FOREWORD

Because of the tremendous and encouraging success of the first seven symposia, the Energy Systems Laboratory in the Department of Mechanical Engineering at Texas A&M University is hosting the Eighth Symposium on Improving Building Systems in Hot and Humid Climates. Research to improve the operating efficiency of buildings in hot and humid climates has not received the national or international focus given to cold weather conservation efforts. This symposium serves as a focal point bringing together many of the researchers, policy makers, building managers and designers who deal daily with buildings in the hot and humid areas of the world.

This proceedings contains papers which have been submitted and peer-reviewed prior to publication and presentation. The Symposium Notes contain other presentation materials and papers.

The symposium is only part of the program offered by the Energy Systems Lab. The laboratory is the primary research arm of a group of faculty members in the Department of Mechanical Engineering at Texas A&M and is a division of the Texas Engineering Experiment Station. Currently, more than $2 million in research is performed each year at the Energy Systems Lab. The facility has the capability to rate and certify fans, heat pumps, air conditioning units, and heat exchangers. A major program monitoring and analyzing energy use of buildings in the Texas LoanSTAR program was initiated last year. Outreach activities such as the symposium, short courses, and seminars will continure to be a part of energy management at Texas A&M.

We at the Energy Systems Lab express our appreciation to everyone who helped make this conference a success. These include our co-sponsors (the Texas Governor's Energy Office, ASHRAE, Dallas CSI, North Texas AEE, Texas Society of Architects, and Texas A&M's Center for Energy and Mineral Resources), the Building Symposium Advisory Committee, who took time from their busy schedules to provide guidance and suggestions, all the authors, reviewers, session chairs, plenary speakers, and the keynote speaker for sharing their knowledge and experience.

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Effects of Radiant Barrier Systems on Ventilated Attics in a Hot and Humid Climate

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ABSTRACT

Results of side-by-side radiant barrier experiments using two identical 144 ft^2 (nominal) test houses are presented. The test houses responded very similarly to weather variations prior to the retrofit. The temperatures of the test houses were controlled to within 0.3 ^{o}F. Ceiling heat fluxes were within 2 percent for each house.

The results showed that a critical attic ventilation flowrate (0.25 CFM/ft^2) existed after which the percentage reduction produced by the radiant barrier systems was not sensitive to increased airflows. The ceiling heat flux reductions produced by the radiant barrier systems were between 25 and 34 percent, with 28 percent being the reduction observed most often in the presence of attic ventilation. All results presented in this paper were for attics with R-19 unfaced fiberglass insulation and for a perforated radiant barrier with low emissivities on both sides.

INTRODUCTION

Radiant barrier systems 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 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 from being transferred to the top of the insulation which is in the floor of the attic. This radiation blockage produces a reduction in the amount of ceiling heat gained by the conditioned space.

Recent studies conducted at different locations within the U.S. [2-11,14] have reported ceiling heat flux reductions during the cooling season, due to the use of radiant barrier systems, of 20-63 percent and overall cooling energy savings between 8-20 percent. Some reductions in heating energy consumption have also been reported [12-13]. Most literature on radiant barrier systems concludes that radiant barriers are effective in reducing part of the cooling load and are somewhat effective during the heating season.

The main purpose of attic ventilation is to remove heat from the attic during hot summer days and to reduce moisture buildup in both the cooling and heating seasons. Many types of attic ventilation, both natural and forced, are used today. Some are more effective than others in reducing attic air temperatures during the hottest times of the day. Wolfert and Hinrichs [15] presented data showing the most effective way of reducing the attic floor temperature was a combination of continuous ridge and soffit louvers. The second best way was to use either roof, gable or soffit louvers, with no difference in effectiveness among them. Burch and Treado [1] have reported that power venting is 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. A series of tests was run on the houses to ensure that both performed similarly under identical weather conditions. The results of airflow tests were then discussed and conclusions presented.

INSTRUMENTATION

Each test house was instrumented with approximately 120 sensors. The sensors included: Type T thermocouples (T/C), surface heat flux meters (HFM), relative humidity transmitters (RH), and water flow meters (WFM). Besides the instrumentation from the houses, 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 1-minute intervals and integrated every hour. The integrated values were then sent to a micro-computer for storage and analysis.

Temperatures were recorded for the indoor room, attic air, roof, attic deck, and ceiling, as well as across the fiberglass. Each of the temperatures in question was measured using grids of T/Cs connected in parallel. The indoor room temperature was measured by a grid 4.5 ft. from the floor. Attic air temperatures were measured at different levels 5 in. apart from the bottom to the underside of the roof. Attic air temperatures also were measured at different distances from the centerline and at different levels. Temperature distribution across the fiberglass insulation was recorded at 0 in., 2 in., and 4 in. from the top of the insulation.

Each test house was instrumented with five (5) HFMs (4.0"x4.0"x3/32") with calibration traceable to NIST standards. Four HFMs were inside each house and one was in the floor of the attic. One of the four HFM measured the heat flux through a ceiling joist. All reported heat flux readings were weighted averages of all HFMs.

The chilled water/ethylene glycol solution provided to each house for cooling purposes was monitored with a turbine flow meter. The flow meters were calibrated using the water/glycol solution at the actual experimental temperature of 40 °F. The WFMs were accurate to within 0.50% full scale (0-3 gpm).

Total global sun and sky radiation on a horizontal surface was measured with a pyranometer whose calibration was traceable to NIST standards. An emissometer was used to measure the emissivity of any surface of interest. The major sensors and their accuracy are presented in Table 1.

Table 1. Listing of major sensors and their accuracy.

Sensor	Range	Accuracy (+ or -)
Heat Flux Meter	0-10^5 Btu/hr/ft^2	1%
Type T T/C	0-200 °F	1 °F
Water Flow Meter	0-3 GPM	0.5%
Pyranometer	0-500Btu/ft^2	3%
Relative Humidity Sensor	10-95%	2%
Emissometer	0-1	1%

EXPERIMENTAL SET UP

The radiant barrier experiment was located in College Station in Central Texas. The area climate is humid subtropical with hot and humid summers. Summer temperatures as high as 103 °F have been reported. The mean relative humidity for the area is high, ranging from 51 percent to 62 percent at noon CST, and the estimated possible summertime sunshine for the area is 74 percent.

The radiant barrier experiment was composed of two test houses labeled "west" and "east". The ridge line ran west-east in both houses. The nominal floor areas were 12 ft. x 12 ft. with 8 ft. floor to ceiling distance. The houses were built 25 ft. apart from each other. No shadow was cast on them from any direction. Trees were located on the north side of the houses.

The houses were 144 ft^2 with 8 in. walls and had slab-on-grade foundation. The walls were constructed of a 2 in.-by-6 in. frame with R-19 paper-faced fiberglass batt insulation. The exteriors and interiors were completed with 1/2 in. sheathing and 1/2 in. gypsum board, respectively. The ceiling also was made up of a 2 in.-by-6 in. framing, with R-19 unfaced fiberglass insulation and 1/2 in. gypsum board. The houses' three window areas, (one on each side except south), were filled with insulation board inserts. This eliminated a significant heat gain/loss through the envelope and forced a major part of the load to proceed from/to the attic. A vapor barrier was placed in the interior part of the walls to minimize any air infiltration which might occur. The roof was made of asphalt shingles over 1/2 in. plywood sheathing. There was a 12-inch overhang on the north and south sides.

The attics originally were built with gable vents which provided natural ventilation. To be able to measure the airflow rates, the gable vents were sealed with removable inserts. New inlet and outlet ventilation areas were made. The inlet area was a strip 1.5 in. by 10 ft. located on the east side of each house and 3 inches above the ceiling frame. The outlet area was a 4 in. diameter hole fitted with an attached fan. The outlets were located 25 in. above the ceiling frame. The fan induced airflow currents. Located at the exhaust side of each fan was a damper mechanism to control the airflow rates. To set the airflow rates, the static pressure curves of each fan were obtained experimentally at the test site. A static-pressure gauge was attached to each fan and provided the information on the amount of air volume per unit time that was being removed from each attic. The fans had a 1/20 HP motor and operated on a continuous cycle.

Both houses were equipped with identical Fan Coil Units (FCU), digital thermostats and water pumps. A chilled water circuit was designed to supply both houses with a cold water/glycol solution (60/40) at approximately 40 °F. The solution was kept in a well insulated 120-gallon tank. The water temperature was kept at 38 °F with a 3-ton heat pump. Water/glycol flowrates were controlled by a set of precision valves. Water flowrates and the temperatures in and out of the cooling coils were recorded in 10-second intervals during the "ON" time of the pumps. These readings, integrated over an entire day, gave the daily overall cooling energy consumption. The fans on the FCU were kept on at all times to eliminate any discrepancies in heat gain caused by the fan motors which results from automatic fan control when one house requires more cooling than the other.

BASELINE CALIBRATION

The first phase of the experimental effort was to evaluate how closely the two test houses would compare with each other in ceiling heat flux and energy use. Calibration periods were run to spot any differences between both test houses. It was found that both houses were very similar in their dynamic responses. Figure 1 depicts the ceiling heat fluxes for the period of June 11 through June 14, and Figure 2 depicts the indoor temperatures for the same period. The total ceiling heat transferred for this period was less than one percent different between the two houses. The average indoor temperature was 73.8 °F for the west house and 73.5 °F for the east. During this period, the attics were vented naturally and neither house had radiant barriers.

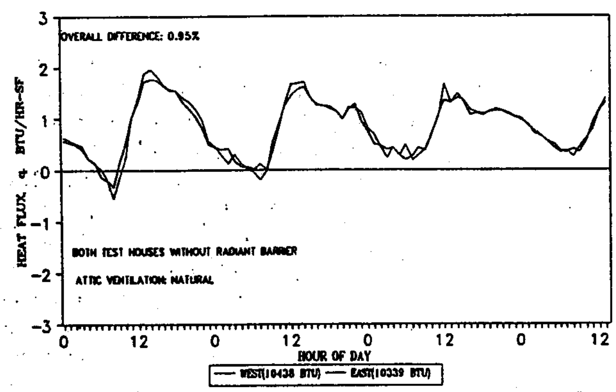

Figure 1. Ceiling heat fluxes for calibration. Tracking started on June 11,1990 at 00:00 and ended June 14, 1990 at noon.

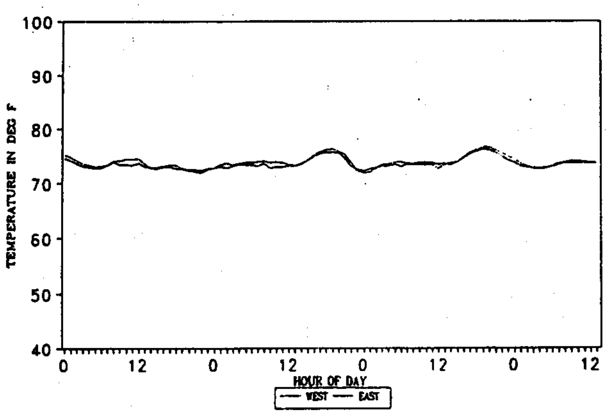

Figure 2. Indoor Temperature (same period as Figure 1).

A second calibration period was required. During this period, both attics were retrofit with radiant barriers and were vented by power fans. The ventilation rate for this period was 1.0 CFM/ft[2] of attic floor. Again, the same parameters shown in Figures 1 and 2 are depicted in Figures 3 and 4 for the period of July 18 through July 22, 1990 except that Figure 3 is presented in a cumulative manner. The results of the second calibration period presented in Figures 3 and 4 showed the similarities between both test houses. The cumulative ceiling heat transfers were almost identical (0.27 percent difference). The average indoor temperatures for the same period were 73.5 °F for the west house and 73.2 °F for the east house.

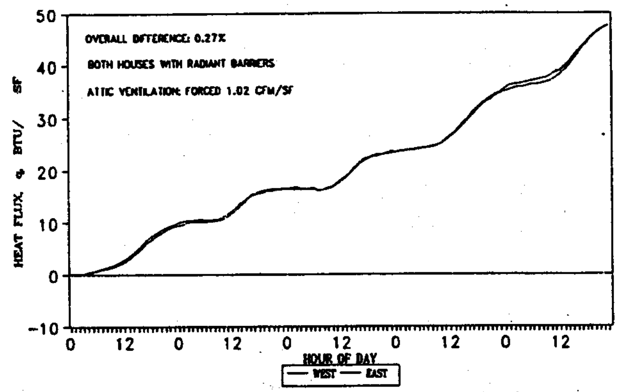

Figure 3. Cumulative ceiling heat fluxes for calibration phase. Tracking started on July 8,1990 at 00:00 and ended July 22, 1990 at midnight.

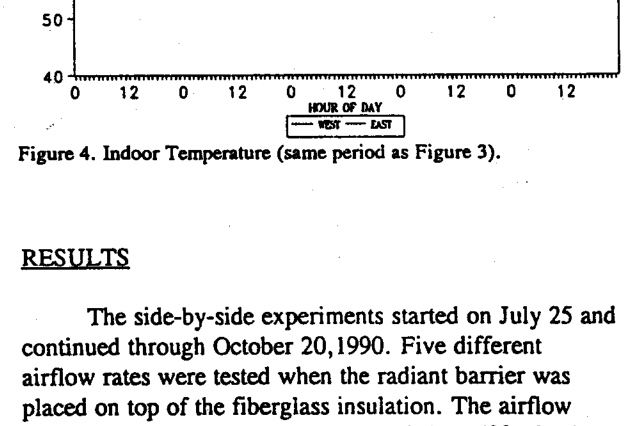

Figure 4. Indoor Temperature (same period as Figure 3).

RESULTS

The side-by-side experiments started on July 25 and continued through October 20,1990. Five different airflow rates were tested when the radiant barrier was placed on top of the fiberglass insulation. The airflow rates were 0, 0.125, 0.25, 0.5 and 1.0 CFM/ft[2] of attic floor.

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 5 depicts ceiling heat fluxes on a daily cycle for a period of two days. The ventilation rate for these days was 1.0 CFM/ft^2 of attic floor. These data correspond to July 28-29, 1990. The maximum outdoor temperature and average insolation recorded for this period were 96.8 °F and 2165 Btu/day, respectively. The maximum shingle temperature recorded was 154.4 °F. 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 houses was 0.3 °F.

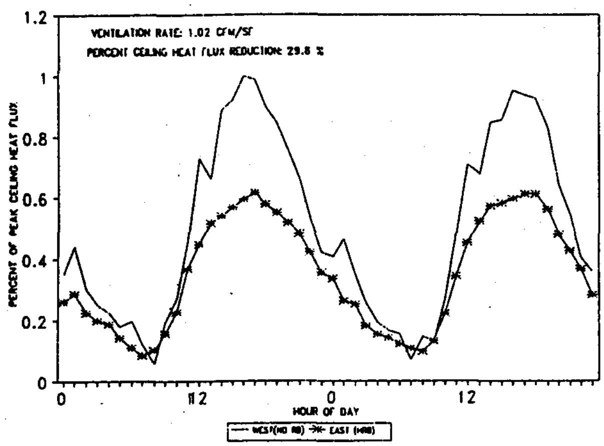

Figure 5. Ceiling heat fluxes. Period of July 28 - July 29, 1990.

The data showed that a reduction in ceiling heat flux occurred even when there was no solar activity. The stored heat in the attic structure created a heat flux which entered the house through the ceiling. The radiant barrier blocked a major fraction of this flux.

The ceiling percent reduction was defined as the ratio of the difference in ceiling heat flux transferred in both houses to the amount of ceiling heat flux transferred to the control house (the house without a radiant barrier). In equation form:

% Reduction = (q"(control) - q"(hrb))/q"(control) ......Eq. 1

where,

q"(control)= Ceiling heat flux of house without a radiant barrier,
q"(hrb)= Ceiling heat flux of the retrofit house.

The percent reductions produced by the radiant barrier were calculated on daily basis. That is, all 24 hours of the day were taken into account in the integration calculations. These percent reductions were averaged depending on the testing period. The results are presented in Figure 6.

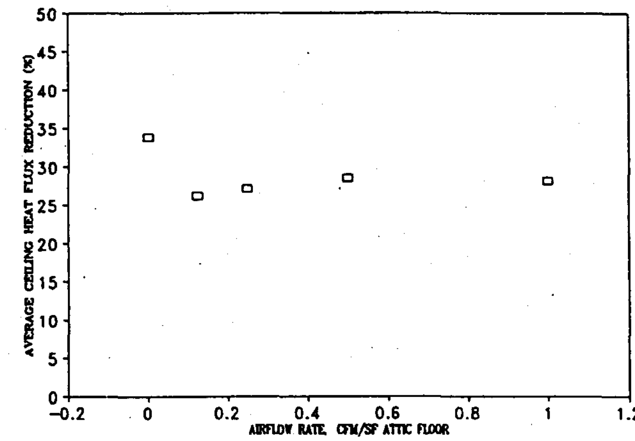

Figure 6. Percent ceiling heat flux reduction as a function of attic airflow rate.

The data indicated that radiant barrier performance was only slightly sensitive to airflow variations in the range of airflows tested. This is true because after a critical attic flowrate of has been reached (0.25 CFM/ft^2 of attic floor in our case), the integrated ceiling heat flux in each attic remains fairly constant. The amount of air which is channeled through the attic has no major impact in reducing the attic air temperature, or in enhancing the combined convection in the overall heat transfer process since the forced convection component in the overall heat transfer process in an attic is very small. Therefore, any variations in attic airflow showed only a small impact on the overall energy transfer.

It is important to note that in ventilated attics the amount of solar radiation incident on the roof sections had only a small effect on the percent ceiling heat flux reduction produced by the radiant barriers. In other words, radiant barriers were just as effective on clear days as well as on somewhat overcast days. This was true for daily insolation in ranges larger than 1500 Btu/day. On rainy and completely overcast days, radiant barriers were not effective. The data are presented in Figure 7.

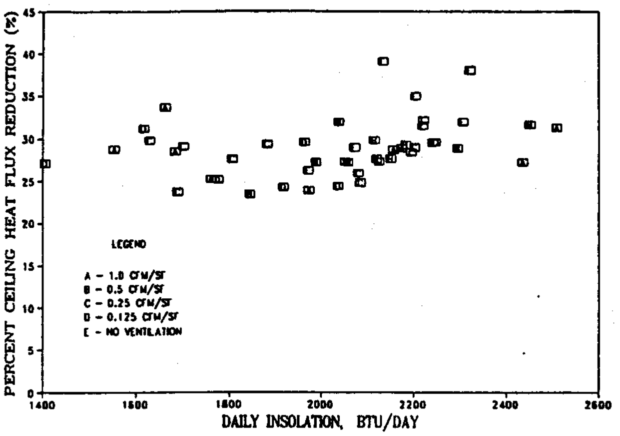

Figure 7. Percent ceiling heat flux reductions vs. solar radiation under different ventilation conditions.

SUMMARY AND CONCLUSIONS

Radiant barriers systems were tested for a period of two months in two well calibrated test houses. The test houses responded to weather variations within 2 percent of each other. Once the houses were calibrated, any major changes observed 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.

It was found that radiant barrier effectiveness was not sensitive to airflow variations past 0.25 CFM/ft^2 of attic floor. It was also found that radiant barrier effectiveness was not increased past 1500 Btu/day of solar radiation. In other words, radiant barriers were as effective on totally clear days as on somewhat overcast days. Rainy days were exceptions.

For the case of the horizontal radiant barrier, average attic air, deck, and shingle temperatures were not significantly affected by the retrofit. Moisture problems were not detected in the retrofit attic.

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