# A SURVEY OF SOME SOLAR ENERGY RETROFITS

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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## ABSTRACT

The report briefly describes a survey of some solar energy retrofits, such as solar heaters and Trombe walls, that can be easily adapted into existing buildings belonging to the Department. With their relatively high cost, commercial solar heaters have been determined not to be cost-effective. However, homemade solar heaters are reasonably simple to construct and appear to be cost-effective. The relatively simple and inexpensive Trombe wall also can be cost-effective.

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## INTRODUCTION

The rapidly rising cost and uncertain availability of conventional fuels has brought public awareness of the need to conserve energy and to search for other sources of energy that can be utilized at reasonable costs. In response to this situation, the Council has recently established an energy research task group to examine ways of minimizing or making more efficient the uses of energy in the Department's daily operations. One of the approaches being considered is the use of solar energy.

Solar energy can be used in two general ways in the operation and maintenance of transportation agencies and their facilities. One is to use this type of energy to generate electricity through the use of solar cells, or photovoltaic cells, made of semiconducting materials, mostly silicon. Electricity so generated may be used in remote areas to power traffic counters, highway warning signs, and cathodic protection systems for bridge decks. A second method of use is to generate heat through the use of solar collectors. This method may be used to heat asphalt storage tanks, domestic water, and buildings. The investigation described here concerns, in particular, the use of solar energy for heating buildings.

A careful review of the literature pertinent to the subject has raised questions, from the viewpoints of technology and economics, on the advisability of using active solar systems for heating buildings at this time. A review of operating performance data collected from hundreds of installations sponsored by the Department of Housing and Urban Development between January 1976 and November 1979 revealed that over one-fourth of the installations needed repairs.(1) Many of the problems were caused indirectly by the complexity of the systems and were traced to a lack of competent installers, poor system design, improper selection of materials and components, and, in a few cases, poor manufacturing quality control. It is generally easier to install a system in a building during its construction than to retrofit an existing building. This is a disadvantage, since the Department probably doesn't have any significant need for additional shops or office buildings at this time. In addition, solar systems do not replace the conventional heating systems so that their cost is extra. Based on recent fuel costs, it is estimated that the payback period for an investment in an active solar heating system is at least 12 years, usually longer.

The search for some solar systems that do not have the complexity and drawbacks of the systems described above, and yet are economical and adaptable to many of the Department's existing buildings, focused on some solar energy retrofits such as window-mounted solar heaters and Trombe walls.

## OPERATIONAL PRINCIPLES OF WINDOW-MOUNTED SOLAR HEATERS AND TROMBE WALLS

Typically, solar heaters are composed of a collector panel and a blower unit (Figures 1 and 2). The collector panel, in turn, consists of a frame, insulation, a transparent cover plate, and a heat-absorbing plate. The heat-absorbing plate is usually made of aluminum and painted with flat black paint. Conductive heat losses through the sides and bottom of the panel are minimized by insulation, which can be fiberglass, urethane, or urea formaldehyde. Convective heat loss through the top is minimized by the cover plate, or glazing, which can be tempered plate glass, low-iron plate glass, polyvinyl fluoride film (Tedlar), etc. Steel, treated pine, or, usually, extruded aluminum is utilized for the frame.

On a sunny day, sunlight passes through the cover plate and is absorbed by the black plate beneath. The black plate heats up and in turn heats air flowing over or under it. When the temperature inside the panel reaches a preset level, usually $10^{\circ}$ above room temperature, a thermostat turns on the blower which drives the heated air out into the room. At the same time, cool air in the room is drawn into the panel. The heater operates as long as the sun shines on it.

Unlike conventional solar heating systems, such heaters would make little, if any, difference in the appearance of highway buildings designed with emphasis on the functional purposes, such as area headquarters, shops, garages, etc., and they can be installed at any angle within $20^{\circ}$ from due south and as easily as a window air conditioner. However, the simplicity of their design does entail disadvantages. Because it doesn't have the heat storage capability of the conventional solar heating system, it cannot provide heat during cloudy days. But whatever heat it generates during sunny days means a saving in the heating bills, because the existing heating system would run less.

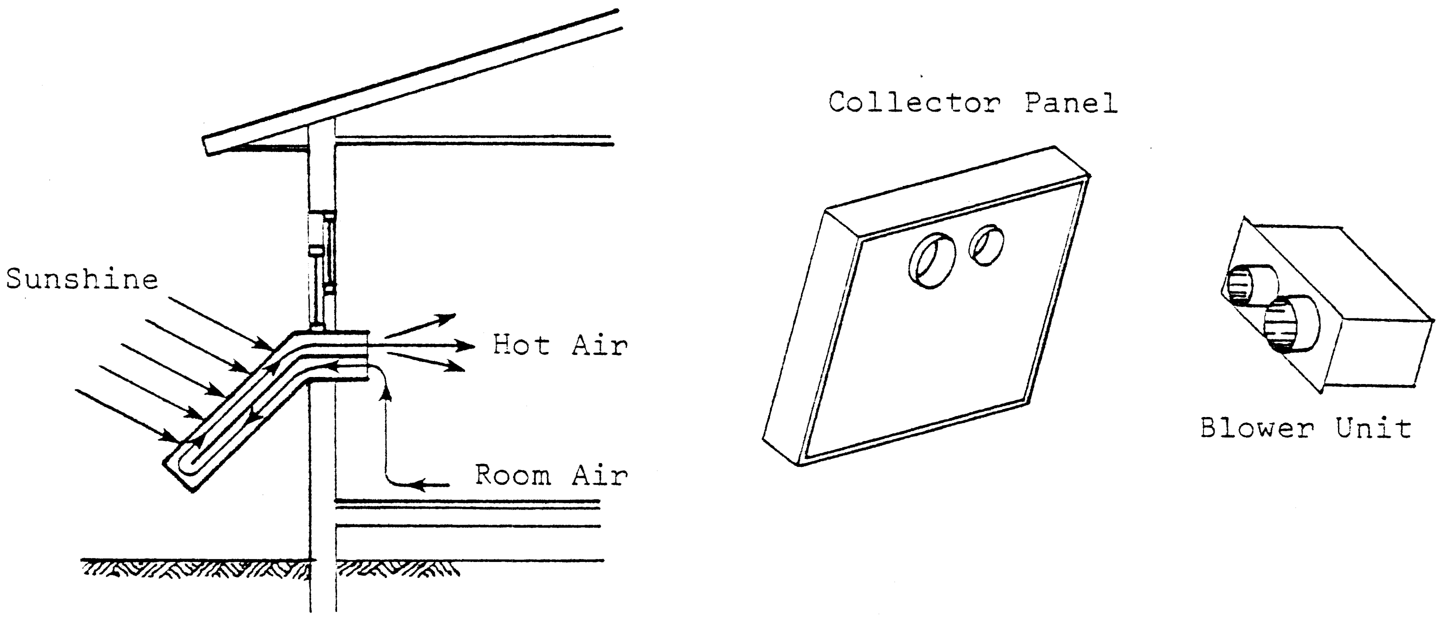



Figure 1. Auxiliary window-mounted solar heater.

inlet duct — 4-in. diameter
outlet duct — 4-in. diameter

1 in. = 2.54 cm
1 ft. = 0.305 m

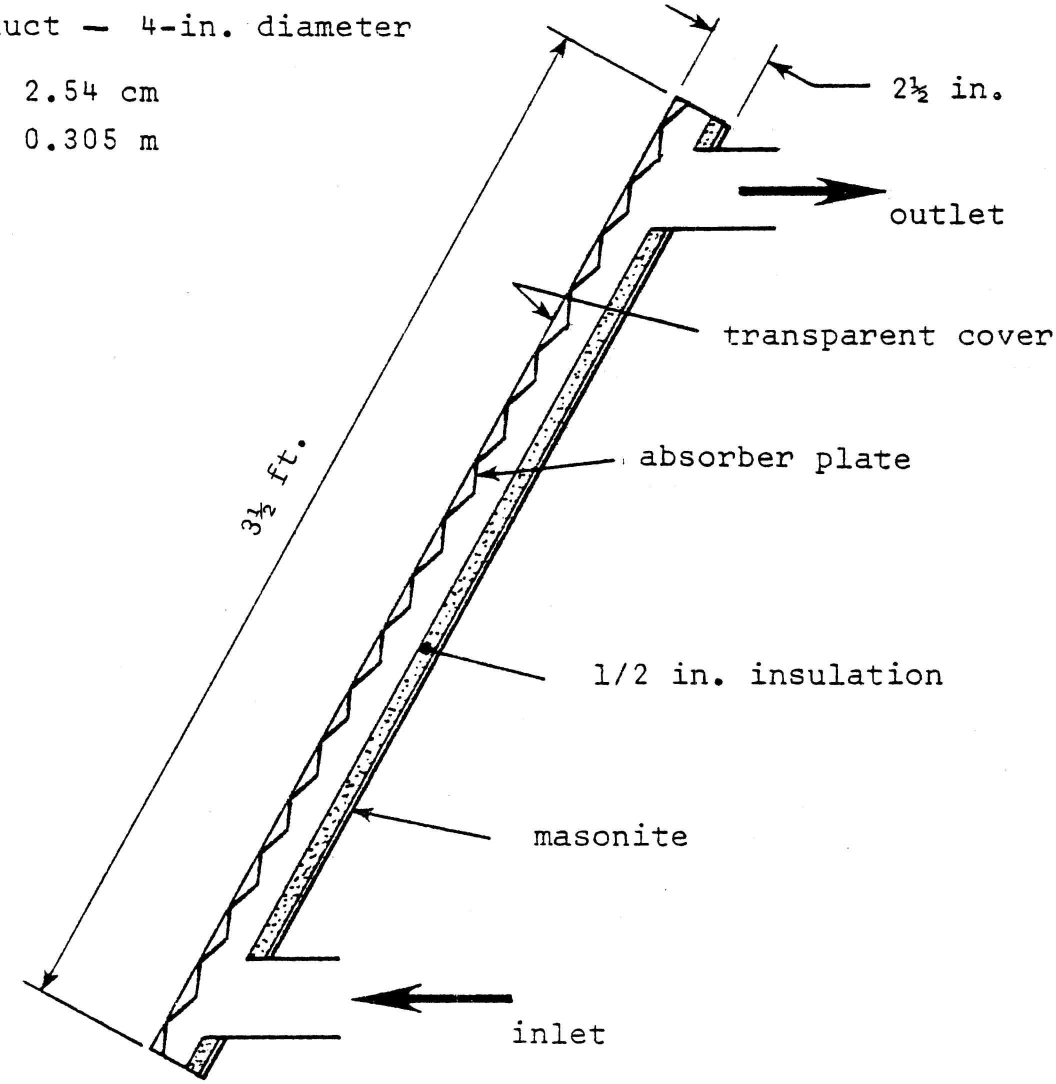



Figure 2. Cross section of creative alternative Model 2010 solar air collector.

The use of a Trombe wall is conceptually simple.[3] For high thermal storage capacity, it should be made of either concrete, concrete block (solid or filled), brick, stone, or adobe, and covered by glass or transparent plastic located 4 inches or more in front of it (Figure 3). The wall must be south-facing and usually painted black or, at least, a dark color (the order of decreasing desirability is dark blue, dark brown, brown, red, and green).

When sunlight strikes the wall, it is absorbed and converted to heat, which is stored and transferred by conduction and radiation to the living space. If openings or vents are added at the top and bottom of the south wall, warm air rising in the air space inside the Trombe wall can enter a room while simultaneously drawing cool air through the low vents in the wall. In this manner additional heat can be supplied to a room during periods of sunny weather. Such walls can be readily retrofitted into some of the Department's area headquarter office buildings and shops.

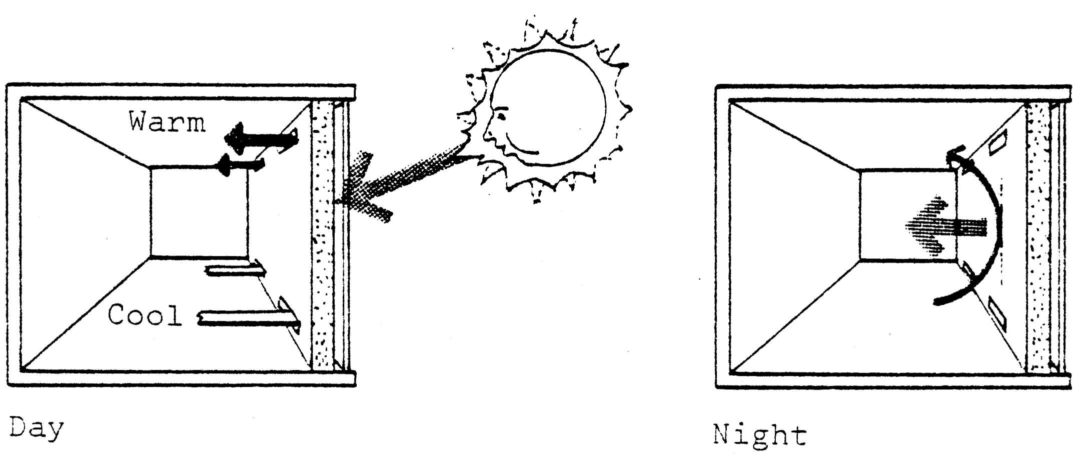



Figure 3. A Trombe wall with ventilation.

## OBJECTIVE AND METHODOLOGY

In view of the potential savings to the Department if these solar energy retrofits could be used, a pair of commercially manufactured heaters were installed in the area headquarters building at Boyds Tavern in the Culpeper District and monitored. The main objectives were (1) to evaluate how efficiently such heaters operate, (2) to estimate the possible fuel savings, and (3) to recommend how such heaters might be utilized by the Department for maximum benefit.

The heaters were the Creative Alternatives Model 2010 (see specifications in the Appendix). As illustrated in Figure 2, the heater circulates air between the pyramidal patterned aluminum absorber plate and the aluminum foil-faced insulation. The foil reflects the thermal radiation back to the absorber plate.

To estimate the heat output and the efficiency of the window heaters, measurements were made of the inlet and outlet air temperatures of the collector panels, air flow rate, and insulation. From these parameters, the heat output and the efficiency of the heater were estimated by the equations

$$Q = C_p \cdot M \cdot (T_o - T_i) = 60\,Cp\,pav(T_o - T_i) = 38.63\ (T_o - T_i) \qquad \text{Eq. (1)}$$

and $$\eta = \frac{Q}{A \cdot I_t}, \qquad \text{Eq. (2)}$$

where

$Q$ = heat output in Btu/hr;

$\eta$ = collector panel efficiency;

$C_p$ = specific heat of air - 0.241 Btu/lb. - F$^o$;

$M$ = air mass flow rate in lb./hr.;

$p$ = density of air = 0.068 lb./ft.$^3$ at 68$^o$F and 1 atm;

$a$ = outlet duct cross-sectional area = 0.0873 ft.$^3$;

$v$ = air velocity = 450 ft./min.;

$T_o$ = outlet air temperature in deg. F.;

$T_i$ = inlet air temperature in deg. F.;

$I_t$ = insuloation in Btu/hr./ft.$^2$; and

$A$ = collector size in ft.$^2$.

In addition, two homemade window solar heaters constructed by W. B. Coburn, Jr., assistant resident engineer at the Charlottesville Residency, with assistance from J. C. Stulting, laboratory instrument maker at the Research Council, were also examined. These units measured 3 ft. x 4 ft. and were constructed from ordinary materials such as 2 in. x 8 in. and 1 in. x 3 in. finish wood, 3/8 in. exterior plywood, corrugated aluminum sheeting, flat black paint, rigid polyurethane foam insulation, aluminum L, plate glass, box fans, and caulking. A Trombe wall retrofitted, also by W. B. Coburn, Jr.,on a south-facing cinderblock wall at the Yancey Mill area headquarters office was also examined. With the wall painted dark green, the retrofitting was completed with 2 in. x 4 in. and 2 in. x 8 in. finish wood and greenhouse-type plastic film.

## RESULTS AND DISCUSSION

### Window Solar Heaters

A prerequisite for achieving maximum performance of a solar system is proper orientation and tilt of the collector panel to ensure optimum exposure to sunlight. An orientation of true south in most situations is the best position. However, research has indicated that a 20° variation either side of true south does not significantly alter the performance of most solar collectors.(2) For optimum tilt, the most often mentioned rule of thumb is geographic location of the building, i.e. site latitude, plus 12°. To satisfy this requirement when retrofitting existing buildings, it may be necessary in some cases to have collector-supporting frames oriented and tilted in a manner that detracts from the appearance of the buildings.

In this investigation, the orientation of the building, its relation to the layout of the building, the size of the building, and closeness to the Research Council were used as criteria for choosing a test building for the two commercial solar heaters. Under these criteria, the Boyds Tavern area headquarters of the Culpeper District were chosen from three other area headquarters considered, all being within a 20-mile radius of Charlottesville. As Figure 4 shows, a heater was installed on each of the two front windows of the building. Since the site latitude was 38°, the collector panels were tilted at approximately 50°. So that the panels would not detract from the appearance of the building, the panels were oriented as the front of the building, which means that the orientation was slightly less than ideal since the building faces southeast (Figure 5), and the panel would receive about 20% less insolation than if facing due south. Nevertheless, it was felt that the setup would be adequate for achieving the objectives of this relatively short investigation.

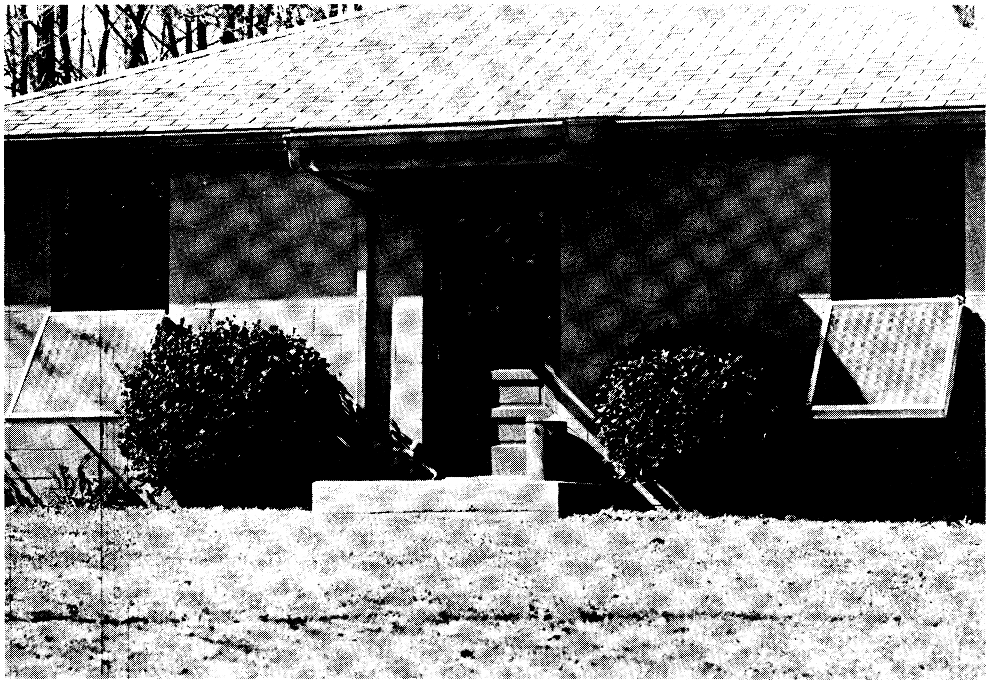


Figure 4. Commercial solar heaters installed at Boyds Tavern.

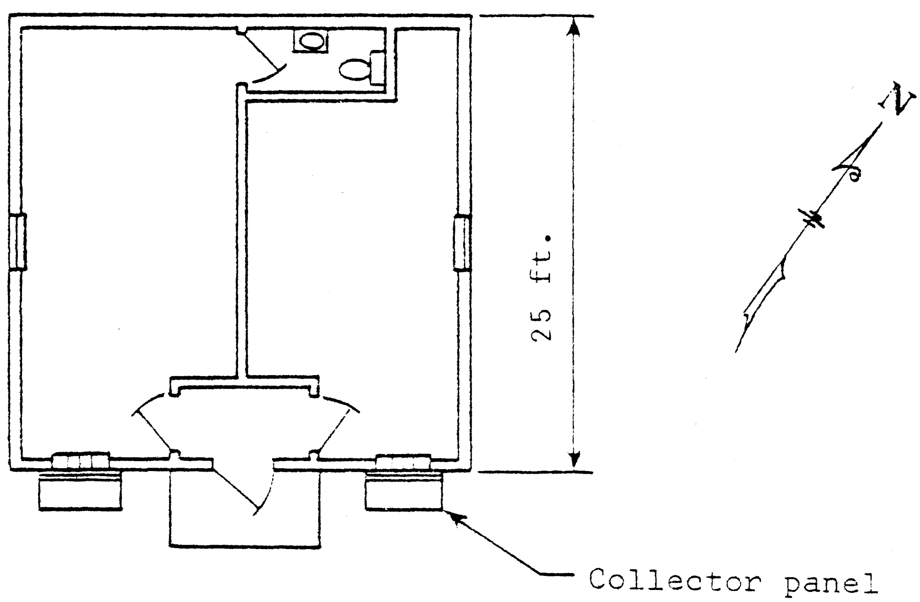



Figure 5. Orientation of the Boyds Tavern area headquarters office.

Table 1 shows some typical results obtained when the performance of one of the commercial solar heaters was monitored. These data indicate that in the middle of a day in March the difference in the temperature of the air at the inlet and that of the air at the outlet of the panel can be as high as 40°F. The estimated heat outputs ranged from 348 Btu during one early morning hour to a high of 1,545 Btu in a midday hour. It must be emphasized that the estimated heat outputs are instantaneous since the measurements made were instantaneous.

It is easy to appreciate the performance of these solar heaters from only the difference in the temperatures of air going in and out of the panel. However, when viewed in terms of kilowatt-hours (kWh) saved and their cost, these particular commercial solar heaters are not cost-effective. This point is illustrated in the following simplified analysis. If it is optimistically assumed that a minimum of 20 sunny days can be expected with 8 hours of good insolation per sunny day producing an average output of 1,073 Btu/hr/solar heater, the amount of electric heat saved each month would be

$$\frac{1{,}073 \text{ Btu/hr} \times 8 \text{ hr/day} \times 20 \text{ day/month}}{3{,}410 \text{ Btu/kWh}} = 50.3 \text{ kWh/month.}$$

At the current rate of $0.06/kWh, this amounts to a saving of only $3.02/month/solar heater. (When the efficiency of electric baseboard heaters, which is the existing heating devices at the Boyd Tavern area headquarter office, are considered, the actual saving could likely be twice as much of the above estimate.) By any criterion, this compares unfavorably with the commercial cost of the heater, which was $350. After close examination, it is believed that such heaters are overpriced, since similar units can be easily built for about $100. (Other commercial heaters considered and then rejected for use in this investigation were even more overpriced.) Undoubtedly, window solar heaters do produce heat; however, if they aren't sufficiently efficient, the amount of heat produced would not be of practical benefit. As indicated in Table 1, this was the case with the heaters involved in this investigation, whose efficiencies averaged only 0.34. (An average efficiency greater than 0.5 had been reported for similar heaters of larger collector area.[4])

A collector panel could suffer problems with heat loss when its sidewalls are not adequately insulated. This is particularly so for window heaters, which tend to have smaller collector areas (20 ft.$^2$ or less) and therefore relatively high ratios of collector perimeter to area. Close examination of the Creative Alternative solar heaters showed that side insulation for the panels is, at best, insufficient and may partly account for the poor performance of the heaters.

Table 1

Estimated Heat Output of a Creative Alternatives Solar Heater

| Date | Hour | Temperature, °F: Inlet Air | Outlet Air | Difference | Insolation, Btu/hr/fl$^2$ | Heat Output, Btu/hr | Efficiency |
|---|---|---|---|---|---|---|---|
| 3/13/81 | 0800 | 72 | 82 | 10 | 159.7 | 386 | 0.23 |
| | 0900 | 73 | 102 | 29 | 309.5 | 1,120 | 0.34 |
| | 1000 | 71 | 110 | 39 | 340.5 | 1,507 | 0.42 |
| | 1100 | 72 | 112 | 40 | 336.2 | 1,545 | 0.44 |
| | 1200 | 73 | 105 | 32 | 319.0 | 1,126 | 0.37 |
| 3/17/81 | 0815 | 62 | 81 | 19 | 140.9 | 734 | 0.50 |
| | 0915 | 64 | 94 | 30 | 335.7 | 1,159 | 0.33 |
| | 1005 | 66 | 103 | 37 | 335.7 | 1,429 | 0.41 |
| | 1115 | 69 | 106 | 37 | 323.2 | 1,429 | 0.42 |
| | 1215 | 70 | 104 | 34 | 307.6 | 1,313 | 0.41 |
| | 1315 | 71 | 105 | 34 | 308.6 | 1,313 | 0.41 |
| 3/20/81 | 0800 | 67 | 84 | 17 | 260.2 | 657 | 0.24 |
| | 0905 | 69 | 92 | 23 | 311.9 | 889 | 0.27 |
| | 1000 | 69 | 93 | 24 | 311.6 | 927 | 0.28 |
| | 1100 | 70 | 90 | 20 | 313.1 | 773 | 0.24 |
| | 1200 | 72 | 93 | 21 | 311.7 | 811 | 0.25 |
| | 1300 | 74 | 98 | 24 | 286.4 | 927 | 0.31 |
| 3/24/81 | 0800 | 68 | 77 | 9 | 169.7 | 348 | 0.20 |
| | 0900 | 68 | 97 | 29 | 295.7 | 1,120 | 0.36 |
| | 1000 | 66 | 98 | 32 | 329.8 | 1,236 | 0.36 |
| | 1100 | 72 | 106 | 34 | 365.0 | 1,313 | 0.34 |
| | 1200 | 69 | 104 | 34 | 354.1 | 1,352 | 0.36 |
| | 1300 | 73 | 103 | 30 | 291.6 | 1,159 | 0.38 |
| | | | | 28 | 296.4 | 1,073 | 0.34 |

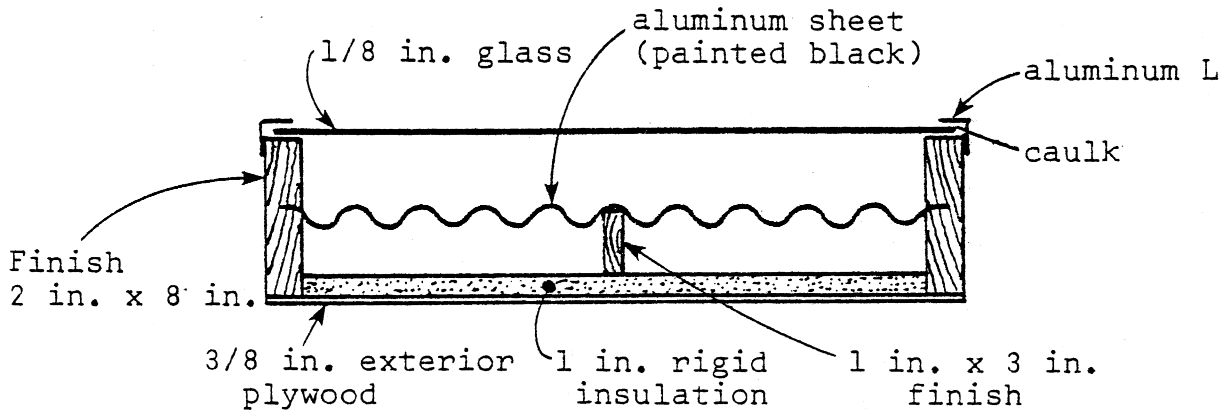
Another intrinsic problem relating to the design of the heaters, and most other window heaters, is the closeness (less than 10 in.) of the air inlet to the outlet of the blower unit. Although the inlet and the outlet in the Creative Alternative collector panel are properly separated, as shown in Figure 2, the air flows through these openings are actually brought close to one another at the blower unit by insulated flexible ducts. This problem can be eliminated by installing, close to the floor, an air vent on the wall below the window sill on which the blower unit is mounted, and connecting the vent with the inlet duct of the panel. This will ensure that cold air, which normally stays at the lower portion of a room, and not some partly heated air is sucked into the collector panel.

Since the efficiency is also directly related to the rate of the flow of the air mass across the collector panel, as indicated in equation 1, the use of a fan larger than the 100-cfm ft$^3$/min box fan used may improve the efficiency.

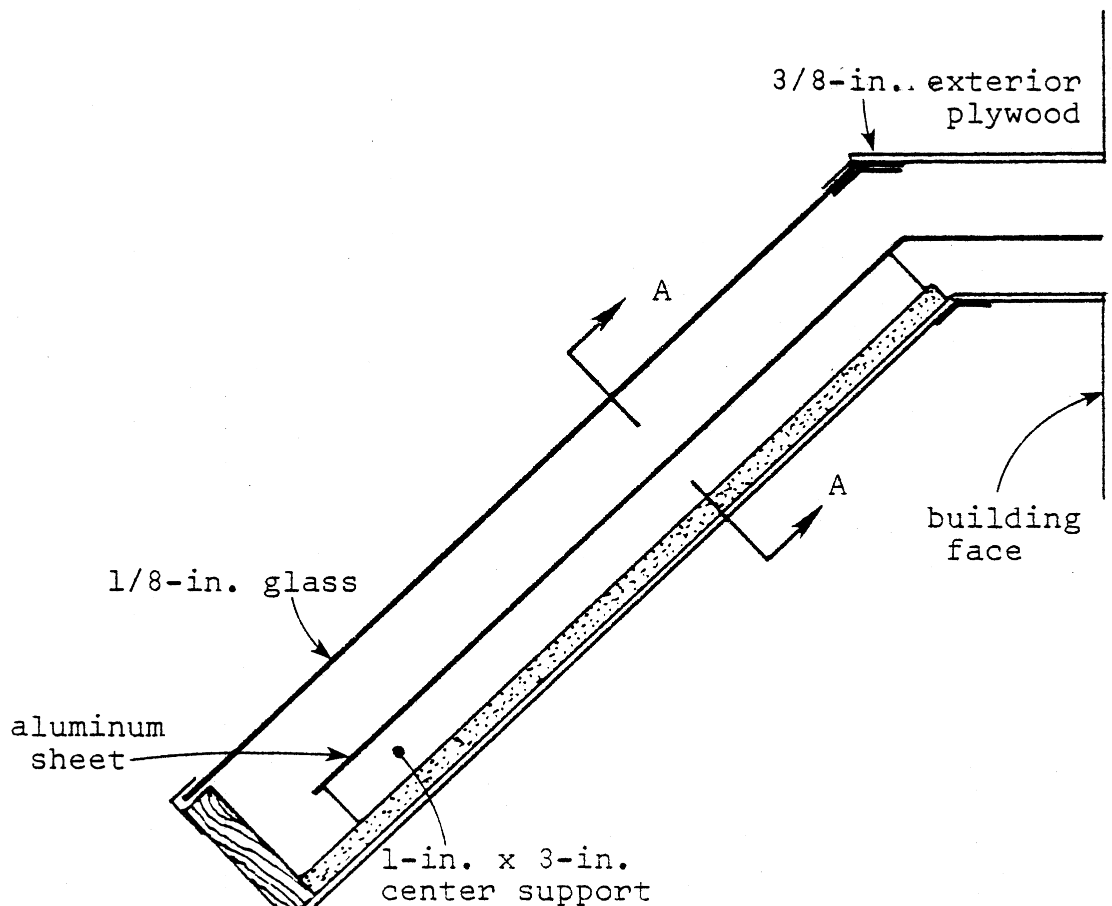
As mentioned earlier, comparable units can be easily built for about $100. To illustrate this point, W. B. Coburn constructed, with little effort, two 3-ft. wide by 4-ft. long units from ordinary materials such as 2 in. x 8 in. and 1 in. x 3 in. finish wood, 3/8 in. exterior plywood, corrugated aluminum sheeting, flat black paint, 1 in. rigid foam insulation, aluminum L, plate glass, box fans, and caulking (Figure 6). These units were installed in the front of the Charlottesville Residency office , and as shown in Figure 7, blended in well with the appearance of the building. A closer view of one unit is shown in Figure 8.

Table 2 shows the temperatures reached at various points in one of the units (Figure 8) during a sunny and cold morning. Comparing these data with those presented in Table 1 for the commercial solar heaters, it is evident that the homemade heaters have at least a comparable, if not better, heat output. It is possible to improve this output by eliminating, through effective insulation, the heat loss between points 4 and 5 in the homemade heaters (Figure 8) which was manifested by an average air temperature drop of approximately 50$^{\circ}$F. The lower cost of these homemade heaters should be recovered in no more than 5 years through savings in heating cost that they will provide.

Another setup of these heaters can be adapted to eliminate the aforementioned intrinsic problem associated with the air inlet being close to the outlet at the blower unit. This setup, which involves mounting the collector panels vertically on the south wall and providing air vents through the wall in alignment with the inlets and outlets of the panels, should work well, particularly for the design similar to that of the commercial panel wherein the inlet is at the bottom and the outlet at the top. Such a setup would even allow the use of larger panels, say 3 in. x 8 in., than the smaller sizes normally associated with window-mounted ones, and therefore provide greater benefit.




Section AA




Vertical section

Figure 6. Schematic of homemade window solar heaters. (Courtesy of W. B. Coburn.)

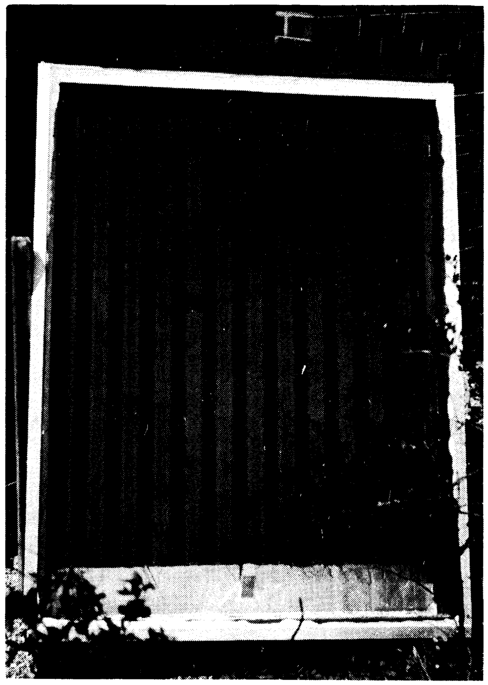


Figure 7. Photos of homemade solar heaters. (Courtesy of W. B. Coburn, assistant resident engineer.)

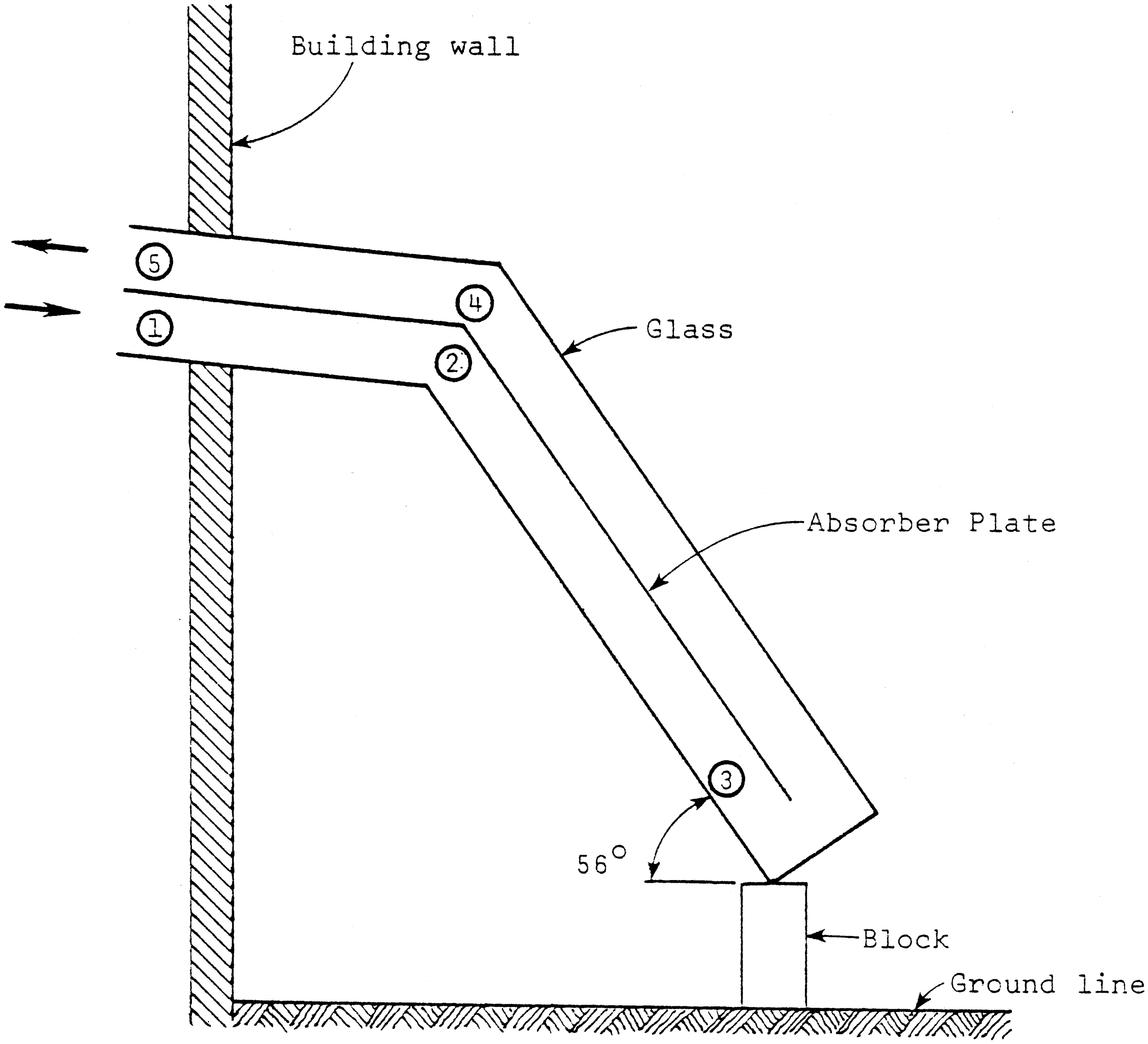



Figure 8. Points in homemade solar heater at which air temperature measurement were made.

Table 2

Temperatures Inside Homemade Solar Heater
(Courtesy of W. B. Coburn)

| Time | Temperature, $^{o}F$, at Indicated Locations | | | | | |
|---|---|---|---|---|---|---|
| | Outside | 1 | 2 | 3 | 4 | 5 |
| 1045 | 39 | 70 | 78 | 112 | 150 | 102 |
| 1145 | 40 | 73 | 82 | 124 | 164 | 115 |
| 1245 | 42 | 74 | 90 | 130 | 170 | 115 |

## Trombe Wall

In the above section, the possible use of window solar heaters as a supplemental heat source was discussed. Another device utilizing solar heating that can also be easily retrofitted into some existing Department offices and shops is the Trombe wall. A fine application of this approach is demonstrated in the conversion, by W. B. Coburn, of a south-facing sidewall in the Yancey Mill area headquarters office building into a Trombe wall as illustrated in Figure 9. Figure 10 shows the wall, which was painted dark green and framed with 2 in. x 4 in. and 2 in. x 8 in. finish wood for covering with a layer of plastic film.

The thermal performance of this Trombe wall is illustrated in Figure 11, which shows the average air temperatures inside the Trombe wall, surface temperatures of the south and east walls inside the office building, and the outdoor air temperature. It is obvious that the temperature on the surface of the south wall, which made up the Trombe wall, was considerably higher than that on the surface of the east wall. This difference arose from the transfer through the south wall of heat generated in the Trombe wall.

Through openings or vents at the top and bottom of this south wall, warm air rising in the air space inside the Trombe wall can enter the warming room while simultaneously drawing cool air through the low vents in the wall, as illustrated in Figure 3. In this manner additional heat can be supplied to the warming room during sunny weather. However, it is doubtful that the Trombe wall can produce more heat per unit area than the solar heaters.

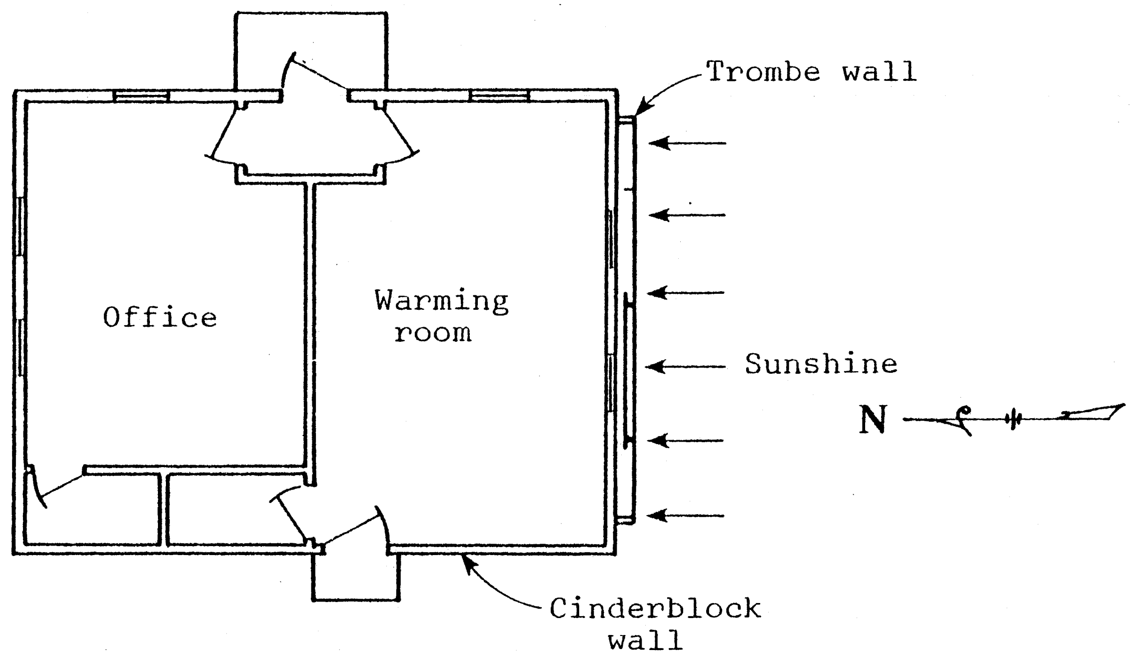



Figure 9. Orientation of the Yancey Mill area headquarters office.

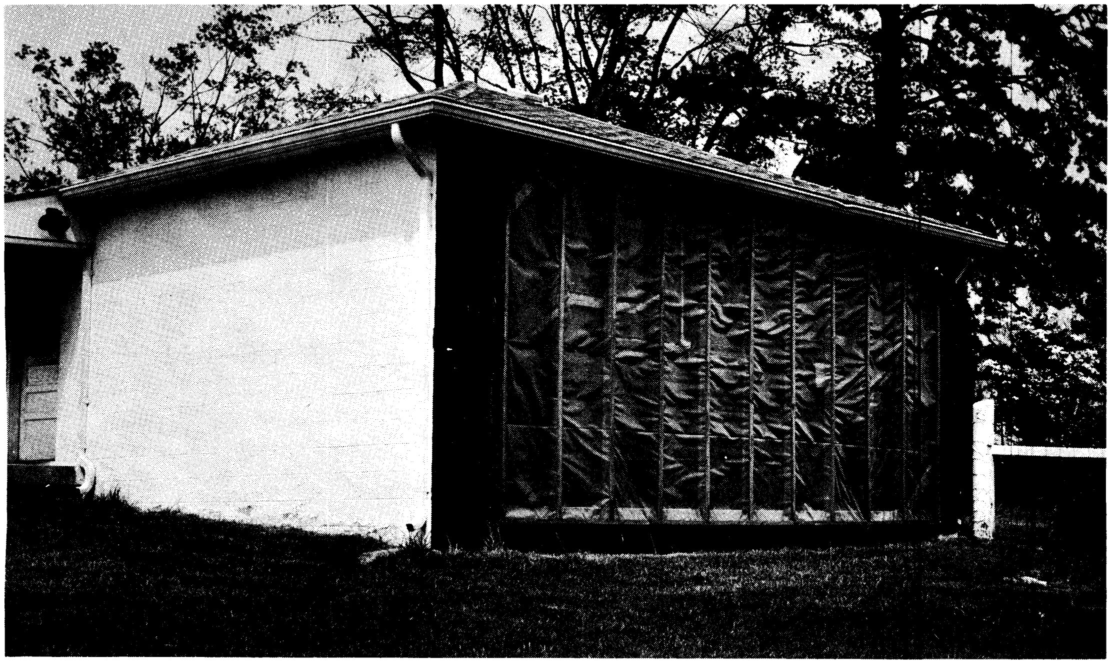


Figure 10. Trombe wall retrofitted on the Yancey Mill area headquarters office.



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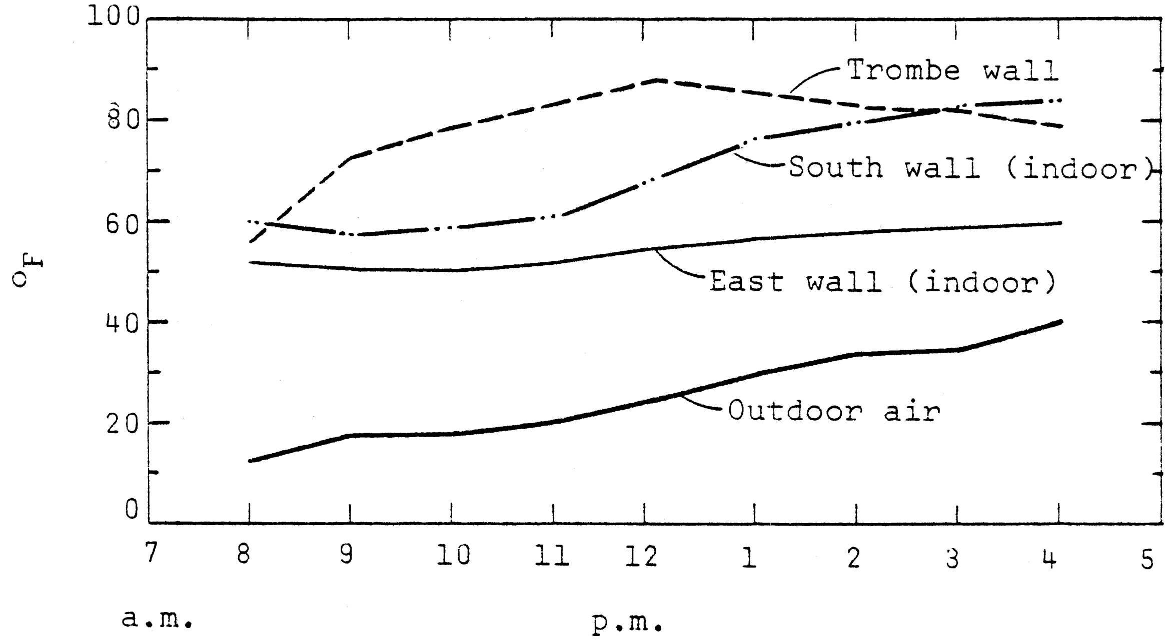
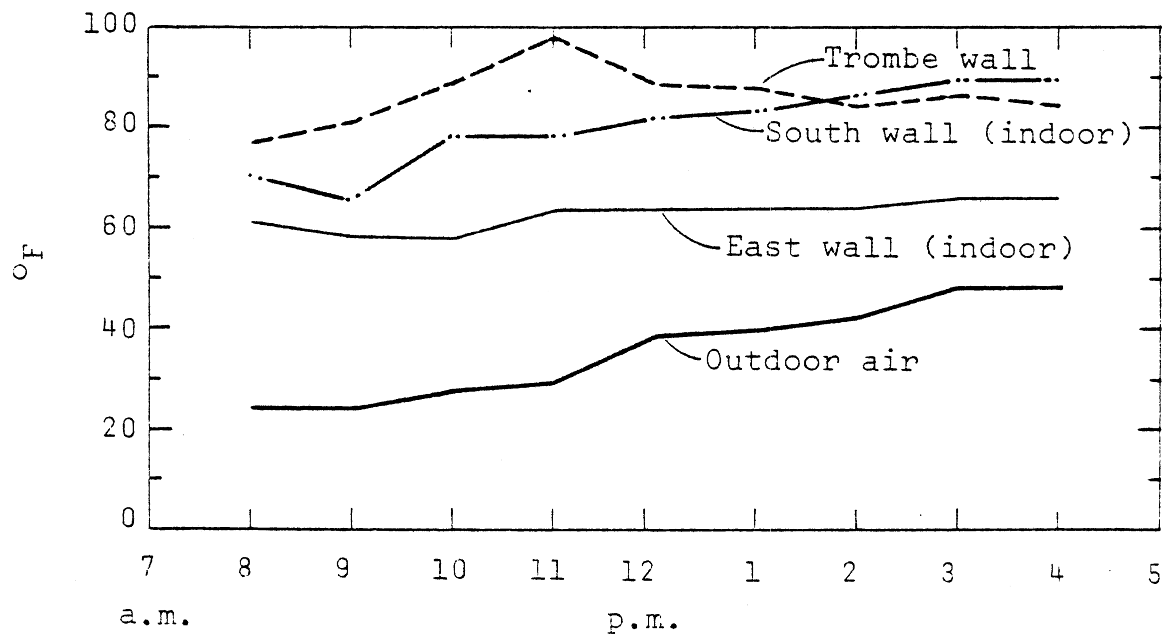



February 5, 1981




February 9, 1981

February 11. Thermal performance of the Trombe wall at Yancey Mill. (Data provided courtesy of W. B. Coburn.)

## CONCLUSIONS AND RECOMMENDATIONS

The preceding sections have discussed two relatively simple ways by which existing field office buildings of the Department can be retrofitted to derive some relief in winter heating cost by using solar energy. From this discussion, the following conclusions can be made.

1. Window solar heaters, either commercial or homemade, do convert sunlight into heat that can be utilized to supplement the existing heating system in a building.

2. However, these heaters have intrinsic limitations on the amount of heat they can produce.

3. Based on the current cost of heating, or even the cost in the foreseeable future, this limitation doesn't make the purchase and use of commercial window solar heaters cost-effective. Most of the heaters are priced very unreasonably high.

4. Homemade heaters that can be easily fabricated from ordinary materials in shops would be more cost-effective than the commercial ones.

5. The use of larger, wall-mounted solar heaters would be a more attractive approach.

6. The economical Trombe wall can be more easily retrofitted into the Department's existing building than can the window units; however, it is doubtful that it can produce more heat per unit area than the solar heaters.

Based on the above conclusions, it is recommended that both homemade solar heaters, window- or wall-mounted, and Trombe walls be used wherever possible. The choice between these would depend upon personal preference, cost or time considerations, and the orientation of the building. For example, if the front of the building being considered is facing south, then a Trombe wall would probably not be as appealing as the heaters.

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# APPENDIX

## SPECIFICATIONS OF CREATIVE ALTERNATIVES SOLAR HEATER MODEL 2010

COLLECTOR PANEL

| | | |
|---|---|---|
| Dimension | : | Approximately 3' x 3½' x 2½" |
| Absorber Plate: | | One aluminum plate stamped in a pyramidal pattern and painted black on both sides |
| Thickness: | | 0.005 inch |
| Paint: | | 0.95 absorptive flat black |
| Glazing | : | 0.04 inch Kalwall Sunlite Premium II plastic |
| Insulation | : | 0.50 inch polyisocyanurate foam between aluminum foil faces |
| Frame | : | 0.070 inch extruded aluminum |
| Back | : | Tempered weather-resistant hardboard |

BLOWER

| | | |
|---|---|---|
| BLOWER | | Thermostat controlled 100-CFM Box-type fan |
| Voltage | : | 15 watts, 115 VAC |
| Panel Size | : | 8" x 12" x 3½" |