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LONG-TERM PERFORMANCE OF THE HUNN PASSIVE SOLAR RESIDENCE

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ABSTRACT

This paper reports detailed performance and annual energy consumption data, as well as occupant observations and conclusions, for three heating seasons in the Hunn hybrid passive/active solar residence located in Los Alamos, New Mexico. The performance data were gathered by the Los Alamos National Laboratory and include hourly storage wall and interior temperature data for a midwinter period, an interior air-temperature histogram, and measured auxiliary energy consumption and solar heating fraction for each heating season. Also, energy and cost savings over the three-year period are estimated.

1. INTRODUCTION

The design, cost, and initial operation of the Hunn residence in Los Alamos, New Mexico, has been documented in earlier papers (1-4). This house, which combines passive [a thermal storage (Trombe) wall and direct gain system] with active (a blower-operated rock bed) solar space heating, has 181.7 m^2 (1955 ft^2) of heated area. A 23-m^2 (250-ft^2) two-story unvented thermal storage wall, 0.3-m (1-ft) thick and made of slump block, is the main passive solar feature. South-facing direct-gain windows of 11.4 m^2 (123 ft^2) area, without night insulation, supplement the storage wall system.

In the active mode, a rock bed is charged by a blower that circulates air up through the storage wall air space and into the rock bed in the crawl space. The rock bed is discharged by the furnace blower, while a thermostat in the furnace inlet air stream activates the burner if the inlet air from the rock bed is below a preset temperature.

The Hunn residence has been monitored by the Los Alamos National Laboratory for the past three years. Earlier papers (2,4) have reported system performance in the form of hourly temperature data for the storage wall and rock bed. This paper documents system performance for the first three heating seasons in the form of measured auxiliary energy consumption and solar heating fraction. Storage wall and interior air temperature data for a two-week midwinter period are reported. An annual interior air temperature histogram is also given. Also reported are heat fluxes in the storage wall calculated from measured temperature profiles. Finally, estimated energy and cost savings over the three-year period, based on solar savings estimated using the Solar Load Ratio (SLR) method (5), are presented.

2. MONITORED PERFORMANCE

2.1 Passive Mode Operation

A two-week period during the 1978-1979 heating season afforded a unique opportunity to observe the house during a cold midwinter period that included cloudy and sunny, as well as occupied and unoccupied, periods. Hourly solar radiation measured at the site, as well as hourly temperatures, are plotted in Fig. 1 for the period from December 26, 1978, through January 8, 1979. Because the house had been unoccupied and the furnace turned off since December 15, 1978, the interior temperatures clearly show the characteristics of the thermal behavior in the unoccupied condition. During the December 26-27 period, the weather was clear and sunny, resulting in outer storage wall temperatures peaking at 63°C (145°F) while outside ambient temperatures dropped to about -9°C (15°F) at night. Note that during this sunny, unoccupied period, the house interior temperatures (measured downstairs in the two-story section) oscillated from 10°C (50°F) to 14°C (58°F) for an average 24-h temperature of 12°C (54°F). During the cloudy period of December 30-31, the interior temperature dropped to a low of 8°C (46°F). This was the lowest interior temperature ever recorded in the house.

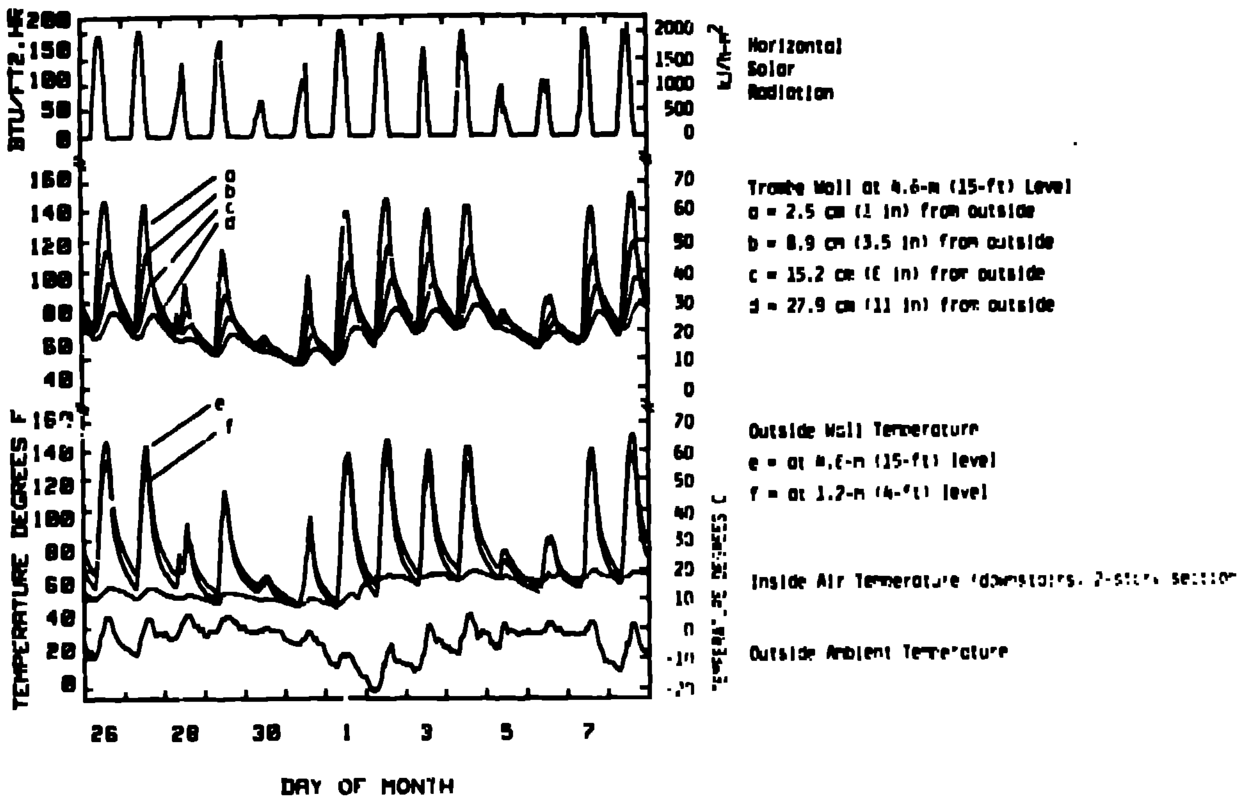

Fig. 1. Measured hourly performance of the Hunn residence for December 26, 1978, through January 8, 1979.

The return of the occupants at about 8 p.m. on January 1, 1979, is marked by the rapid increase in interior air temperature following the turning up of the thermostat to 18°C (65°F). During the following three sunny days, the thermostat in the two-story section was returned to the 16°C (60°F) setting. This period, during which the outside ambient temperature reached a low of -21°C (-5°F), is characteristic of sunny, occupied periods. Note that during this period, the average interior temperature is about 18°C (64°F).

Calculations made recently at Los Alamos have been used to determine heat fluxes in the thermal storage wall of the Hunn residence using measured temperature profiles in the wall (6). Using these heat fluxes, the daily and monthly thermal delivery of the storage wall have been determined. The daily storage wall performance for the 1978-1979 heating season is shown in Fig. 2 in terms of the incident solar energy and the net energy delivery to the house by radiation and convection from the inner wall surface. Note that the overall seasonal efficiency of the wall as a collection device is about 20 per cent. Most of the losses result from heat losses from the outer wall surface, about equally divided between day and night periods (6). A seasonal integral of heat fluxes into the house indicates that the wall provided a net heat input to the house of about 527,000 kJ/m^2-yr (46,500 Btu/ft^2-yr) or about 15.8 x 10^6 kJ (15 x 10^6 Btu) for the entire wall.

A measure of the thermal comfort in the house is given by the downstairs room air temperature histogram shown in Fig. 3. This plot shows that during the majority of the heating-season hours, the room temperature is between 17 and 19°C (63 and 67°F). Few temperatures below 16°C (60°F) are recorded because of the usual 16°C (60°F) thermostat setpoint. The average interior temperature is about 18°C (65°F), and no overheating of the space is evident.

2.2 Active Mode Operation

As reported previously, because of the poor performance of the rock-bed storage system (low storage inlet temperatures), the active mode was used only during a two-month test period in 1977 (2,4). Since that time, several air leaks in the storage wall glazing attachment have been eliminated. This resulted in an increase in the peak rock bed

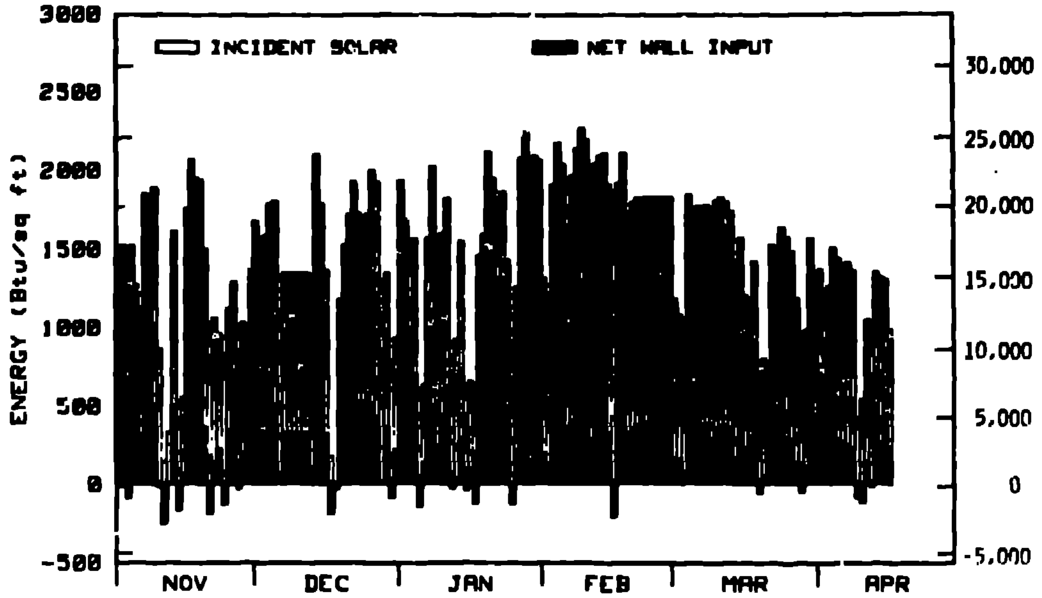

Fig. 2. Daily thermal storage wall performance for the 1978-79 heating season.

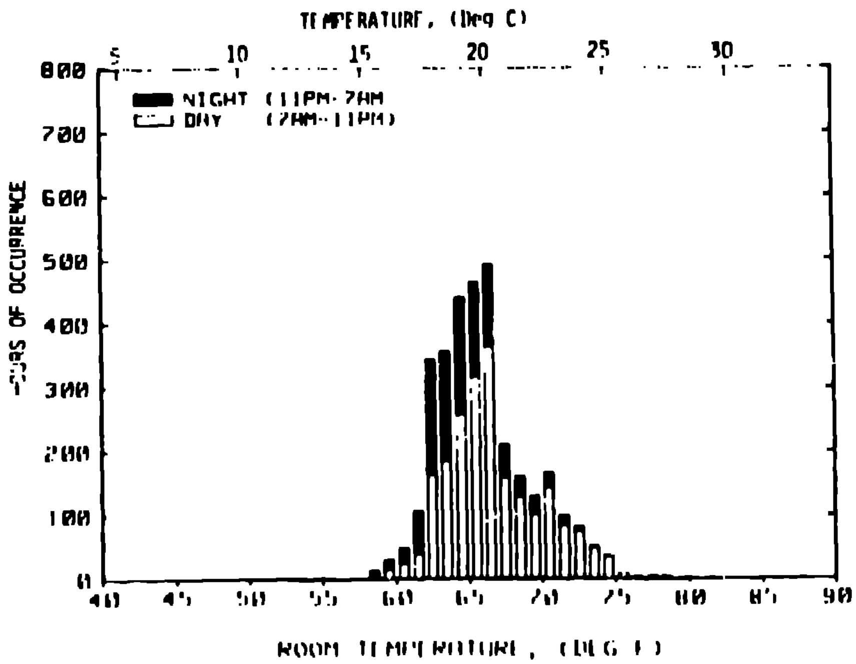

Fig. 3. Room temperature histogram for downstairs in the two-story section of the Hunn residence.

inlet plenum temperature from 32°C (90°F) to 35°C (95°F), but this is still too low to give adequate performance. Lower air flow rates were tried, but no improvement resulted. Sizeable duct losses were indicated by the typical 6°C (10°F) temperature drop from the wall discharge to the rock-bed inlet plenum during the charging mode.

It is concluded that uncontrollable air leakage and significant duct losses are the causes of the poor active mode performance. These problems are not likely to be solved without a major redesign and reconstruction of the system. Consequently, the active mode has not been used since the initial test period. This experience has indicated that a proper design for hybrid operation is that of a rock bed thermally coupled to the heated space, rather than a thermally isolated one (7). The heat is best removed from the rock bed by radiation and convection from the rock-bed container surface, rather than with a blower.

3. PERFORMANCE FOR THREE HEATING SEASONS

Reliable gas and electric utili[illegible]cords have been kept since February 1[illegible]. These data and 18°C (65°F)-based degree days for each heating season were used to compute the gross heat loss, using a calculated heat loss coefficient of 147 kJ/°C-day-m^2 (7.2 Btu/DD-ft^2).

A credit was taken against this computed heat loss for electrical consumption, nonfurnace gas consumption (water heating auxiliary, stove, and clothes dryer), and people, to compute the furnace consumption (space heating requirement) for the nonsolar reference case. The measured credit for heating from internal sources amounts to 92,400 kJ/day (87,600 Btu/day) for the heating season, which converts to an associated ΔT of about 3.4°C (6.2°F) when the daily gain is divided by the building loss coefficient for the solar building. Subtracting the nonfurnace (estimated from summer records) gas consumption for each month from the metered gas consumption yields the actual furnace energy consumption. Assuming a furnace efficiency of 50 per cent, the furnace output is determined. Using these data, an annual energy balance for the house is made (see Ref. 2 for example). The solar heating fraction (SHF) for the year is then

$$SHF = \frac{\text{solar heating}}{\text{net space heating load}}$$

$$= 1 - \frac{\text{furnace output}}{\text{net space heating load}} .$$

The net space heating load is the load that would have to be supplied in the absence of any solar gains.

A summary of the three-year performance is given in Table I. Thus, the annual solar heating fraction is consistently in the 61 to 64 per cent range.

It is interesting to compare the solar contribution to space heating for the 1978-1979 heating season with the results calculated in Ref. 6. Reference 6 reports transmitted solar radiation through the south-facing double glazing, based on total horizontal radiation measured at the site, to be 2.03 x 10^6 kJ/m^2 (179,800 Btu/ft^2) for the season (November-April). Applying this to the

TABLE I

THREE-YEAR MEASURED ANNUAL PERFORMANCE SUMMARY

Year	Degree-Days (65°F reference)	Furnace Output (10^6 Btu)	Net Space Heating Load to be Supplied by Furnace Without Solar (10^6 Btu)	SHF
1977-78	6136	23.3	60.3	0.61
1978-79	6839	26.5	68.2	0.61
1979-80	6192	23.3	64.3	0.64

1 Btu = 1.055 kJ

11.4 m^2 (123 ft^2) of direct-gain aperture yields 23.3 x 10^6 kJ (22.1 x 10^6 Btu) absorbed by the house. Using the net contribution for the storage wall of 15.8 x 10^6 kJ (15.0 x 10^6 Btu) reported in Ref. 6, this results in a total solar contribution of 39 x 10^6 kJ (37.1 x 10^6 Btu) for the season. By comparison, an energy balance on the November-April portion of the measured data for 1978-1979 results in a total solar contribution of 37.5 x 10^6 kJ (35.6 x 10^6 Btu), a difference of only 4 per cent from the value calculated in Ref. 6. This strongly suggests that the two methods are based on a consistent and reasonable set of assumptions.

4. ENERGY AND COST SAVINGS

An estimate of the energy and fuel cost savings resulting from the passive solar system can be obtained by multiplying the Solar Savings Fraction (SSF), obtained using the methods of Ref. 5, by the net heat load on the solar house, exclusive of the solar aperture area. The net heat load for the solar house is the product of the loss coefficient, exclusive of the solar aperture, and the appropriate degree-days for the solar building. Using the internal gain ΔT for the solar building of 3.4°C (6.2°F) calculated above, the appropriate DD value for Los Alamos is 2583 °C-days (4650 °F-days) (5)

Using the simplified Load Collector Ratio (LCR) method of Ref. 5, a SSF for the combined direct-gain and storage wall system of the Hunn residence is 0.32. Correcting this value for a lower wind speed and a larger air gap in the direct gain glazing (5), an approximate SSF = 0.42 is obtained. Thus, the energy saved as a result of the solar system is

$(21{,}340\ kJ/^{\circ}C\text{-day})(0.42)(2583\ ^{\circ}C\text{-day}) = 23.2 \times 10^6\ kJ$

$(11{,}237\ Btu/DD)\ (0.42)(4650\ DD) = 21.9 \times 10^6\ Btu.$

The savings in purchased energy requires division of this result by the estimated furnace efficiency of 0.60. Therefore, the energy cost savings is

$$\frac{23.2 \times 10^6\ kJ\ (\text{or}\ 21.9 \times 10^6\ Btu)}{0.60} \times \text{unit energy cost.}$$

A summary of this calculation for each of the three years is shown in Table II.

TABLE II

ESTIMATED ENERGY COST SAVINGS

Year	Estimated Energy Savings (10^6 Btu)	Unit Cost of Displaced Fuel (\$/10^6 Btu)	Estimated Annual Dollar Savings
1977-78	36.5	2.60	$95
1978-79	36.5	2.71	$99
1979-80	36.5	3.52	$128

1 Btu = 1.055 kJ

The average annual saving experienced was $107/yr for the first three years. The passive system cost estimated in Refs. 2 and 4 (exclusive of rock-bed related costs) is about $3400. Using this figure, a simple payback analysis indicates a payback period of 32 years at average fuel prices of the last three years. Assuming the long-range average gas prices to be double the current prices, the simple payback period is reduced to about 16 years. Although this is not a particularly enticing economic investment under this scenario of fuel prices, more rapidly inflating fuel prices over the coming years will result in a reduced payback period.

5. CONCLUSIONS

The conclusions regarding the passive solar performance of the Hunn residence are as follows.

1. Annual performance was characterized by a SHF of 61 to 64 per cent. The estimated average energy savings for the first three years of operation were $107/yr.
2. The net heating contribution from the passive solar system, determined from measured temperature profiles in the wall, agreed within 4 per cent with the contribution that was deduced from an annual energy balance on the house determined from measured energy use.
3. During unoccupied periods, when the furnace was off, the minimum indoor temperature was 8°C (46°F).
4. Uncontrolled air leakage and significant duct losses have resulted in the active mode operation being unsuccessful. Redesign of the system using a rock bed thermally coupled to the heated space appears to be the only feasible solution.

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