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ABSTRACT

The design and construction of a 100% passive solar building utilizing a clerestory and a trombe wall is described. The use of three selectively absorptive and emissive coverings on the trombe wall outer surface are investigated. One of the coverings and its laminating adhesive are tested for degradation after a year of exposure under normal operating conditions. Ambient temperature, room air temperature, trombe wall interior and exterior surface temperatures, and solar radiation are measured.

1. INTRODUCTION

Movable insulation is an expensive and inconvenient technique for reducing night heat losses from direct gain and trombe wall systems. Volume II of the DOE Passive Handbook (1) indicates that a selective foil applied to the exterior surface of a trombe wall or water wall equals or exceeds the performance of R-9 movable insulation. This represents an extremely cost-effective alternative to movable insulation.

Shortly after Los Alamos National Laboratory obtained these results (1) in test-cell experiments on selective surfaces, F. Sokol requested design assistance for a small furniture-making factory in Boulder, Colo. I agreed to assist under the condition that this novel concept be tested on his building. He consented and we proceeded to design and build what to my knowledge is the first field application of a selective surface on a masonry trombe wall in a residential or commercial building. The building was constructed in February 1980 and has now completed one heating and cooling season.

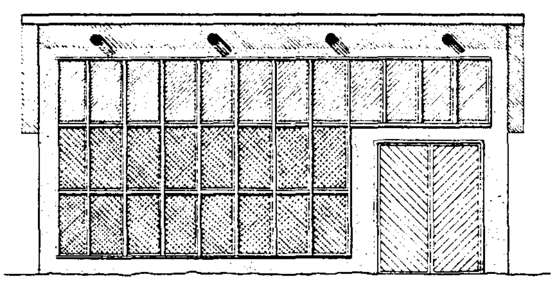

Fig. 1. South Elevation

2. THE PROGRAM

The key requirements of the client were:

- daylighting for the shop area,
- acoustic decoupling from outside to prevent disturbance of nearby residences by machinery noise,
- security for machinery and wood stocks,
- stable temperatures for precise setting of furniture glue joints, and
- minimal auxiliary heating and cooling.

3. THE BUILDING

Figures 1 and 2 show the south elevation and a sectional perspective of the building, respectively.

Although this building would have had enough internal storage mass to support an extensive direct gain system, the requirements for stable temperatures, security, and acoustic decoupling suggested the use of a trombe wall. The requirement for daylighting as well as the building occupancy schedule suggested the addition of a clerestory above the trombe wall. The clerestory along with the ceiling shape is intended to diffuse the light evenly in the space so that supplementary lighting is rarely needed during the day. Additionally, the clerestory provides rapid early morning warm-up and utilizes to some extent the great amount of thermal storage mass available in the structural floor slab, block walls, and machinery. The site slopes somewhat to the south, facilitating a 3-ft earth berm on the north wall.

The clerestory allows a solar collection area of 100 ft^2. The trombe wall collection area is 130 ft^2. Heat loss through the clerestory is prevented at night by a 3-in.-thick panel of bead board insulation which is controlled by a timer and a 1/15-hp Dayton motor.

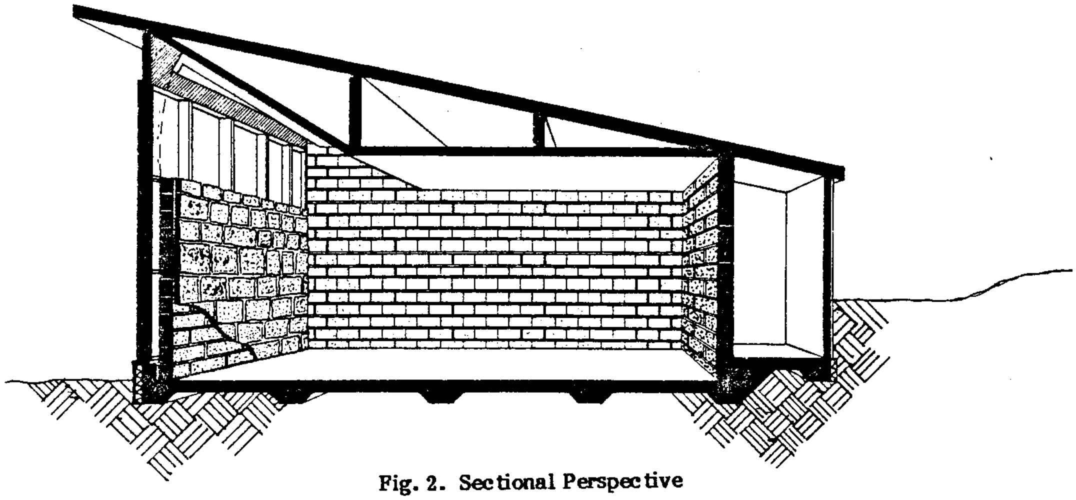

Fig. 2. Sectional Perspective

Figure 3 illustrates the different modes of operation of the building. In summer the north doors can be opened along with the vents low on the trombe wall and those high on the south wall. This facilitates a strong ventilative flow which is reinforced by any heating at the outer surface of the trombe wall. The roof overhang provides total shading of the clerestory and about 50% shading of the trombe wall through the summer months. On summer nights the north doors are shut for security reasons. However, vents in these doors allow natural flushing of the building mass with cool night air. The movable insulation panel may be left in the open position throughout the summer. In winter the trombe wall vents are sealed. The selective surface keeps the air-gap temperature relatively cool so that there is little to be gained by allowing thermocirculation of the wall. The clerestory provides morning warm-up and more than offsets any daytime heat losses from the building. It is better, therefore, to store that energy, which would otherwise be transferred into the building during the day via thermosyphoning, in the trombe wall for night use.

Figure 4 shows a typical wall section, and Table 1 lists the building materials and the thermal properties of typical sections.

4. THE SELECTIVE SURFACE

In choosing the selective surface, Microsorb paint, Berry Products selective foil, and Maxorb selective foil were investigated. These products were tested in July 1979 for solar spectrum absorptivity and long-wave emissivity at the Solar Energy Research Institute Materials Laboratory. The results are presented in Table 2.

The Microsorb paint was not selective enough and was eliminated from further consideration. The two foils were equally selective; however, the Berry product had several advantages. It came in wider strips and was thus easier to apply. It did not have an adhesive backing. This was crucial since the adhesive backing on Maxorb foil was intended for the metallic surfaces of active solar collector panels; and Maxorb could not guarantee their adhesive over the long term when applied to a masonry substrate.

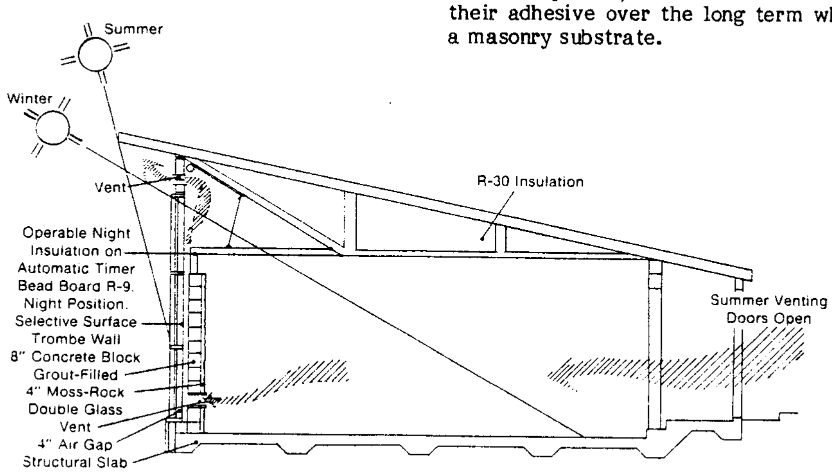

Fig. 3. Modes of Operation

Table 1. BUILDING CHARACTERISTICS

Location: Boulder, Colo.
Latitude: 39.7 north
Orientation: 12° east of south
Trombe wall area: 130 ft^2
Clerestory area: 100 ft^2
Floor area: 800 ft^2

Typical Floor Slab: U = 0.4/perimeter·ft

10-in. structural slab
Perimeter insulation: 36 in. x 3 in. Dow Styrofoam SM

Typical Roof Section: R-38

0.5-in. gypsum board
10-in. loose fill insulation
0.5-in. exterior ply
Tar paper
Pro-panel metal roofing

Trombe Wall

Double-glazed, 1/8-in. standard glass
Selective surface: Berry Products selective foil, black chrome on copper substrate
Laminating adhesive: Dow Corning 795 silicone building sealant
8-in. concrete block, grout-filled
4-in. moss rock

Other Features

Air-lock vestibule entry
R-9 night insulation on single-glazed clerestory

5. SELECTION OF AN ADHESIVE

The selection of an adhesive to affix the selective foil to the masonry trombe wall involved a rather lengthy investigation. Los Alamos National Laboratory used a neoprene-based construction adhesive in their test-cell experiment with selective foils; however, their investigation lasted only several weeks, leaving doubt as to the long-term performance of the neoprene in contact with copper and masonry. A number of construction adhesive manufacturers and Berry Products indicated that we were the first to attempt such an application in a full-scale building intended for long-term usage, and they gave no guarantees. We eliminated neoprene-based glues at the suggestion of several adhesive company technical representatives (2). We finally selected the silicone-based building sealant #795 by Dow Corning.

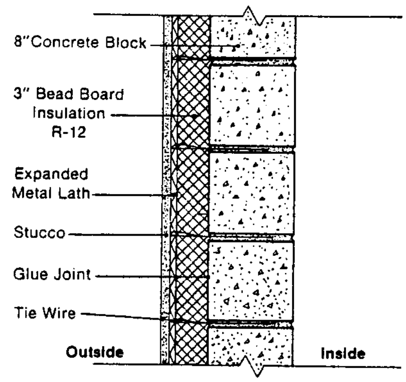

Fig. 4. Typical Wall Section

6. ONE-YEAR DEGRADATION TEST OF SELECTIVE FOIL AND LAMINATING AGENT

On 13 March 1981, several small samples of selective foil were removed from the trombe wall surface to be tested for solar spectrum absorptivity and infrared emissivity. The results of the tests are shown in Table 3.

Table 3.
Date of Test: March 13, 1981

Coating	Solar Spectrum Absorptivity	Infrared Emissivity
Berry Products selective foil after 1 year of normal operating exposure	0.89	0.05
Adhesive	**Delamination**	**Bubbling**
Dow Silicone #795 building and joint sealer after 1 year of normal operating exposure	None	None observable in addition to that noted at time of installation

TABLE 2.

Selective Surface Coating	Substrate	Cost	Solar Spectrum Absorptivity	Infrared Emissivity
Microsorb paint, well agitated, 2 coats applied	Dry standard finish, hollow-core concrete block	\$32/gal	0.91	0.75
Berry Products selective foil	NA	\$1.35/ft^2	0.87	0.08
Maxorb selective foil	NA	\$1.35/ft^2	0.88	0.09

The results indicate no measurable degradation after a year of normal operating exposure. This suggests that highly selective surfaces can be applied to masonry substrates. The selective surface costs approximately $2/ft^2$ installed, while the R-9 movable insulation systems cost $7 to $15/ft^2$.

The selective foil tends to crinkle and bubble somewhat when installed due to the uneven surface of the wall. If aesthetics are a consideration, it is recommended that the foil be used in conjunction with a translucent rather than a transparent glazing material.

7. MEASURED BUILDING THERMAL PERFORMANCE

Figure 5 shows data collected hourly from 8 March to 21 March 1981 for ambient temperature, room air temperature, trombe wall inner and outer surface temperatures, and solar radiation in the plane of the collector wall. The trombe wall exterior surface temperature was measured with a thermocouple pressed between the selective foil and the masonry. The sequence of days was chosen to show a cold clear period during which the wall was charged, in conjunction with a relatively cloudy period of discharge.

The week of 8-14 March followed a period in which the inner trombe wall surface was discharged to a temperature of 65 F. On 8 March the wall began warming due to strong insolation, even though the ambient temperature averaged about 30 F. The exterior surface temperature is primarily a function of solar radiation. This is especially true with the selective surface since radiative losses are reduced during the day as well as at night. On 9 March, with 1800 Btu/ft^2·day of solar radiation on the glass, the trombe wall outer surface reached a temperature of 154 F. (Exposed to the more direct sun angles of deep winter, the wall would attain even higher temperatures.) By 14 March the inner surface of the wall had risen by 10 F on the average. These inner wall temperatures were extremely stable, with a diurnal fluctuation of approximately 6 deg F. The room air temperature was equally stable, running about 7 deg F cooler than the wall temperature. The room temperature tended to peak earlier in the day than the inner trombe wall surface in response to direct gain from the clerestory. The room temperature averaged between 65-70 F during the prime hours of building occupancy. At no time during the week of 8 March did the room temperature dip below 60 F.

The data for the week of 15 March shows declining ambient temperatures and increasing cloudiness. The wall slowly discharged to a temperature of 62 F on 21 March. At this point the room temperature reached a minimum for the week of 60 F. These declining room temperatures were accelerated somewhat by the fact that the movable insulation was not operated that week. By 22 March the front had passed and the wall began to recharge.

Throughout the data collection period the maximum diurnal temperature of the trombe wall

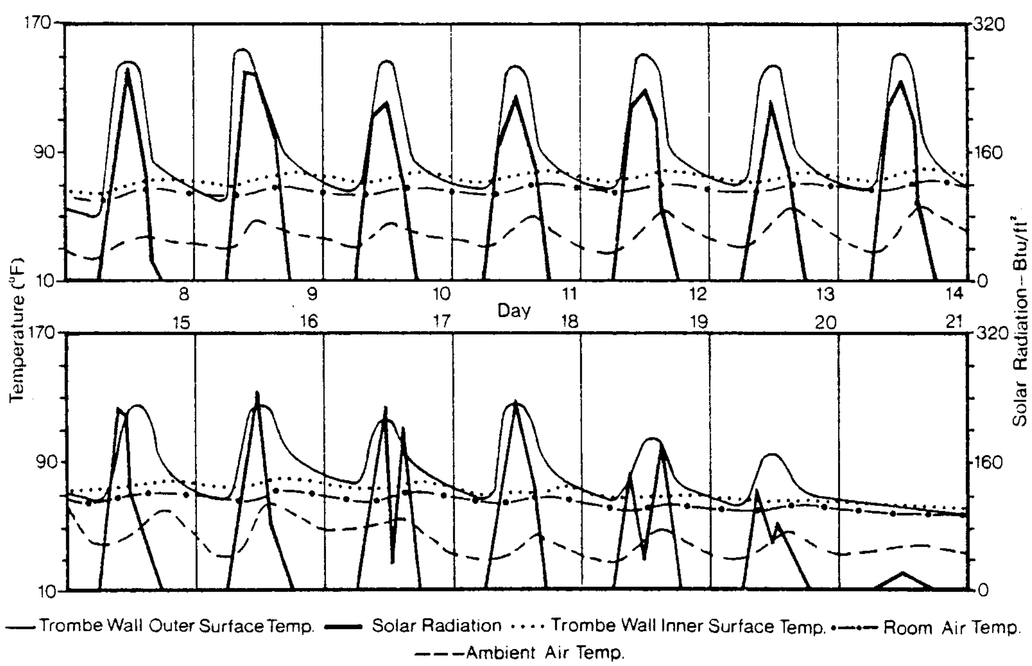

Fig. 5. Solar Radiation in Plane of Collector and Free-Floating Temperatures

interior surface occurred about 7 h after the maximum outer surface temperature. This is in close agreement with the lag time reported for 12-in. trombe walls in the DOE Passive Handbook (1). The temperature fluctuation on the interior surface of the selective trombe wall is about 6 deg F. The DOE Passive Handbook predicts a 13-deg temperature swing for an unvented 12-in. nonselective wall without movable insulation.

8. OWNER'S OBSERVATION OF LONG-TERM THERMAL PERFORMANCE AND COMFORT

Only one month of quantitative data has been collected at the time of writing, but the owner has made several observations concerning the long-term thermal and comfort performance of the building: 1) he has not found it necessary to install an auxiliary heating or cooling system; 2) the lowest room temperature observed in the past year was 58 F, after an extended period of inclement weather; 3) door openings and forced venting of noxious glue fumes do not disturb comfort significantly; and 4) there is occasional glare from the clerestory.

9. CONCLUSIONS

- Selective foils may be affixed to masonry trombe walls with silicone-based adhesives. Tests after one year of normal operation showed no degradation of either the foil or the adhesive.
- Selective-surface trombe walls appear to be a cost-effective alternative to trombe walls with movable insulation.
- Translucent glazing material should be used on the trombe wall where aesthetics are of concern.
- Translucent glazing material will be added to the clerestory to diminish glare and improve daylighting.
- Selective trombe walls exhibit less inside-surface temperature fluctuation than nonselective walls without night insulation.
- More measurements should be taken to investigate air-gap temperature in the selective trombe wall.
- Certain types of small commercial buildings are ideal for passive solar applications. Such buildings tend to: 1) normally be of massive construction; 2) have few internal zones; 3) have envelope loads which dominate internal heat generation; and 4) have large uncontrollable infiltration loads such as door openings.
- Service garages, fire stations, warehouses, workshops, and bank branches are particularly appropriate for this type of application.

10. ACKNOWLEDGMENT

We thank Pat Call for his assistance in measuring the selectivity of the paint and foil samples.

11. REFERENCES

(1) U.S. Department of Energy. "Passive Solar Design Handbook," Vol. II (Jan. 1980). Available from the National Technical Information Center.

(2) Lampert, Carl M. "Metal Foils For Direct Application of Absorber Coatings On Solar Collectors," Lawrence Berkeley Laboratory.