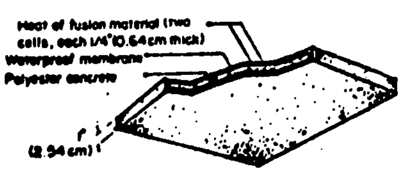


Fig. 4. Solar ceiling tile construction.

combination of sodium sulphate and water (Glauber's salts), Cab-O-Sil fumed silica, borax and sodium chloride - stores a day's heat and then releases the retained heat as needed. Because the core stores heat latently at 73°F, it maintains nearly a constant room temperature and thus prevents overheating, which normally is wasted heat. At night, as the outside temperatures drop, the chemical core sealed within the tile parcels out enough heat to maintain room temperature near its daytime level. The core, therefore, acts as a built-in thermostat to stabilise the temperature in the room.

The tile stores 220 BTU/ft^2 over a 10°F swing and weighs 11 lbs/ft^2. Over 2400 freeze-thaw cycles have been accumulated with no sign of aging. Aging problems have been overcome by packaging the appropriately thickened salts in two adjacent 3/8 inch layers that are thin enough to approximate the long dimension of a Glauber salt crystal.

The chemical core was developed at MIT and produced for the MIT demonstration facility by the Cab-O-Sil Division of Cabot Corporation at its Billerica, MA research laboratories.

The ceiling tiles, marketed under the trade name Sol-Ar-Tile, are composed of waterproof polymer concrete that can be colored and textured to simulate architectural building materials.

The tiles were developed at MIT with the assistance of Architectural Research Corporation of Livonia, Michigan. Their use in storing solar energy is not restricted to ceilings, however, and some of the heat collecting tiles have been installed in settees below the windows in the solar heated building.

Monitoring Equipment

The auxiliary electric base board heaters are monitored with a separate watt/hr meter. Overall electric consumption is displayed by the power company meter. Insolation is measured by a glazed vertical, south facing photovoltaic cell. The cell has not been calibrated at this time and only relative measurements are presented in the subsequent sections. Tile core temperatures, outdoor air temperatures and room air temperatures are measured with linear thermistor arrays and recorded on strip chart recorders. Fourteen other temperatures are currently being monitored by a digital data logger which places the information on a magnetic tape cassette. The tape cassettes have not been processed at the time of this writing due to difficulties in interfacing the recorder with our off-site computer. All information is sampled and recorded once an hour.

Building Performance

The reported measurements were logged between February 5, 1978 and March 4, 1978. Although monitoring began January 27, the building did not exhibit representative weather skin losses until February 5, when construction was essentially completed. Table 1 shows average daytime and nighttime outdoor temperatures for the 28 day period.

TABLE 1

Average outdoor temperatures and % clear day insolation

Date	Average Daytime Temperature (°F)	Average Nightime Temperature (°F)	% Clear Day Insolation
Feb. 5	27	13.7	50
6	29.5	29	0
7	32.9	31.8	0
8	39.8	26.8	100
9	39.8	26.5	100
10	33.4	20.3	100
11	33.4	26	90
12	37.5	28.3	40
13	42.1	31.8	50
14	37.5	29.5	0
15	39.8	32.9	0
16	45.6	36.4	80
17	49.4	35.2	20
18	42.1	35	15
19	35.2	22.6	80
20	36.4	26.0	90
21	36.4	24	80
22	36	24	80
23	39.8	30.6	10
24	39.8	32.9	80
25	41.5	32.2	80
26	39.2	29.8	80
27	36.9	25	90
28	34.5	25	90
March 1	34.5	19.3	80
2	29.8	20.5	90
3	31.0	27.5	10
4	22	18.1	20

Building skin losses were measured on February 7 under windless conditions by monitoring the auxiliary heating use after two cloudy days had exhausted the stored energy in the building. Using the measured loss of 280 BTU/hr°F and noting the difference between indoor and outdoor temperatures throughout the 28 day period, the building heating requirement was calcualted to be 5,835,144 BTU or 1710 kw/hr. Coincidently, this load corresponds closely to the normal degree day load published for the Boston area. Table 2 summarizes the various internal gains measured during the period.

TABLE 2

Measured internal gains compared with computed building load for February 5 through March 4, 1978

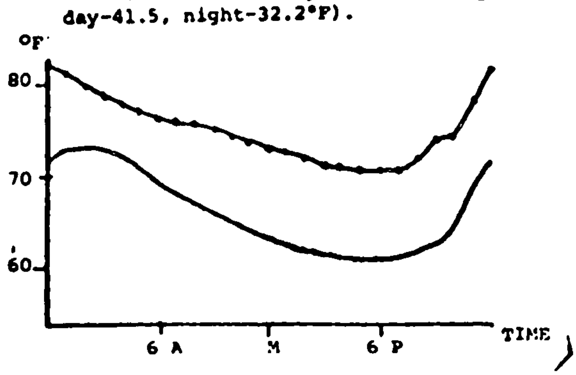
Computed load	1710 kw
Baseboard heating energy	459 kw
% heat supplied by auxiliary	26.8%
Gains from lights and people	241 kw
% heat supplied by internal gains	14%
% heat supplied by solar energy	59.2%

The solar heating fraction of 59.2% is artificially high since the insolation was 15% higher than normal. However, the building has not yet reached its full level of insulation. It is planned to install Heat Mirrors on the north and east casement windows. This missing Heat Mirror was not simulated as the missing south Heat Mirror was. Also, the 7 south windows that are without Heat Mirror are not fully sealed at this point, and infiltration rates are still higher than expected. It is assumed that a 15% reduction in the building skin losses can be easily achieved by installing the remaining Heat Mirrors. Thus,one can still expect a 60% solar heating fraction for a normal February since the reduced building skin losses will compensate for the reduced insolation.

It is possible to use February data to form a rough estimate of the solar heating fraction for the entire heating season using published climate data. A 75% solar heating fraction is expected under these assumptions. Internal gains are expected to furnish another 10% of the season's heating requirement.

Figure 5 shows typical room air and tile core temperatures over a 24 hour period bordered with 2 sunny days.

FIG.5 Tile and room air temperature for Feb. 25-26, 1978 (90% sun. Average outdoor temp; day-41.5, night-32.2°F).



The room air temperature is measured at the 5 foot level near the thermostat mounted at the south-east corner of the building. The ceiling tile core temperature is measured with a thermistor cast in place at the louver interface between the modified Glauber's salt and the polymer concrete. The ceiling tile is located at the center of the building and 2 feet away from the south windows. The tile temperature profile does not show much of a plateau at the phase change temperature since the moving crystal front offers an increasing resistance to heat flow. The highest the room air temperature ever hit in February was 74°F. This occurred on a 80% sunny day with a daytime outdoor air temperature high of 45.6°F. Before the tiles were installed, similar weather conditions generated indoor temperatures of 85°F.

Carry through was measured during a cloudy period when day and night outdoor air temperatures remained at 29°F. No internal gains occurred from light or appliances during this period. The tiles lost their charge 24 hours after sunset. If the remaining Heat Mirror had been installed, the February carry through would have been 28 hours. It is estimated that half the heat liberated in this period came from the 4 inch concrete floor slab and 5/8 inch thick drywall which underwent a 11°F drop in temperature. Normal internal gains from lights of 2.2 kw/hr would have extended the carry through to 34 hours after sunset.

SUMMARY

Direct gain solar heating using the described architectural finish materials provides a significant February solar heating fraction of 60% for the MIT Solar Building 5. This is achieved by glazing only 45% of the south wall with the new window materials. (Or alternately, the window area is 22% of the floor area.) Monitoring is continuing for the remainder of the heating season.

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TABLE 3

Average outdoor temperatures and % clear day insolation for March

Date	Average Daytime Temperature (°F)	Average Nightime Temperature (°F)	%Clear day Insolation
March 5	29.9	21.7	100
6	35.7	26.4	100
7	38.1	24.0	100
8	41.6	29.9	56
9	41.6	31.0	83
10	45.1	34.1	22
11	46.0	39.2	72
12	51.4	39.7	33
13	39.9	33.8	82
14	42.0	47.0	0
15	49.1	38.1	47
16	42.7	33.4	0
17	48.6	31.0	35
18	40.4	32.2	47
19	46.7	37.4	35
20	41.6	35.7	86
21	56.8	48.6	69
22	48.5	40.4	63
23	57.9	43.9	75
24	52.1	29.8	87
25	41.5	36.9	80
26	46.0	47.2	0
27	46.2	47.0	0
28	53.4	46.4	56
29	59.7	37.5	86
30	46.4	38.2	100
31	48.7	40.1	50
April 1	52.9	47.5	0
2	42.9	31.7	80
3	44.0	37.5	80

March Building Performance

Table 3 shows the average daytime and nighttime outdoor temperatures for the following 30 day period beginning March 5, 1978. Using the same measured building skin loss of 280 BTU/hr°F as was used in the February analysis, the heating required computed to be 1483 KWH. This load also coincides with normal degree day loads published for the Boston area. Table 4 summarizes the various internal gains measured during the period.

Solar radiation for the month was about 10% higher than normal but, as before, expected glazing improvements will compensate for lowered insolation rates leaving the March solar heating fraction at 76%. For vertical, south facing glazing the March solar heating fraction is indicative of what the heating fraction will be for the entire year since outdoor temperatures are near the heating season average temperatures and the sun position is still low in the sky.

TABLE 4

Measured internal gains compared with computed building load for March 5 through April 3,1978

Computed load	1483 KWH
Baseboard heating energy	144 KWH
% heat supplied by auxiliary	9.7 %
Gains from lights and people	.215 KWH
% heat supplied by internal gains	14.4 %
% heat supplied by solar energy	75.9 %

MIT SOLAR BUILDING 5

ECONOMIC ANALYSIS

March 1978

I. New Building Component Costs (based on mass produced quantities).

A. Ceiling Tiles

1. Projected tile and chemical core cost: $3.00/ft^2$ (not including hanging system)
2. Cost of materials being replaced: Drywall, taping, prime, and finish cost $.75/ft^2$
3. Net Costs: $3.00-0.75 = $2.25/ft^2$

B. Transparent Insulation

1. Heat Mirror cost: $1.00/ft^2$ (installation costs are low since weight is low and seals are simple)
2. Cost of materials being replaced: assume double glazed windows already exist
3. Net Costs: $1.00-0.00 = $1.00/ft^2$

C. Modified Louvers

1. Mirrored venetian blinds: $2.50/ft^2$
2. Assume additional window dressing is still used
3. Net Costs: $2.50-0.00 = $2.50/ft^2$

II. Typical square footage involved (where 80% of the heating load is met by passive gains). The following material percentages are based on the MIT Solar Building 5 performance

A. Two story single family detached residence (1600 ft^2)

1. Ceiling area 52% of ceiling is in sunshine: 833 ft^2
2. Window area: 480 ft^2 (effective collection area = 460 ft^2)

B. Multiple family construction (1100 ft^2)

1. Ceiling area (40% of ceiling is in sunshine): 440 ft^2
2. Window area: 255 ft^2 (effective collection area = 242 ft^2)

III. Incremental building cost

A. Single family

1. Ceiling ($2.25 ft²) $1875
2. Window ($1.00+2.50=$3.50 ft²) 1680
3. Total $3555

B. Multiple family

1. Ceiling $ 990
2. Window 892
3. Total $ 1882

IV. Seasonal energy balance (Boston climate); when operating with internal heat gains, the ceiling and window area can be reduced.

A. Single family: Building losses (with Heat Mirror) is 9600 BTU/degree day.

Month	Deg. Days	Heat Loss	$\times 10^6$ BTU Window heat gain	Solar used	% Heated
OCT	316	3.034	6.001	3.034	100
NOV	603	5.789	7.152	5.789	100
DEC	983	9.437	7.078	7.078	75
JAN	1088	10.445	6.267	6.267	60
FEB	972	9.331	5.600	5.600	60
MAR	846	8.121	7.309	7.309	90
APR	513	4.925	5.109	4.925	100
MAY	208	1.997	3.502	1.997	100
	5627	53.079		41.999	79

B. Multiple family (4900 BTU/degree day)

OCT	1.538	3.123	1.538	100
NOV	2.934	3.721	2.934	100
DEC	4.783	3.587	3.587	75
JAN	5.294	3.176	3.176	60
FEB	4.729	2.837	2.837	60
MAR	4.117	3.705	3.705	90
APR	2.496	2.501	2.496	100
MAY	1.012	1.822	1.012	100
	26.903		21.285	79

V. Payback period (if 98,000 BTU can be delivered from each gallon of oil at $.51 per gallon, then 10^6 BTU cost $5.20).

The payback period is conservatively computed by dividing the first cost by the annual savings. This is based on the assumption that fuel inflation covers the interest payment on the borrowed capital.

Annual savings are the sum of captured solar energy fuel equivalent and the savings developed by placing Heat Mirror on the windows. Conventional energy loss through double glazed windows is proportional to the heat conductance (.55 BTU/hr°Fft^2) times the degree days. Energy loss with Heat Mirror is one quarter the conventional loss.

A. Single familv: Payback = $\frac{\text{capital cost (\$)}}{\text{annual savings (\$/yr)}}$

$$= \frac{\$3555}{\$5.20/10^6\text{BTU}((.55-.55/4)\text{BTU/hr}^\circ\text{Fft}^2\text{x}460\text{ ft}^2\text{x}24\text{ hrs/dayx}5627^\circ\text{F days})+41.999\text{x}10^6\text{BTU}}$$

= 10 years

B. Multiple family:

$$\frac{\$1882}{(((.55-.55/4)\text{x}242\text{x}24\text{x}5627) + 21.285)\text{x}\$5.20} = 10 \text{ years}$$

*U.S. GOVERNMENT PRINTING OFFICE: 1978-740-306/4332. Region 4.