The Effect of Various Attic Venting Devices on the Performance of Radiant Barrier Systems in Hot Arid Climates

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ABSTRACT

Optimum performance of radiant barrier systems is to achieve an attic air temperature as close to the outdoor air temperature as possible. It has been shown that the type of venting device used in the attic would dramatically vary the heat transfer performance of a radiant barrier system. In desert climates, heat gain from the roof component is significantly higher than from other building surfaces. While the radiant barrier system can prevent excessive heat gain during the day, it inhibits the release of heat to the night sky. Therefore it is assumed the ventilation system plays an important role in the performance of a radiant barrier system both day and night. Two identical, side-by-side, occupied, existing houses were monitored during the summer of 1987; one of the houses received a retrofit of radiant barrier system on the attic floor above the R-11 insulation, while the other remained unchanged (no radiant barrier system). Three different ventilation situations were studied: (1) gable and static vent, (2) rooftop turbine vent, and (3) ceiling up-duct of an evaporative cooler. These houses were monitored to compare system performance of each vent type. Results indicate the RBS performance improved as expected with use of ventilation.

INTRODUCTION

Early work by Joy (1958) indicated that attic ventilation was important in the determination of heat gain due to the changes of surface conductance. Recent studies on radiant barrier systems have claimed an average of 16% to 42% of heat flux reduction due to the radiative heat transfer. Fairey (1985) tested the performance of RBS with 0 and 5 ach of attic ventilation and found improved performance with higher ach. In a full-scale attic test with ridge and soffit vents, Ober (1988) observed the importance of venting devices on a radiant barrier system performance. Although the modeling of radiant barrier systems with ventilation can be achieved theoretically, the model contains several deficiencies when using correlations for the ventilated attic (Wilkes 1988).

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The results from a previous study of two side-by-side residences in Arizona (Wu 1987) concurred with the findings by other researchers on the heat flux reduction of the attic radiant barrier system. In that study, both attics were equipped with gable vents on east and west elevations and static vents located near the ridge. Since in hot, arid regions summer wind speed is very low, attic ventilation relies heavily on the stack effect. While a turbine vent can passively promote attic ventilation through both stack and wind effects, it is intended to take advantage of breezes to assist the airflow created by temperature differences. An up-duct is an exhaust outlet for evaporative cooling systems where the large volume of air change in the living space passes through the attic space before exiting to the outdoors. For houses without up-ducts, the exhaust is usually vented by opening windows. The two test houses were monitored on these different venting devices.

Typical soffit and ridge vents can provide a fairly parallel flow of air along the direction of trusses, hence the removal of heat from attic surfaces would be optimized. A gable vent introduces air in the direction perpendicular to the truss, thus creating a series of obstructions along attic surfaces, and performance could be diminished. An evaporative cooler's up-duct injects a high-speed volume of chaotic air into the attic. The flow inside the attic becomes very unpredictable, but the large number of air changes reduces the attic temperature. The purpose of this study is to investigate the performance of an attic radiant barrier system with gable vents, static vents, turbine vents, and up-ducts of an evaporative cooler, without intending to optimize the flow direction. The retrofit of each type of device is determined by market availability and ease of installation.

HOUSE DESCRIPTION AND VENTING DEVICES

The two side-by-side houses from the previous study were monitored during June and August of 1987. Turbine vents were installed in August. Thermocouple sensors ("T" type) were installed on the roof deck, attic space, insulation surface, ceiling surface, and in the living space. A heat flux meter (1 in. square) was also installed on the top side of ceiling gypboard, underneath the attic insulation (R-11, average 4 in. batt insulation) to measure the amount of heat transfer simultaneously.

Both houses are typical tract homes with masonry wall construction and wood truss for roof assembly. Each is a three-bedroom, one-story, slab-on-grade home with a two-car garage, and approximately 1860 ft^2 of living area. The houses face north with south orientation for the backyard. There are proper overhangs on both north and south, which provide timely shadings for the summer overheating problem. The thermal integrity is low, with R-11 on the attic floor, R-6 on the walls, and single-pane window glazing. Both houses have lightgrey roof shingles. The air-conditioning systems are standard air-to-air heat pump systems. House 1 has an additional evaporative cooler. The radiant barrier system was a two-sided foil film on craft paper with emissivities of 0.2 and 0.05 laid on the attic floor above the insulation. The shiny side of the system faced upward to the attic.

The three venting systems investigated were (1) gable and static vents, (2) turbine vents in addition to gable and static vents, and (3) the use of up-duct with evaporative cooler. The use of gable and static vents is a common practice in the region because of their low cost and ease of installation. They provide some positive flow of air during calm desert summers. A turbine vent is also quite economical to install and provides an added induction of airflow whenever there is wind and large temperature stratifications in the attic. Because the desert summer is calm, the stack effect will normally be the only force for attic ventilation. The third type of venting is the use of up-ducts in an evaporative cooling system. A basic design parameter of an evaporative cooling system is the large amount of air change per hour. The air would either be exhausted through window openings or through the up-duct designed to replace the warm air in the attic. A one-time measurement of the airflow through these up-ducts was about 3460 cfm, which is equivalent to 38 ach for 5400 ft^3 of attic space. The turbine vents remove 283 cfm (3.18 ach) of attic air during a 1.7 mph wind condition. Due to the small flow rates and the nature of flow patterns, the gable and static vents' flow was not measured. The attic ventilation area ratio is about 3.22 ft^2 per 1000 ft^2.

MONITORING AND MEASUREMENT

On-site monitoring began on June 8 with the room thermostat set at 82°F for both houses. The data from June 10 are chosen to illustrate the performance of a radiant barrier system with only gable and static vents. For June 11 to 15, the evaporative cooler of House 1, which received the radiant barrier system, were turned on, so the up-duct would be activated whenever the cooler was on. The data of June 12 are presented to compare the improved performance of induced venting through up-duct. On August 18, two turbine vents were installed near the ridge of the roof in House 1. The data of August 20 are used to show the impact of the added airflow by these turbine vents. Since this occurred at the same time as the monsoon (rainy) season, performance of the radiant barrier system varied slightly, especially at night. But on August 21 the evaporative cooler was turned on for a small amount of time in the afternoon. The performance of the radiant barrier system with up-duct exceeded all the other venting devices in terms of heat flux reduction through the roof/ceiling envelope.

MONITORING RESULTS

The comparison of respective temperature sensors installed in both houses under identical indoor conditions was reported in the previous paper. No differences were detected before the radiant barrier system was installed. The only perceivable change for this study was a slight accumulation of dust on the radiant barrier surface one year after the installation.

Gable and Static Vents

Data recorded from June 8 to June 10, 1987 were used to examine the effect of gable and static vents on the radiant barrier system performance. Data from June 10 are presented in the study. The comparison plots of roof deck, attic air, insulation surface, and ceiling surface temperatures between two monitored houses are shown in Figures 1 through 4. It is important to note the increased magnitude of roof deck and attic air temperatures for the house with the radiant barrier system, and the significantly lower temperatures on the insulation surface and ceiling surface. The lower insulation surface temperature in House 1 indicates that the amount of conductive heat transfer between attic and room is dramatically reduced. The lower ceiling surface temperature indicates the enhanced comfort from mean radiant temperature during the day for House 1. Due to the dry climate, nighttime sky radiative heat loss was inhibited in House 1 and the insulation surface, and ceiling surface temperatures were higher than House 2. The accumulated heat flux for the day in $Btu/ft^2/day$ is shown in Figure 5, where a net reduction of 24% is realized for House 1. If only considering the amount of heat gain during the daytime, a reduction of 22% is observed for House 1. The temperature differences between Houses 1 and 2 are shown in Figure 6; results are similar to the previous study. The lower roof deck temperature in early morning for House 1 was due to shading of the sensor by a roof-top air-conditioning unit.

Induced Ventilation with Evaporative Cooler Up-Ducts

Data from June 11 to 15 were recorded for the investigation of the attic radiant barrier system with up-ducts and evaporative cooler operation. An obvious phenomenon occurred in that the roof deck and attic air temperatures of House 1 were significantly reduced, approaching those of House 2 (Figures 7 and 8). The temperature of the insulation surface was very close to the outdoor air temperature, an optimum for the radiant barrier system, as stated at the beginning of this paper (Figure 9). Ceiling surface temperatures shown in Figure 10 did not show significant differences compared to Figure 4 of June 10. Figure 11 shows that a net heat flux reduction of 30% was realized for June 12 while the up-duct was in operation. If one considers only the amount of heat gain reduction during the daytime, the benefit is improved to 38.6% over House 2. The temperature differences between Houses 1 and 2 on June 12 were shown in Figure 12. The daytime temperature of the insulation surface for House 1 is lower than that in Figure 6 of June 10 when there is only gable and static vents.

Turbine Vents

During early August, two turbine vents were installed near the ridge of House 1. Turbine vents are widely promoted by radiant barrier vendors as greatly improving the performance of any RBS. Data of August 20 were studied to determine the effectiveness of these turbine vents on the performance of the attic radiant barrier system. Figures 13 through 16 show the temperature plots of roof deck, attic air, insulation surface, and ceiling surfaces. The improvement over the attic with only gable and static vents can only be compared with the data from June 10th. The daily net heat flux shown in Figure 17 indicates a reduction of 35.2% in House 1, compared to a 24% reduction in the case of an attic with only gable and static vents in Figure 5. If only comparing the heat gains during the daytime, the observation shows no differences between the two houses. Apparently the turbine vents did not increase the airflow through stack effect during the daytime, but at night, with the help of wind, the turbine vents did increase the airflow rate and improve the heat reduction. Although the nighttime heat loss for House 2 was larger than House 1 in June (dry season) it was much less in August. The presence of increased moisture in the air reduced the amount of nighttime heat loss for House 2 (without RBS). The temperature differences between Houses 1 and 2 are shown in Figure 18. The temperature profiles of August 20 and June 10 are similar except that the insulation surface temperature differences at night were dramatically diminished. This may be due to the moisture air of the "monsoon" season, which inhibits night sky radiation.

Reduced Operation with Evaporative Cooler and Up-Ducts

Since the weather conditions at night were not intolerable during August, an investigation was performed to examine the use of an evaporative cooler only as needed. Findings indicate that the only hours in which evaporative cooling was needed were between 2:00 p.m. and 5:30 p.m. Figures 19 through 22 show the temperature plots of roof deck, attic air, insulation surface, and ceiling surface between Houses 1 and 2. The dramatic reduction of temperature was observed in both roof deck and attic air when the evaporative cooler was activated. Figure 23 shows the daily net heat flux between Houses 1 and 2. There was a net daily reduction of 57.9% for House 1 over House 2, and a 46.1% daily reduction in heat gains during the daytime. The temperature differences plotted in Figure 24 show the effect of evaporative cooler operation with up-duct in reducing the heat transfer from roof to living space between House 1 and 2.

ENERGY CONSUMPTION COMPARISON

Energy consumption data were recorded daily for both houses, and an average daily domestic usage recorded during the mild season was subtracted from the whole house consumption to derive the approximated daily energy use for space cooling. The energy comparison of these two houses can be made only when both houses were operated under the exact same mode of air conditioning. Data from those days only using gable/static vents or turbine vents can be directly compared. Other periods with the operation of different AC equipment such as heat pumps and evaporative coolers cannot be easily compared. Through the observation of heat flux measurement and the recorded energy consumption, the reduction of energy is as expected from the benefit of venting devices.

CONCLUSIONS

The question of how an attic ventilation system affects the performance of an attic radiant barrier system is addressed by this on-site monitoring study. The various types of venting devices used in this research were readily available. It was found that the heat flux from attic to living spaces can be greatly reduced with the use of up-duct in evaporative coolers, and a lesser degree of heat flux reduction is observed in the use of turbine vents. User control of any attic venting systems, such as the operation of evaporative coolers and up-ducts, proved to be the most effective method in attic venting to enhance the reduction of heat gains. In the monsoon season, due to the condition of high moisture content in the air at night, the attic with RBS performed better in net daily heat flux than the attic without RBS; this was not the case when the weather is dry. Findings indicate that the use of evaporative cooler up-ducts provides neither laminate flow nor parallel flow along the structure member. Instead, the flow of exhaust air sought the shortest route to the outside. This study provides evidence that RBS performance can be enhanced by the addition of various attic ventilation systems. The systems tested in this study are readily available and easily installed by the homeowners. Furthermore, it also raises the issue that more studies with controlled venting conditions and direct energy usage measurements are needed for a true understanding of the improved performance.

NOMENCLATURE

OA	=	outdoor dry-bulb air temperature
ID	=	inside roof deck temperature (underneath the roof deck)
AA	=	attic air temperature (dry-bulb)
IS	=	insulation surface temperature (loosely laid on top of insulation, or right underneath the radiant barrier in House 1)
CS	=	ceiling surface temperature (on the top side of gypboard, underneath the attic insulation)
ID1-ID2	=	in-deck temperature differences between House 1 and 2
AA1-AA2	=	attic air temperature difference between House 1 and 2
IS1-IS2	=	insulation surface temperature difference between House 1 and 2
CS1-CS2	=	ceiling surface temperature difference between House 1 and 2

REFERENCES

Fairey, P.W. 1985. "The measured side-by-side performance of attic radiant barrier systems in hot, humid climates." Proceedings of the 19th International Thermal Conductivity Conference, Cookeville, TN.

Joy, F. A. 1958. "Improving attic space insulating values." ASHRAE Transactions, Vol. 64, pp. 251-266.

Ober, D. G. and Volckhausen, T. W. 1988. "Radiant barrier insulation performance in full scale attics with soffit and ridge venting." Fifth Annual Symposium on Improving Building Energy Efficient in Hot and Humid Climates, Houston, TX, September.

Wilkes, K. E. 1988. "Modeling of residential attics with radiant barriers." 5th Symposium on Improving Building Energy Efficient in Hot, Humid Climates, Texas A & M University.

Wu, H. 1987. "In-situ measurement of attic radiant barrier performance in hot, arid climates." Proceedings of ASHRAE Far East Conference on Air-Conditioning in Hot Climates, Singapore.

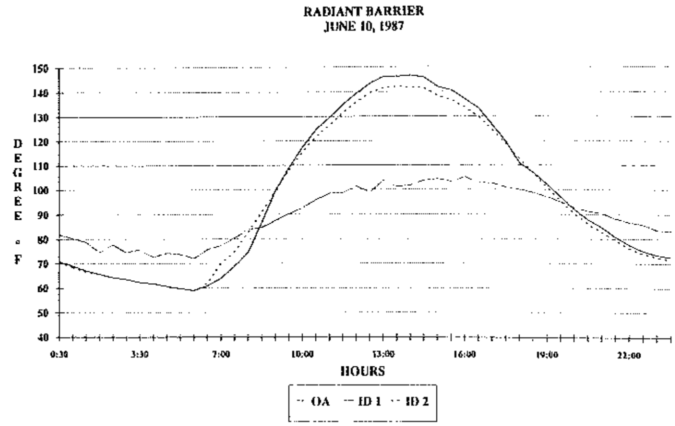

Figure 1. *Roof deck temperatures (June 10, 1987)*

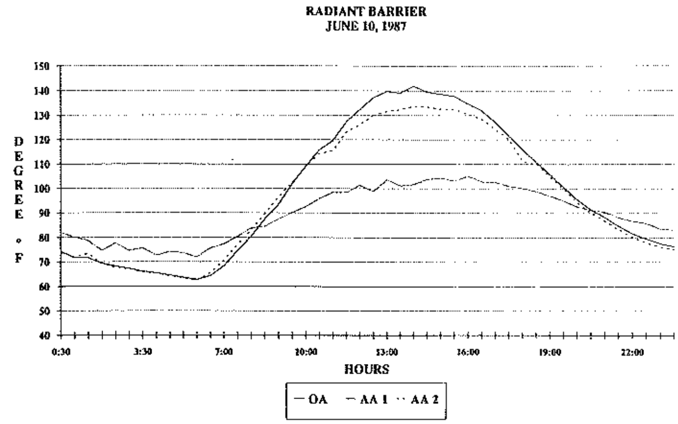

Figure 2. *Attic air temperatures (June 10, 1987)*

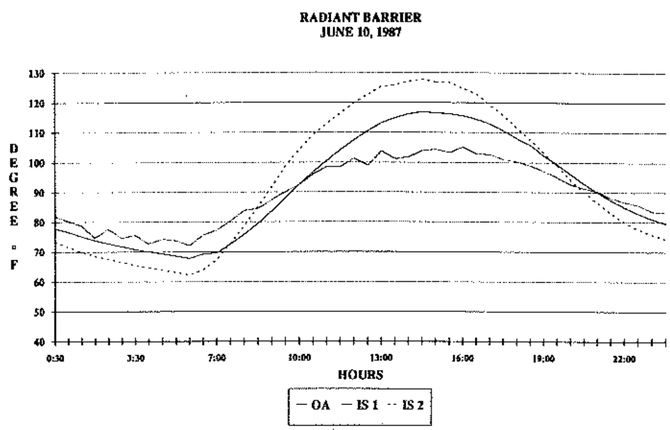

Figure 3. *Insulation surface temperatures (June 10, 1987)*

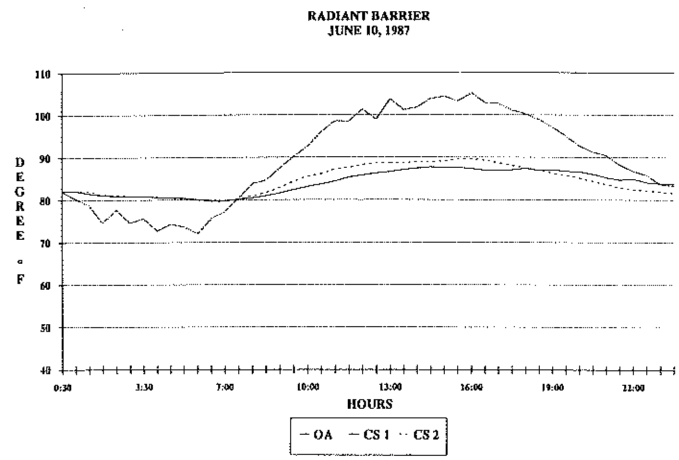

Figure 4. *Ceiling surface temperatures (June 10, 1987)*

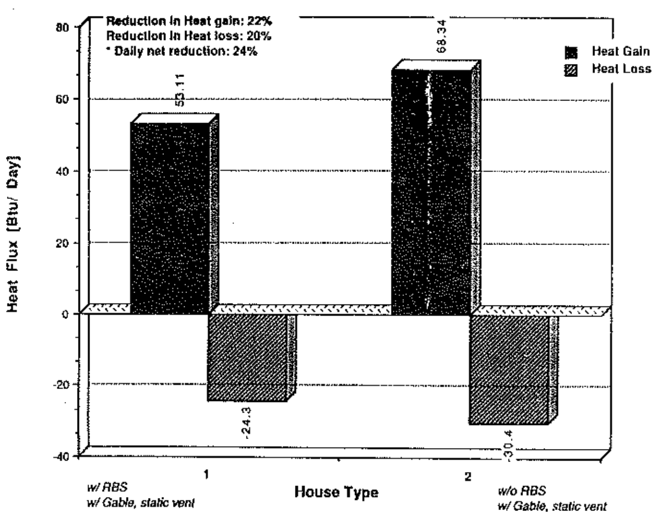

Figure 5. *Heat flux comparison (June 10, 1987)*

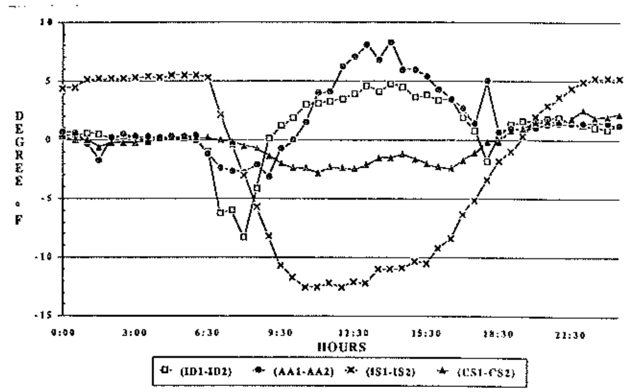

Figure 6. *Temperature differences between house 1 and 2 (June 10, 1987)*

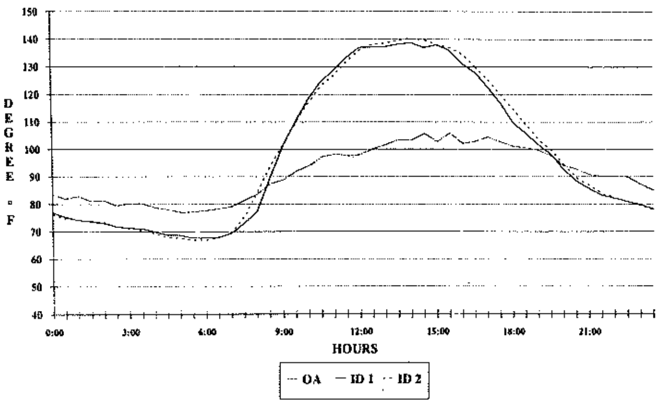

Figure 7. *Roof deck temperatures (June 12, 1987)*

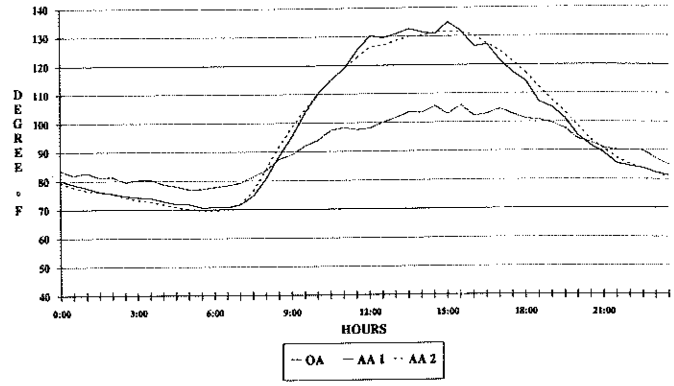

Figure 8. *Attic air temperatures (June 12, 1987)*

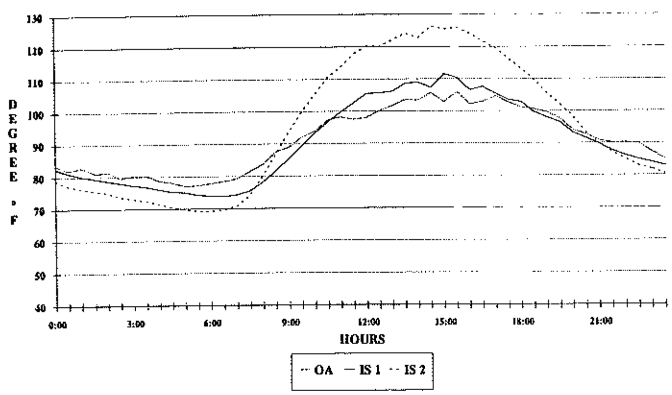

Figure 9. *Insulation surface temperatures (June 12, 1987)*

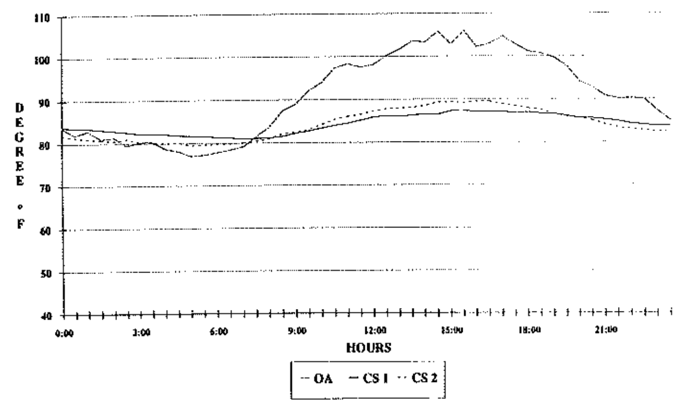

Figure 10. *Ceiling surface temperatures (June 12, 1987)*

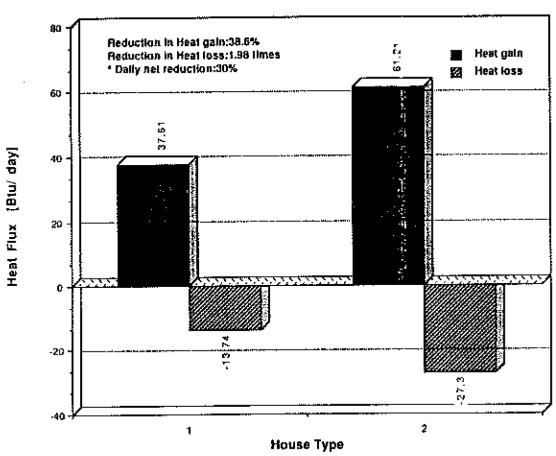

Figure 11. *Heat flux comparison (June 12, 1987)*

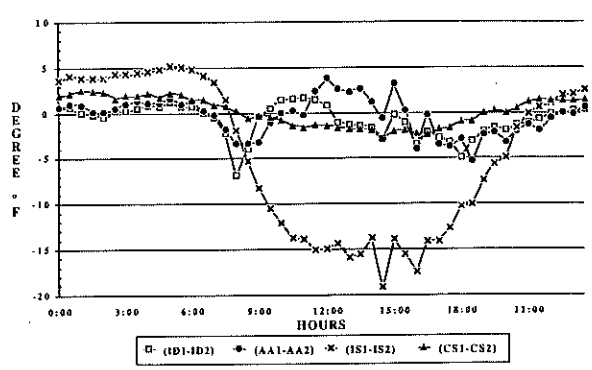

Figure 12. *Temperature differences between house 1 and 2 (June 12, 1987)*

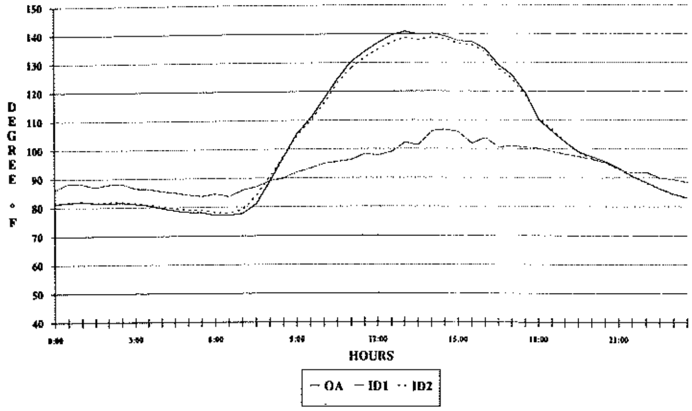

Figure 13. Roof deck temperatures (August 20, 1987)

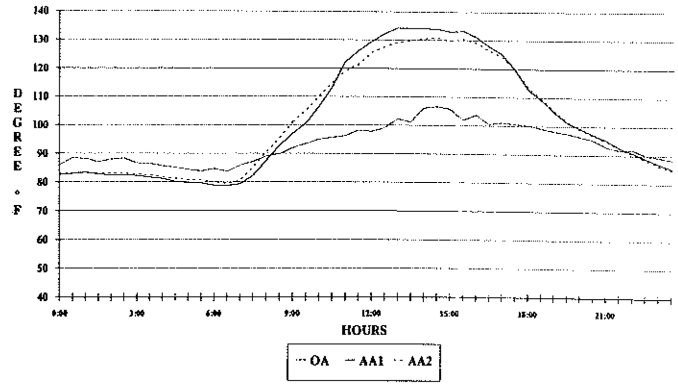

Figure 14. Attic air temperatures (August 20, 1987)

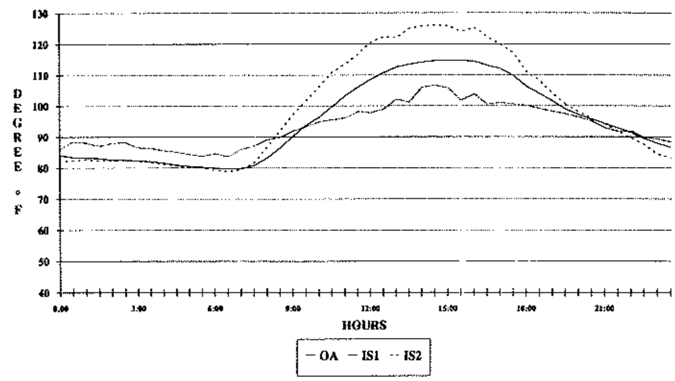

Figure 15. Insulation surface temperatures (August 20, 1987)

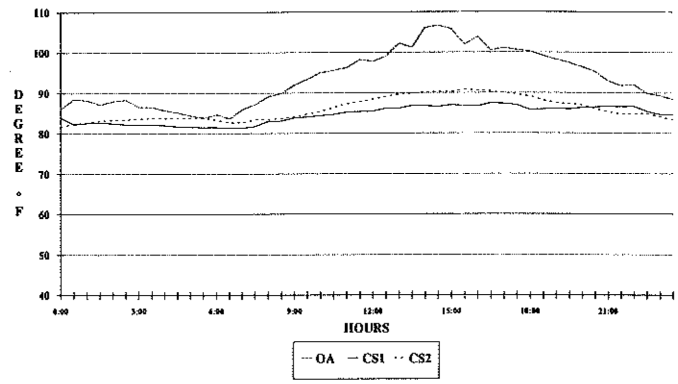

Figure 16. Ceiling surface temperatures (August 20, 1987)

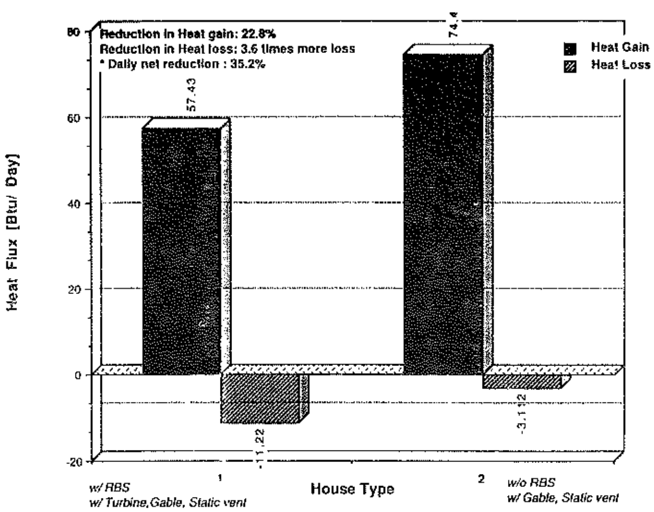

Figure 17. Heat flux comparison (August 20, 1987)

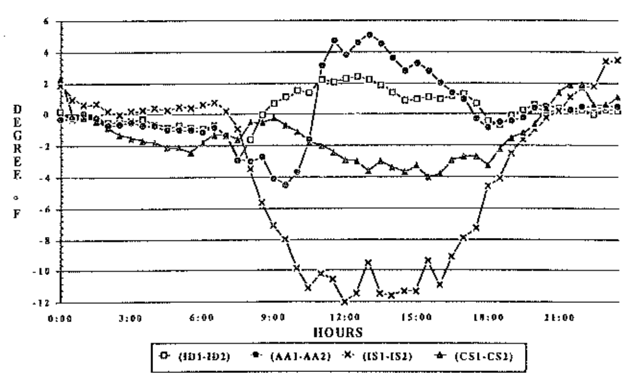

Figure 18. Temperature differences between house 1 and 2 (August 20, 1987)

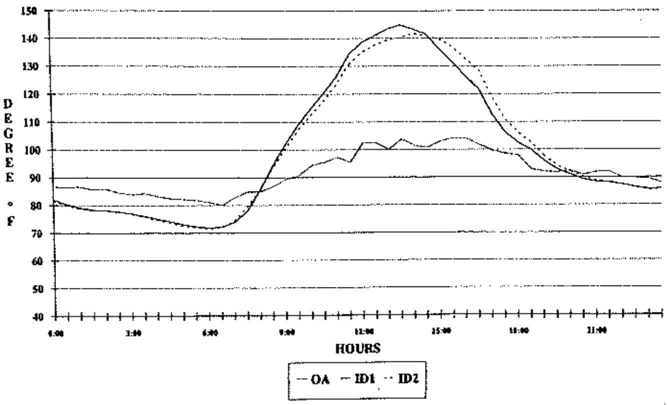

Figure 19. Roof deck temperatures (August 21, 1987)

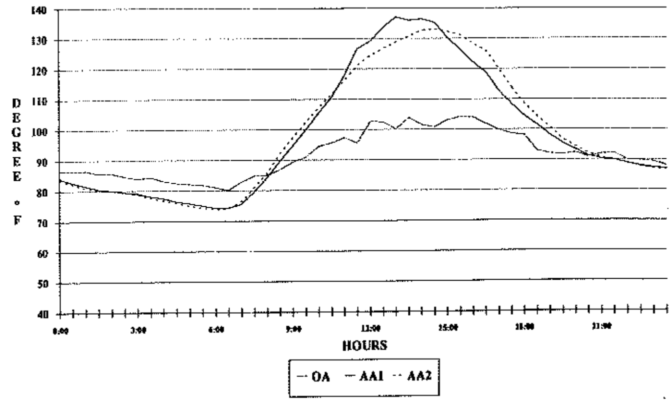

Figure 20. Attic air temperatures (August 21, 1987)

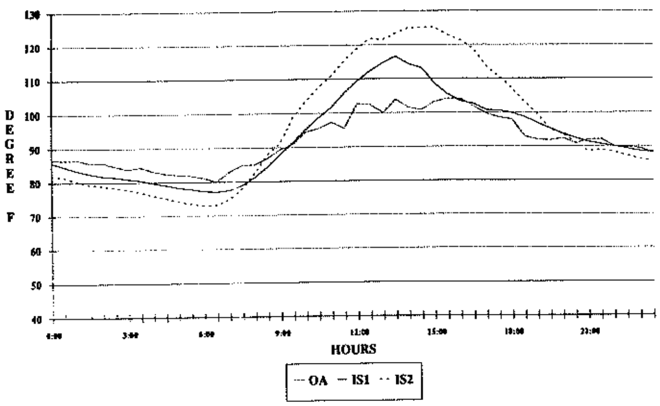

Figure 21. Insulation surface temperatures (August 21, 1987)

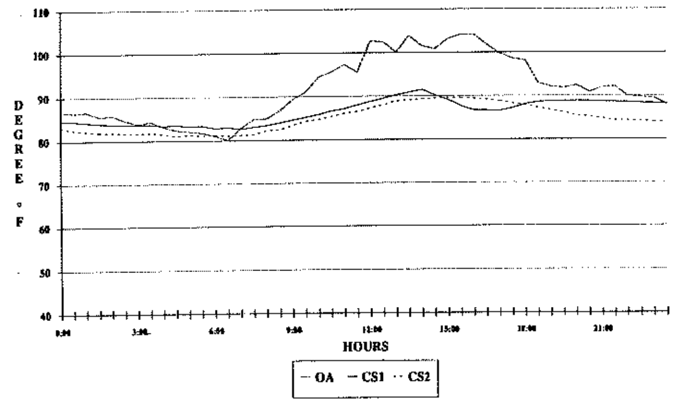

Figure 22. Ceiling surface temperatures (August 21, 1987)

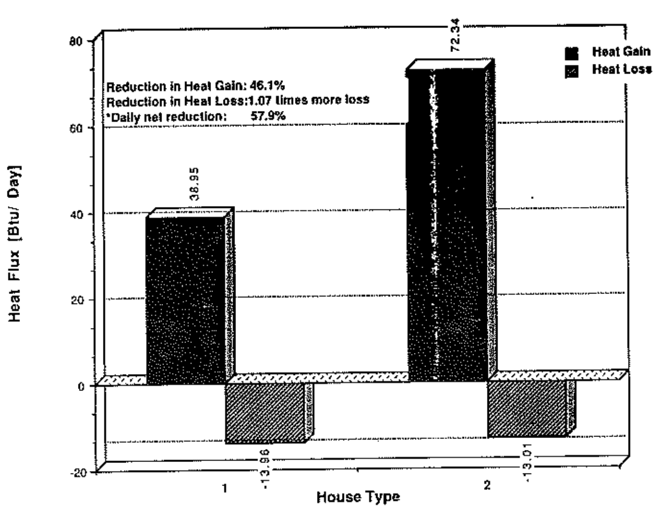

Figure 23. Heat flux comparison (August 21, 1987)

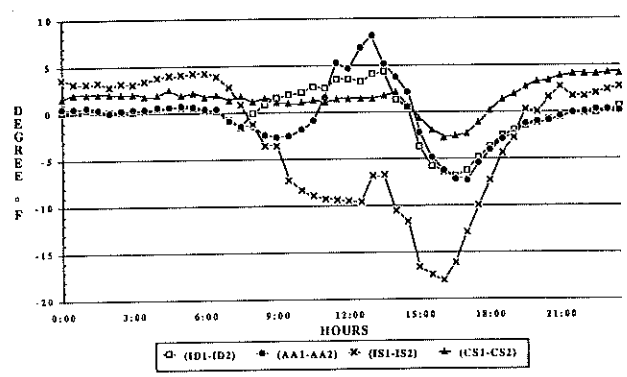

Figure 24. Temperature differences between house 1 and 2 (August 21, 1987)