Effect of Attic Ventilation on the Performance of Radiant Barriers

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The objective of the experiments was to quantify how attic ventilation would affect the performance of a radiant barrier. Ceiling heat flux and space cooling load were both measured. Results of side-by-side radiant barrier experiments using two identical 13.38 m^2 (nominal) test houses are presented. The test houses responded similarly to weather variations. Indoor temperatures of the test houses were controlled to within 0.2°C. Ceiling heat fluxes and space cooling load were within a 2.5 percent difference between both test houses. The results showed that a critical attic ventilation flow rate of 1.3 (l/sec)/m^2 of the attic floor existed after which the percentage reduction in ceiling heat fluxes produced by the radiant barriers did not change with increasing attic airflow rates. The ceiling heat flux reductions produced by the radiant barriers were between 25 and 35 percent, with 28 percent being the percent reduction observed most often in the presence of attic ventilation. The space-cooling load reductions observed were between two to four percent. All results compiled in this paper were for attics with unfaced fiberglass insulation with a resistance level of 3.35 m^2 K/W (nominal) and for a perforated radiant barrier with low emissivities (less than 0.05) on both sides.

Introduction

Radiant barriers have received increased attention during the past decade due to their potential to reduce the radiant heat absorbed through the ceiling in a residence. Radiant barriers are thin sheets of aluminum characterized by having at least one low emissivity surface (typically less than 0.05). The barrier is applied in the attic space of a residence by facing the low emissivity surface toward the air space. The barrier can prevent a major part of the infrared radiation from the attic deck and gable ends to be transferred to the top of the insulation, which is on the floor of the attic. This radiation blockage results in a reduction in the amount of ceiling heat gain into the conditioned space.

Recent studies conducted at different locations within the U.S. (Joy, 1958; Chandra et al., 1984; Fairey, 1985; Katipamula and O'Neal, 1986; Levins and Karnitz, 1986, 1987a, 1987b; Levins et al., 1986; Fairey et al., 1988; Hall, 1988; Ober and Volkhausen, 1988) have reported ceiling heat flux reductions due to the radiant barriers of 20–63 percent and overall cooling energy savings between 8–20 percent. Some reductions in heating energy consumption have also been reported (Levins and Karnitz, 1987c, 1988). The reported experiments differ from one another in many ways. Such differences include climate, attic geometry and size, house orientation, attic ventilation configuration, radiant barrier orientations, etc. Most of the literature on radiant barriers concludes that radiant barriers are effective in reducing part of the space cooling load and somewhat effective during the heating season.

The main purpose of attic ventilation is to remove heat from the attic during hot summer days. Many types of attic ventilation, both natural and forced, are used in practice today. Some are more effective than others in reducing attic air temperatures during the hottest times of the day. Wolfert and Hinrichs (1974) presented data showing that the most effective way of reducing attic floor temperature was by a combination of continuous ridge and soffit louvers. The second best way was by using either roof, gable, or soffit louvers, with no difference in effectiveness among them. Burch and Treado (1978) have reported that power venting was as effective as ridge venting in reducing ceiling heat gain.

This paper summarizes the results of experiments on two small test houses that were retrofit with radiant barriers. Previous relevant work was first reviewed, then the experimental set-up was discussed. Series of tests were run with the houses to ensure that both performed similarly to identical weather conditions. The results of the airflow tests were then discussed and conclusions were presented.

Literature Review

Published reports on the effect of ventilation on attics retrofit with radiant barriers were few and the results inconclusive. Some of the most relevant literature is summarized below.

Joy (1958) was credited as being the first one to conduct attic airflow tests in conjunction with radiant barriers. Joy reported results of tests performed under controlled steady-state conditions on two 3.66 m × 4. 96 m attics, one with a flat roof and the other with a gabled roof. The ventilation rates were steady and metered, but with different air paths depending on the kind of attic. The flat roof had an airflow path parallel to the roof and had ceiling joists with the intake and exhaust through slots at low attic level. This configuration was more representative of a soffit/soffit parallel flow attic

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ventilation. The gabled roof had the flow perpendicular to the joists and had intake and exhaust ports high in the gables. He reported that there was a higher ceiling heat flux percent reduction, which increased with flow rate, in the flat roof geometry when compared to the gable roof geometry. Both attics were retrofit with radiant barriers and compared to attics without radiant barriers. The flat roof geometry, when ventilated, approached a value close to 50 percent ceiling heat flux reduction whereas the gabled roof produced heat flux reductions of approximately 28 percent and was not sensitive to airflow variations.

Joy's experiments were conducted under controlled steady-state conditions. Actual conditions in an attic are transient because the air temperature and solar input vary during the day. Therefore, it could be difficult to generalize Joy's results.

Hall (1988) studied the relative effects on ceiling heat flux of ridge/soffit and gable/soffit combinations in 3.25 m^2 cells containing radiant barriers. The attic ventilation in each cell was provided by four soffit vents and gable or ridge vents, depending on the particular test. The ventilation was natural and the rates were not metered. When the attics were retrofit with radiant barriers placed against the trusses, the average ceiling heat reduction using gable or ridge vents was 48 percent for an average wind speed of 5.31 km/h. When attics were retrofit with horizontal radiant barriers, the heat reduction using "low vent" areas and "high vent" areas were 58 percent and 63 percent, respectively. The reductions reported by Hall seemed unusually high, which was probably due to the time of the year in which the experiments were carried out (late September) and the fact that only day hours were used in calculating the percent heat flux reduction. During the time when the experiments were carried out at low ambient temperatures, solar radiation dominated the heat flux, yielding high heat flux reductions.

Ober and Volckhausen (1988) tested the performance of radiant barriers on two 78.97 m^2 attics under natural ventilation configurations using a soffit/ridge combination. One ventilation configuration used baffles, installed under the roof deck, in order to maintain airflow within the space between the wall and the underside of the roof. The second configuration just removed the baffles. The airflow rates were not reported but were indicated as the same for both configurations. The reported ceiling heat flux reduction was around 20 percent for both configurations.

Fairey et al. (1988) developed a heat balance steady-state model to show trends and parameter sensitivities on the performance of radiant barriers as a function of attic airflow rates. The parameters included radiant barrier emittance, Sol-Air temperature, room temperature, insulation value, and radiant barrier location. The same parameters were examined for a range of attic ventilation rates and the results were presented as a percent of ceiling heat flux reduction with respect to the same conditions in an attic without radiant barriers. The trends of percent reduction were all similar in shape and indicated that a value was approached after which increasing the airflows did not produce any change in radiant barrier performance. The value was between 1.3–1.8 (l/sec)/m^2 of attic floor area. The results presented by Fairey were only valid for a flat roof geometry similar to the one described by Joy, and under steady-state conditions.

Experimental Set-up

The radiant barrier experiment set-up was composed of two test houses located 24 km west of College Station, Texas. The two test houses were labeled "west" and "east." The ridge line ran west-east in both houses. The nominal floor areas were 3.66 m × 3.66 m with 2.44 m floor-to-ceiling distance. The houses were built 7.62 m apart from each other. No shade was cast on them from any direction. Trees were located on the north side of the houses.

The houses were 13.38 cm^2 with 17.8 cm walls and had slab-on-grade foundations. The walls were constructed of a 5.08 cm-by-15.24 cm (nominal) frame with paper-faced fiberglass batt insulation with a resistance level of 3.35 m^2 K/W. The exteriors and interiors were completed with 1.27 cm sheathing and a 1.27 cm gypsum board, respectively. The ceiling was also made up of a 5.08-cm-by-15.24-cm (nominal) framing, but with unfaced fiberglass insulation with the same resistance level as that of the walls and a 1.27 cm gypsum board. The house's three window areas, one on each side except south, were filled with insulation board inserts; thus eliminating a significant heat gain/loss through the envelope and thus forcing a major part of the load to proceed from/to the attic. An air infiltration retarder was placed in the interior part of the walls to minimize any air infiltration which might occur. The roof had asphalt shingles and 1.27 cm plywood sheathing. There was a 30.48 cm overhang on the north and south sides.

The attics were originally built with gable vents which provided natural ventilation. To be able to measure the airflow rates, the gable vents were sealed with removable inserts. Two new ventilation areas, one inlet and one outlet, were made. The inlet area, located on the east side of each house, was a strip 3.81 cm by 3.05 m along the side of the houses and 7.62 cm above the ceiling frame. The outlet area was located 63.5 cm above the ceiling frame. The outlet was a 10.16 cm diameter hole to which a fan was attached. The fan induced the airflow currents. Located at the exhaust side of each fan is a damper mechanism which was used to control the airflow rates. To control the airflow rates, the static pressure curves of each fan were experimentally obtained at the test site. A static-pressure gauge was attached to each fan which in turn provided the information on the amount of air volume per unit time that was being removed from each attic. Each fan operated on a 38 Watt motor on a continuous cycle.

Both houses were equipped with identical fan coil units, digital thermostats, and water pumps. A chilled water circuit was designed which supplied both houses with a cold water/glycol solution (60/40) at approximately 4.4°C. The solution was kept in a 450-liter tank which was well insulated. The water temperature was kept at 3.3°C by means of a 10.6 kW (nominal) heat pump. A separate 2.6 kW (nominal) heat pump was connected in parallel if more cooling were required. The water/glycol flow rates were controlled by a set of precision valves. Both the water flow rates and the temperatures in and out of the cooling coils were recorded in ten-second intervals during the "on" time of the pumps. These readings, once integrated over an entire day gave the daily overall space cooling load. The fans on the fan coil units were kept "on" at all times to eliminate any discrepancies in heat gain caused by automatic fan control, should one house require more cooling than the other.

Instrumentation

Each test house was instrumented with approximately 120 sensors. The sensors included: Type T thermocouples, surface heat flux meters, relative humidity transmitters, and water flow meters. Besides the instrumentation from the houses the ambient temperature, ground temperature, and global sun and sky radiation were measured at the test site.

All the data were recorded by means of a data logger. The data were collected at one minute intervals and integrated every hour. The integrated values were then sent to a microcomputer for storage and analysis.

Temperatures were recorded for the indoor room, attic air, roof, attic deck, ceiling, as well as across the fiberglass. Each of the temperatures in question was measured using grids of Type T thermocouples connected in parallel. The indoor room temperature was measured by a grid 1.37 m from the ground. Attic air temperatures were measured at different levels, 12.7

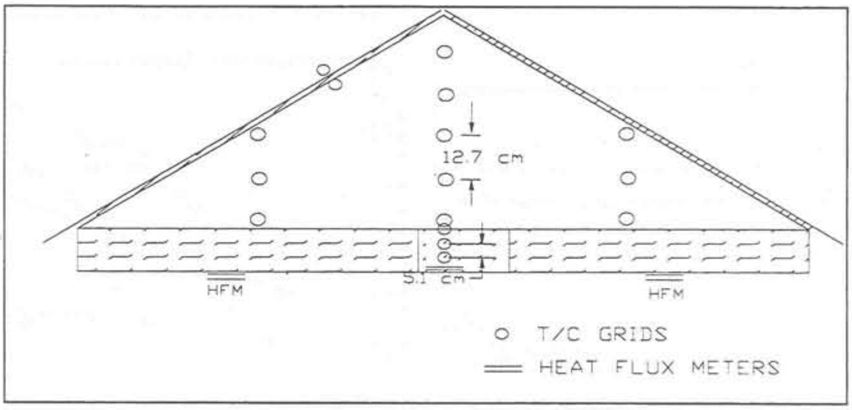

Fig. 1 Location of thermocouples and heat flux meters in the attics

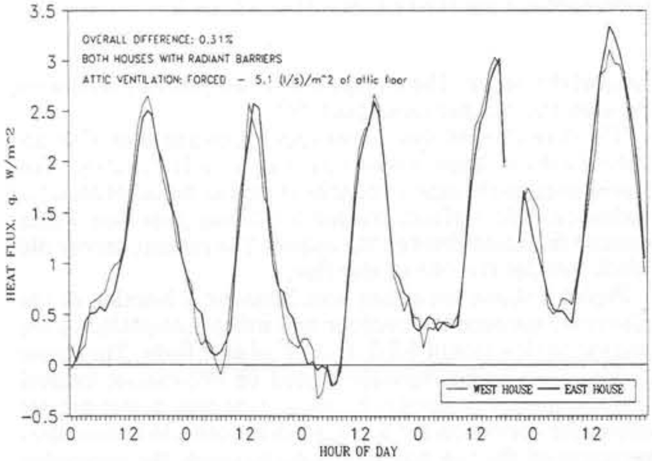

Fig. 2 Ceiling heat fluxes during calibration period. (Tracking started on July 18, 1990 at 00:00 and ended July 22, 1990 at midnight.)

cm apart from the bottom to the underside of the roof. Attic air temperatures were also measured at different distances from the centerline and at different levels. Temperature distribution across the fiberglass insulation were recorded at levels 0, 5.1, and 10.2 cm from the top of the insulation. Figure 1 shows the placement of the thermocouples and heat flux sensors in the attics.

Each test house was instrumented with five heat flux meters 10.2 cm × 10.2 cm × 2.38 mm with calibration traceable to NIST standards. Four heat flux meters were inside of each house and one was in the floor of the attic. One of the four heat flux meters measured the heat flux through a ceiling joist. All reported heat flux readings were weighted averages of all heat flux meters. The heat flux meters were factory calibrated using standard guarded hot plate tests. The manufacturer provided one calibration constant per HFM. The accuracy of the sensors was reported to be one percent of actual heat flux.

The chilled water/ethylene glycol solution provided to each house for cooling purposes was monitored with a turbine flow meter. The flow meters were on site calibrated using the water/glycol solution at the actual experimental temperature of 4.4°C. The calibration consisted on constructing curves of volume flow rate versus millivolts recorded by the data logger at specific flow rates. The volumetric flow rates were calculated by recording the time required to fill up a calibrated container. The water flow meters were accurate to within 0.50 percent of the actual flow.

The fans, which induced airflow currents through the attic, were rated following the "Laboratory Methods of Testing Fans for Ratings" guidelines proposed by ANSI/AMCA Standards 210-85 and ANSI/ASHRAE Standards 51-1985 (ASHRAE

Table 1 Major sensors and their accuracy

Sensor	Range	Accuracy
Heat Flux Meter	$0\text{–}3.1\times10^5$ W/m^2	1 percent
Type T Thermocouples	−18 −93°C	0.6°C
Water Flow Meter	0–0.2 l/sec	0.5 percent
Pyranometer	$0\text{–}5.7\times10^3$ KJ/m^2	3 percent
Emissometer	0–1	1 percent
Relative Humidity	10–95 percent	2 percent

1985). These tests provided the static pressure curves which were used to set the volumetric airflow rates leaving the attic. Once the fans were on site and operating, the static pressure were measured using magnahelic pressure sensors. The required airflow rates were set manually by a damper.

The total global sun and sky radiation on a horizontal surface were measured with a pyranometer and calibrated traceable to NIST standards. An emissometer was used to measure the emissivity of any surface of interest. The pyranometer and emissometer were factory calibrated to within three and one percent of full scale, respectively. Table 1 shows the major sensors and their respective accuracy.

Baseline Calibration

The first phase of the experimental effort was to evaluate how close the two test houses would compare with each other in ceiling heat flux, indoor temperature, and energy consumption. Calibration periods were run to spot any of the differences between both test houses. It was found that both houses were very similar in their dynamic responses. The calibration period was divided in two subperiods. The first subperiod was designed so that both houses would be compared in side-by-side testing with both attics naturally vented and without radiant barriers. The period for the first calibration run was June 11 through June 14, 1990. The total ceiling heat transferred for this period was 218.2 W-h/m^2 for the west house and 217.9 W-h/m^2 for the east house, or 0.95 percent different between the two houses. The average indoor temperature was 23.2°C for the west house and 23.0°C for the east house.

The second calibration period, July 18 through July 22, 1990, required that both attics be retrofit with radiant barriers and be vented by the power fans. The ventilation rate for this period was 5.1 l/sec/m^2 of attic floor. The ceiling heat fluxes are depicted in Fig. 2. Indoor temperatures are presented in Fig. 3. The results of the second calibration period presented in Figs. 2 and 3 also showed the similarities between both test houses. The cumulative ceiling heat transfer were 0.31 percent different. The average indoor temperatures for the same period were 23.0°C for the west house and 22.9°C for the east house.

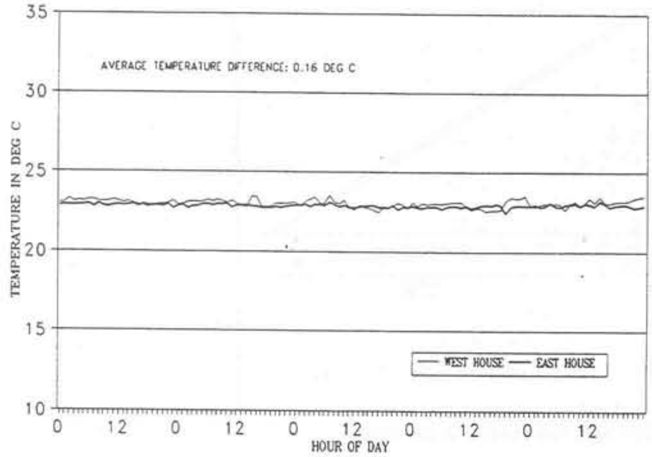

Fig. 3 Indoor temperature (same period as Fig. 2)

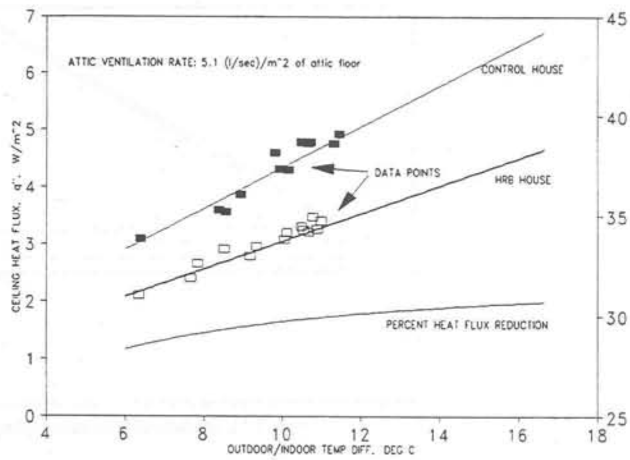

Fig. 5 Ceiling heat fluxes versus outdoor/indoor temperature difference (attic ventilation rate of 5.1 (l/sec)/m^2 of attic floor)

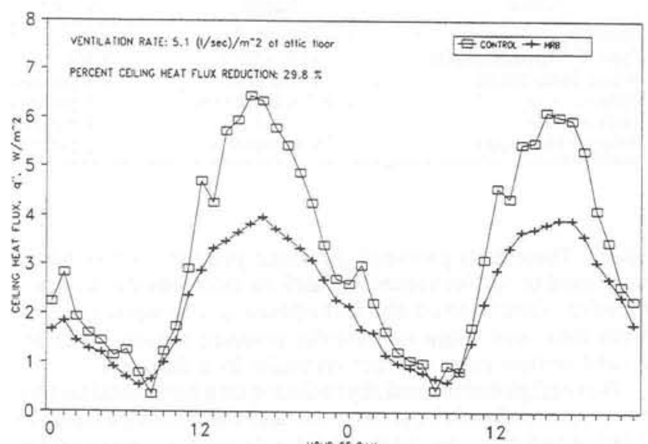

Fig. 4 Ceiling heat fluxes (period of July 28-29, 1990)

The difference in space cooling load for the period of July 18th to July 22nd between the two test houses was 2.5 percent.

Results

The side-by-side experiments started on July 25 and continued through Oct. 20, 1990. Five different airflow rates were tested when a radiant barrier was placed on top of the fiberglass insulation (HRB). The west house was kept as the control house while the east house was retrofit. The airflow rates were 0, 0.6, 1.3, 2.5, and 5.1 (l/sec)/m^2 of attic floor. The duration of each test varied depending on the quality of the data. Weather and sensor functioning determined the outcome of the data. Two airflow rates were tested for the truss barrier configuration, 0 and 5.1 (l/sec)/m^2 of attic floor. These last tests were carried out during late Sept. and early Oct. and therefore were not as representative of real summer conditions.

The data collected during the different periods clearly showed that radiant barriers contributed to a decrease in ceiling heat flux. This reduction trend was observed on a daily basis and under different conditions. Figure 4 depicts ceiling heat fluxes on a daily cycle for a period of two days. The ventilation rate for these days was 5.1 (l/sec)/m^2 attic floor. These data correspond to July 28–29, 1990. The maximum outdoor temperature and average insolation recorded for this period were 36.0°C and 2284 KJ/day, respectively. The maximum shingle temperatures recorded was 68.0°C. The daily integrated percent ceiling heat flux reduction produced by the radiant barriers was 29.8 percent and reached 40.6 percent during the hottest hour of the period. The average indoor temperature difference between the two houses was 0.15°C.

The data showed that a reduction in ceiling heat flux occurred even at times when there was no solar activity. The stored heat on the attic structures as well as moisture condensation on attic surfaces created a positive heat flux which entered the house through the ceiling. The radiant barrier did block a major fraction of this flux.

Figure 5 shows the ceiling heat fluxes as a function of the difference between the outdoor and indoor temperatures for an attic airflow rate of 5.1 (l/sec)/m^2 of attic floor. The curves in Fig. 5 are linear regression based on one-minute interval readings integrated hourly. Presenting the data in this manner allows for correction for the small differences in indoor temperatures of the two houses at specific times. By integrating the one-minute interval data, the effects caused by sudden changes in wind speed as well as effects created by passing clouds should be reduced. The percent ceiling heat flux reduction is also presented as a function of such temperature difference. The percent heat flux reduction was defined as

Percent reduction

$$= \frac{\int_{\text{test period}} q''_{\text{control}} dt - \int_{\text{test period}} q''_{\text{radiant barrier}} dt}{\int_{\text{test period}} q''_{\text{control}} dt} \times 100 \ldots, \quad (1)$$

where $\int_{\text{test period}} q''_{\text{control}} dt$: heat transferred from control attic (attic without radiant barrier) and $\int_{\text{test period}} q''_{\text{radiant barrier}} dt$: heat transferred from retrofit attic (attic retrofit with a radiant barrier).

The ceiling heat fluxes in both houses increased at different rates as solar radiation and thus the outdoor temperature increased. The radiation component of the heat transfer process in the control attic was the dominant force for the ceiling heat fluxes in the control house while this was not the case in the house with the horizontal radiant barrier. Once the outdoor/indoor temperature difference reached a value of approximately 8°C, the rate of increase in heat fluxes in the control house was large enough and had a similar slope as the difference in ceiling heat fluxes between both houses; therefore, the ceiling heat flux percent reduction remained constant.

Figure 6 is an extension of Fig. 5 in which all the ceiling heat flux percent reductions for the different attic airflow rates are presented. The figure clearly indicated that there were differences in ceiling heat flux reductions with varying airflow rates which were more detectable before such flows approached 1.3 (l/sec)/m^2 of attic floor. Once the attic airflow surpassed

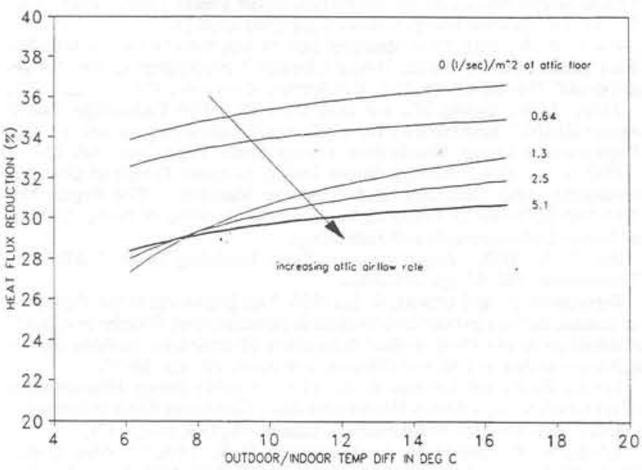

Fig. 6 Percent heat flux reduction versus outdoor/indoor temperature difference for various attic airflow rates

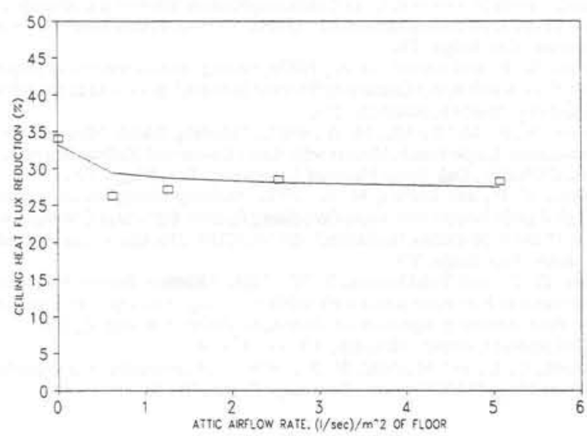

Fig. 7 Percent ceiling heat flux reduction versus attic airflow rate

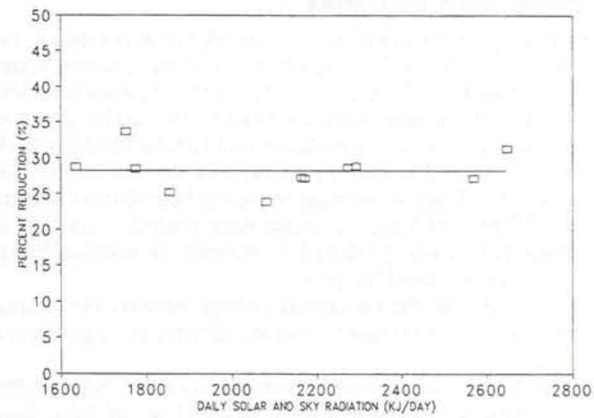

Fig. 8 Percent ceiling heat flux reductions versus solar radiation for a ventilated attic

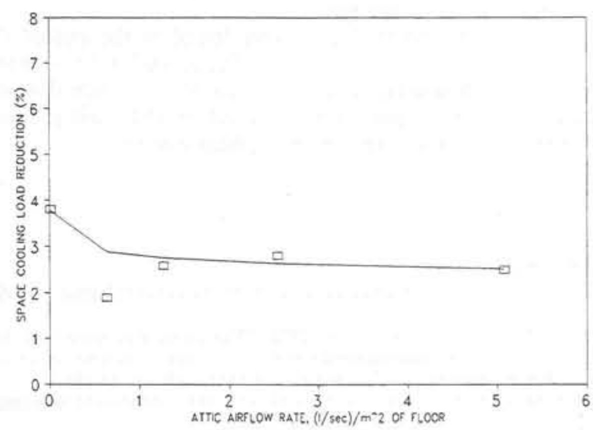

Fig. 9 Space cooling load reduction versus attic airflow rate

1.3 (l/sec)/m^2 of attic floor, the percent reductions in ceiling heat flux became very similar regardless of airflow rate.

Daily integrated ceiling heat flux reduction data indicated a percent reduction of approximately 28 percent for most of the days when attic ventilation was 1.3 (l/sec)/m^2 or higher. The data showed that as the attic airflow was increased, the percent ceiling heat flux reduction decreased. Radiation from the attic deck and end gables to the fiberglass located on the attic floor was the principal mode of heat transfer in the attic structures. Convection from the top of the insulation and attic deck to the attic air stream was the secondary mode of heat transfer (heat carried out of the attic). Each of these two modes contributed a certain percentage depending on the particular situation, that is, the larger the attic airflow rate the larger the convection component was. In the case of low attic airflow rates, the radiation component was dominant and since the radiant barriers had only the potential of reducing the radiation mode, this resulted in relatively higher ceiling percent reductions. The experiments showed that this was true for attic airflow rates of less than 1.3 (l/sec)/m^2. When the attic airflow rates surpassed 1.3 (l/sec)/m^2, slight differences in ceiling heat flux reductions were observed, but only at high outdoor temperatures. Again, at high outdoor temperatures, the radiation component in the attic heat transfer became more significant than the convection and air conduction modes. At about a temperature difference of 8°C and below, the radiation mode was not yet dominant; therefore, the percent ceiling heat flux reductions were the same for different attic airflow rates.

Figure 7 shows how the airflow rates influenced the performance of the radiant barriers during extended periods of testing. The data in Fig. 7 were averages of integrated daily heat flux reductions which took into account the 24 hours of each day. When the attics were nonvented, the data showed larger percent ceiling heat flux reduction. This happened because when the attics were not ventilated, the convective forces, other than natural convection, became negligible, which in turn made the radiation component the controlling mode.

As the periods of testing progressed from one ventilation period to the next, it became apparent that daily integrated radiant barrier performance was not dependent on the amount of insolation that impinged on the roof on a particular day. That is, radiant barriers were just as effective on clear days as well as on somewhat overcast days. This was only true for daily insolation in ranges larger than 1600 KJ/day. On rainy and completely overcast days, radiant barriers were not effective. The data of Fig. 8 were for a ventilation rate of 5.1 (l/sec)/m^2 of attic floor.

As expected, space cooling load was also only slightly influenced by attic airflow variations. The percent reduction in space cooling load produced by the radiant barrier, observed for most of the days, was in the range of 2–4 percent. This is shown in Fig. 9. The effect of radiant barriers on the overall cooling will depend on the ratio of ceiling area to wall surface area; therefore, more savings in cooling energy would be expected for real size houses. In other words, the larger the ratio of ceiling-to-wall area, the most effective the radiant barrier will be in reducing cooling energy usage.

Summary and Conclusions

Radiant barriers systems were tested for a period of two months in two very well calibrated test houses. The test houses responded within 2.5 percent of each other to weather variations. Once the houses were calibrated, any major observed changes in their dynamic responses was attributed solely to the radiant barriers. The radiant barriers in the horizontal configuration produced a decrease in ceiling heat flux of approximately 28 percent when the attics were vented. These ceiling heat flux reductions produced a decrease in cooling energy requirements of two–four percent.

For the case of the horizontal radiant barrier, the average attic air, deck, and shingle temperatures were not significantly affected.

It was found that radiant barrier effectiveness was not sensitive to airflow variations past 1.3 (l/sec)/m^2 of attic floor. It was also found that radiant barrier effectiveness was not increased past 1600 KJ/day of solar radiation, that is, that radiant barriers were as effective on totally clear days as on not very sunny days. Rainy and completely cloudy days were exceptions. Attic relative humidity changes were not detected as a consequence of the retrofit.

Traces of accumulated dust were found at the end of the tests. The accumulation was insignificant and did not affect the results. Obviously, in long periods of time such dust accumulation will be significant, and it is believed it will produce increases in the emissivity of the radiant barrier.

References

ASHRAE, 1985, "Laboratory Methods of Testing Fans for Rating," ANSI/ASHRAE 51-1985.

Burch, D. M., and Treado, S. J., 1978, "Ventilating Residences and their Attics for Energy Conservation—Experimental Study," *Summer Attic and Whole-House Ventilation*, NBS Special Publication 548, pp. 73-104.

Chandra, S., Fairey, P. W., Houston, M. M., 1984, "Analysis of Residential Passive Design Techniques for the Florida Model Energy Code," FSEC-CR-113-84, Florida Solar Energy Center, Cape Canaveral, FL.

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.

Fairey, P. W., Swami, M., and Beal, D., 1988, "RBS Technology: Task 3 Report (Draft)," Sponsored by Florida Power & Light Company and the U.S. Department of Energy, Florida Solar Energy Center, Cape Canaveral, FL.

Hall, J. A., 1988, "Radiant Barrier Testing to Assess Effects of Dust Accumulation, Attic Ventilation, and Other Key Variables," TVA Report No. TVA/OP/EDT—88/25, Tennessee Valley Authority, Office of Power, Division of Energy Demonstrations and Technology.

Joy, F. A., 1958, "Improving Attic Space Insulating Values," *ASHRAE Transactions*, Vol. 64, pp. 251-266.

Katipamula, S., and O'Neal, D. L., 1986, "An Evaluation of the Placement of Radiant Barriers on their Effectiveness in Reducing Heat Transfer in Attics," *Proceedings of the Third Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates*, Arlington, TX, pp. 68-77.

Levins, W. P., and Karnitz, M. A., 1986, "Cooling Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers," ORNL/CON-200, Oak Ridge National Laboratory, Oak Ridge, TN.

Levins, W. P., Karnitz, M. A., and Knight, D. K., 1986, "Cooling Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers," *Proceedings of the Third Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates*, Arlington, TX, pp. 78-87.

Levins, W. P., and Karnitz, M. A., 1987a, "Cooling Energy Measurements of Single-Family Houses with Attics Containing Radiant Barriers in Combination with R-11 and R-30 Ceiling Insulation," ORNL/CON-226, Oak Ridge National Laboratory, Oak Ridge, TN.

Levins, W. P., and Karnitz, M. A., 1987b, "Energy Measurements of Single-Family Houses with Attics Containing Radiant Barriers," presented at the ASHRAE Summer Meeting, Nashville, TN.

Levins, W. P., and Karnitz, M. A., 1987c, "Heating Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers," ORNL/CON-213, Oak Ridge National Laboratory, Oak Ridge, TN.

Levins, W. P., and Karnitz, M. A., 1988, "Heating Energy Measurements of Single-Family Houses with Attics Containing Radiant Barriers in Combination with R-11 and R-30 Ceiling Insulation," ORNL/CON-239, Oak Ridge National Laboratory, Oak Ridge, TN.

Ober, D. G., and Volckhausen, T. W., 1988, "Radiant Barrier Insulation Performance in Full-Scale Attics with Soffit and Ridge Venting." *Proceedings of the Fifth Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates*, Houston, TX, pp. 174-185.

Wolfert, C. K., and Hinrichs, H. S., 1974, "Fundamentals of Residential Attic Ventilation," HC Products Company, Princeville, IL.