ENERGY MEASUREMENTS OF ATTIC RADIANT BARRIERS INSTALLED IN SINGLE-FAMILY HOUSES

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ABSTRACT

Testing was conducted by the Oak Ridge National Laboratory (ORNL) to determine the energy savings attributable to radiant barriers installed in attics of unoccupied single-family houses. Three levels of fiberglass attic insulation (R-11, R-19, and R-30) were tested with two types of barrier installation (horizontal and truss). The results showed that horizontally installed radiant barriers were more effective than truss barriers in reducing HVAC loads. Measured cooling load reductions ranged from 4 to 22% (compared to same attic insulation insulation R-value with no radiant barrier) and heating load changes from +4% to -10% were measured (compared to same attic insulation R-value with no radiant barrier). Radiant barriers appeared to decrease the HVAC loads more when lesser amounts of insulation were present in an attic. Minimal changes were measured when R-30 was present in an attic. Long-term effects of dust on the performance of radiant barriers as well as the effects of moisture condensing on the surface of a radiant barrier during cold winter temperatures remain unanswered.

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Introduction

The Department of Energy (DOE) and the Tennessee Valley Authority (TVA) have jointly sponsored a series of experiments to measure the energy performance of radiant barriers installed in attics of single-family houses. A radiant barrier is a foil material with either or both surfaces coated with a low emissivity material (typically aluminum). A radiant barrier works as a system in conjunction with an air space and can theoretically block up to 95% of the far infrared radiant heat transfer. These energy experiments were carried out in three unoccupied houses located in Karns, Tennessee, midway between Oak Ridge and Knoxville, Tennessee. These houses have been used for seasonal space conditioning experiments which measured the energy performance of radiant barriers. The first radiant barrier experiment was a cooling test conducted in the summer of 1985 (Reference 1). The following winter a heating experiment was conducted in the same houses (Reference 2). In these experiments, radiant barriers were installed in combination with R-19 fiberglass batt ceiling insulation. A second cooling experiment was completed in the summer of 1986 when a radiant barrier was installed with both R-11 and R-30 fiberglass batt insulation (Reference 3). The following winter a similar heating experiment was conducted (Reference 4). This paper summarizes all four experiments.

Description of the Karns House Test Facility

The Karns House Test Facility consists of three single-family 1200 ft^2, ranch style houses (Figure 1). The conditioned space (roughly 40 x 30 feet) includes kitchen/living room/dining room combined into one family area, a utility room, a master bedroom with attached bath, and two smaller bedrooms across the hall from a full second bathroom. The houses have identical floor plans, are oriented in the same direction (each house front faces north), and have heat pump space conditioning systems. The shingles are brown and the soffit and gable vents equate to an effective 1/150 area ratio. A photograph of the Karns House Test Facility is shown in Figure 2.

The houses are highly instrumented. Sensors are placed to allow data to be collected in over 50 locations in each house. Most of the data channels consist of temperature measurements taken in and around the houses. They include inside air temperature, attic temperature, outside air temperature, crawl space temperature, and various ground temperatures. Also recorded are wind speed, total solar radiation on a horizontal surface, and a number of relative humidity readings. There are several energy consumption measurements for the heat pump and a total house electric consumption measurement.

Each house has a rather unique sensor to monitor both the heating and cooling load. The design was developed by the Instrumentation and Controls Division of Oak Ridge National Laboratory (ORNL). The device is called a "Btu meter" and consists of three sensors and an electronic logic interface card. Two of the sensors are platinum RTDs (resistance temperature detectors). One

RTD is located at the inlet of the inside coil and one is located at the outlet of the inside coil. Each is coiled in a helix in the cross-sectional area of the duct so the average air temperature entering and leaving the inside coil is measured. The outputs of the RTDs are inputs to the logic card. A small anemometer is also located in the return air duct work in order to measure the air flow rate. This output is also an input to the logic card. The card electrically subtracts the RTD inputs and multiplies the results by the anemometer input and sends a digital (pulse) output to the data logger which is a measure of the heating or cooling load.

Latent loads were measured dynamically by collecting small (60 Btu equivalent) batches of condensate from the evaporator coil. The pulse output from a small calibrated solenoid pump was used to measure the condensate

Estimated accuracies of temperature measurements are +/-1°F, electrical kWh meters are +/-1%, pulse (digital) outputs are +/-1 pulse, and voltage (analog) outputs are +/-0.05%. Sensible and latent load measurements are probably accurate to about +/-2%.

Because the Karns community is adjacent to Knoxville, typical meteorological data from Knoxville provides a good description of the general climatic setting of the Karns Houses. Knoxville has a moderate temperature range with cool winters and warm summers. The heating degree days (65°F base) for the year are 4,004, and for the cooling degree days (70°F base) are 864. The relative humidity for the area is about average for the Southeastern region, which is above average for the entire country. Actual weather data during the experiments were measured at the on-site weather station.

Description of the Test Procedure

The first year's experiment was designed to test the energy performance of the installation of two types of radiant barriers in combination with R-19 fiberglass batt ceiling insulation. The radiant barrier was laid on top of the fiberglass batt insulation for one type, and it was attached to the underside of the roof trusses for the other type. A graphical description of each type of radiant barrier installation is shown in Figure 3. The second year's experiment was designed to test the performance of two levels of ceiling insulation (R-11 and R-30) in combination with the same two installation methods for the radiant barrier (horizontal and truss).

The first phase of each seasonal test was a calibration period to allow a comparison of either the heating or cooling energy use among the three houses without radiant barriers. The houses were operated in this manner from three to five weeks. Radiant barriers were then added to two of the houses after this calibration period. One house was always used as a control house. No radiant barrier was installed in this house. Various tests with radiant barriers ranged from two weeks to approximately six weeks. This test method allowed comparisons to be made among the houses.

Description of the Data Analysis Procedure

The sum of the hourly values of the various data channels for each test period was used to compare energy use, the heating load, and the cooling load differences among the three houses. House #1 was used as a control house for all tests. The control house allowed the ambient weather effects to be factored out by making results relative to the control house. Because neither the loads nor the heat pump efficiency of three houses are identical, it is necessary to normalize the results of the experimental measurements. Results are normalized by deriving relative calibration values for both the house heating and cooling loads and the HVAC electrical consumption before installing radiant barriers, with house #1 being the common denominator. The values obtained for each house may be looked upon as a calibration factor for the house (i.e., its loads or electric consumption relative to house #1, the control house). The equations for the calibration factors are the following:

for house #1: $$CF_1 = \frac{H1_{NRB}}{H1_{NRB}} = 1.0,$$

for house #2: $$CF_2 = \frac{H2_{NRB}}{H1_{NRB}},$$

for house #3: $$CF_3 = \frac{H3_{NRB}}{H1_{NRB}},$$

where NRB means no radiant barrier installed, CF is the calibration factor, and H is either house loads or HVAC electrical consumption. The numbers refer to house numbers.

Measured loads and HVAC electrical consumption for the post-retrofit of the radiant barriers in houses #2 and #3 are made relative to house #1, and this value is divided by the calibration factors of the pre-retrofit test to obtain the normalized results. Equations for normalization are as follows:

for house #2: $$NC_2 = \frac{1}{CF_2} \times \frac{H2_{RB}}{H1_{NRB}} = \frac{H1_{NRB}}{H2_{NRB}} \times \frac{H2_{RB}}{H1_{NRB}} \approx \frac{H2_{RB}}{H2_{NRB}},$$

for house #3: $$NC_3 = \frac{1}{CF_3} \times \frac{H3_{RB}}{H1_{NRB}} = \frac{H1_{NRB}}{H3_{NRB}} \times \frac{H3_{RB}}{H1_{NRB}} \approx \frac{H3_{RB}}{H3_{NRB}},$$

where RB means radiant barrier installed, NC is the normalized factor for either the house loads or the electrical consumption, and H is the measured value for each house.

The normalization procedure allows for comparison between slightly different entities. Because the three houses are undergoing the same ambient conditions at all times, weather effects are essentially factored out and the normalized results present true comparisons between a house with a radiant barrier and a house without a radiant barrier. The control house (house #1) is also essentially canceled out in this normalizing procedure. This does, however, assume a linear relationship between the loads or the electric consumption and ambient weather conditions. The linear assumption should hold, provided weather conditions are approximately similar.

Results of Radiant Barrier Experiments

The results of the energy performance testing are summarized in Figure 4. Cooling results with R-11 attic insulation show that a truss barrier reduced the house cooling load by 10%, while a horizontal barrier reduced the load by 16% compared with R-11 with no radiant barrier. Cooling results with R-19 attic insulation show that a truss barrier reduced the cooling load by about 12%, while a horizontal barrier reduced the load by 21% compared to R-19 with no radiant barrier. Radiant barriers had very little effect when used in combination with R-30 insulation. A horizontal barrier tested in the heating mode with R-11 decreased the heating load by an average of 9%, while a truss barrier increased the load by 1% compared with R-11 and no radiant barrier. A horizontal barrier with R-19 decreased the heating load by an average of 10%. The heating load decrease with a horizontal barrier and the increase with a truss barrier followed the pattern obtained with R-19 and radiant barriers in the winter of 1985-86. However, in the winter of 1986-87, R-30 with a radiant barrier showed a reduction of 3.5% for both the horizontal and the truss barriers. The heating load reduction for a truss barrier with R-30 is inconsistent with the trends obtained with R-11 and R-19 with a truss barrier, and no explanation is offered for this behavior except that the absolute values of the R-30 load changes are relatively small.

Results of the four-season test were integrated using the DOE 2.1 modeling simulation program. Figure 5 summarizes both heating and cooling tests and shows the effect of the radiant barrier relative to R-11 attic insulation with no radiant barrier. The results show that in the cooling mode R-19 with a horizontal barrier outperforms all the other options, including R-30 with a horizontal barrier. It shows that a horizontal barrier in combination with R-19 ceiling insulation reduced the cooling load by 25% in comparison with R-11 with no radiant barrier. This situation is not the same in the heating mode, where R-30 with either type of radiant barrier outperforms R-19 with a horizontal barrier. We speculate that in the heating mode, the horizontal barrier works more as a convective barrier than as a radiant barrier. However, there is no evidence to support this claim. We also believe that the small perforations (0.05% of total area) in the horizontal radiant barrier have little effect on its energy performance, but, again, this is conjuncture. There were no perforations in the truss barrier material.

Both monitored and visual checks of the horizontal radiant barriers showed that moisture can form on the underside of the barrier during the winter. The houses were normally kept at 40% relative humidity in the living area, and light condensation was detected on the horizontal barrier in the early morning hours during cold weather. However, the moisture vaporized in the warmer afternoon hours, and neither the insulation nor the radiant barrier showed any adverse effects for the six-week period when horizontal barriers were present. A three-calendar-day high-humidity test was carried in house #3 when the relative humidity was increased to 60%. The house felt uncomfortable at this humidity level, and condensed water was streaming down the double-pane windows. Much moisture formed on the underside of the horizontal barrier and did not dissipate during the afternoon as it did in house #2 where the inside humidity was 40%. When the humidity in house #3 was reduced to 40%, the moisture on the barrier vaporized after a few days. These observations show that moisture has the potential to be a problem in cold weather with horizontal barriers, especially in excessively humid houses. No high humidity tests were conducted in the control house, so high humidity effects there are unknown. Tracer gas infiltration measurements using SF_6 showed that a horizontal radiant barrier did not alter house infiltration rates.

Summary and Conclusions

The objective of the testing was to quantify the heating energy saving potential of horizontal and truss radiant barriers used in combination with R-11, R-19, and R-30 fiberglass batt attic insulation. The testing was carried out over two cooling and two heating seasons. Figure 4 shows the measured effects on the heating and cooling loads of installing each type of radiant barrier on each level of attic insulation. Figure 5 shows the estimated changes in both heating and cooling loads (based on DOE-2 modeling combined with measured radiant barrier data) relative to R-11 with no radiant barrier for each insulation/radiant barrier combination. These figures represent measured and estimated values for 1200-ft^2 unoccupied ranch-style houses in a Knoxville climate. Factors such as occupancy effects, house type, shingle colors different from brown, attic ventilation area ratios different from 1/150, and different climates are all capable of changing the results.

Radiant barriers work better in cooling than in heating, and also work better in combination with R-11 and R-19 attic insulation than with R-30. Horizontally installed barriers also are more effective than truss-mounted barriers in reducing heating and cooling loads. Moisture can condense on the underside of a horizontal barrier in cold weather and is a potential problem area, even though no deleterious effects were noted in our two heating seasons of operation. Horizontal radiant barriers do not appear to be attic infiltration barriers.

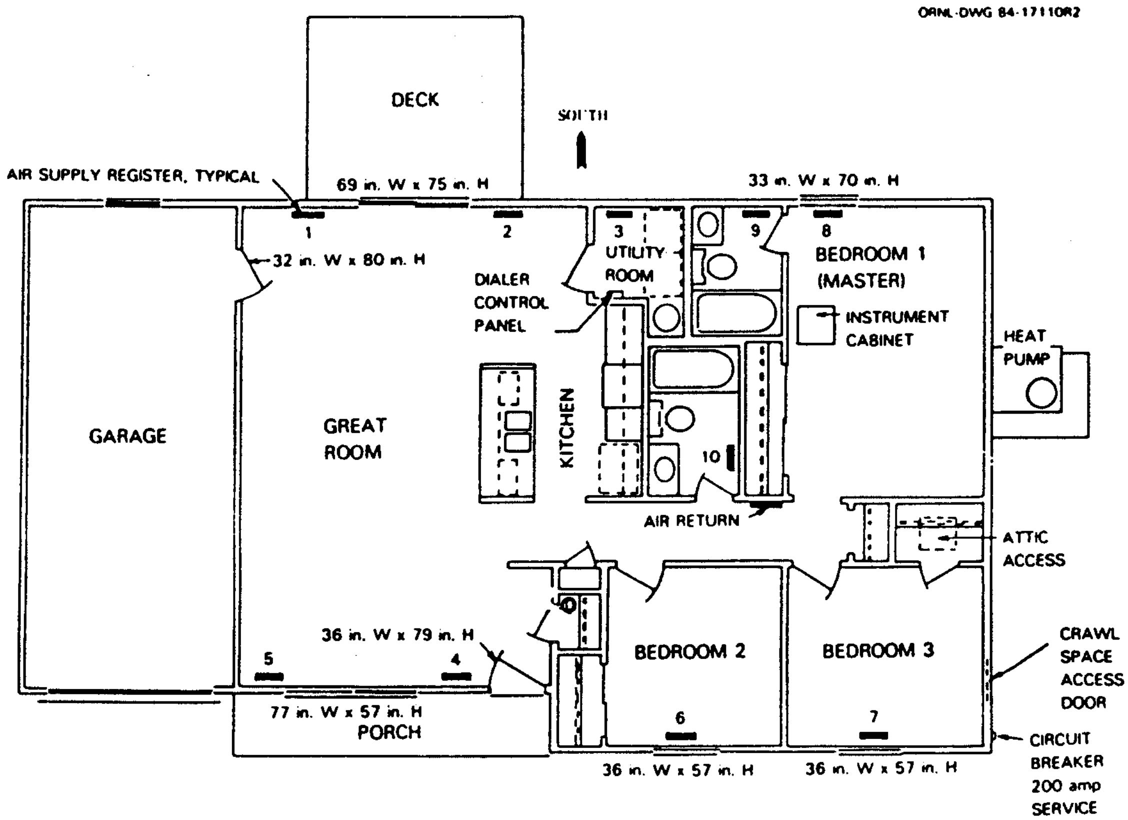

Fig. 1. Floor plan for a Karns house.

ORNL-Photo 3773-82

Fig. 2. Front view of the Karns houses.

ORNL DWG 85-16596AR2

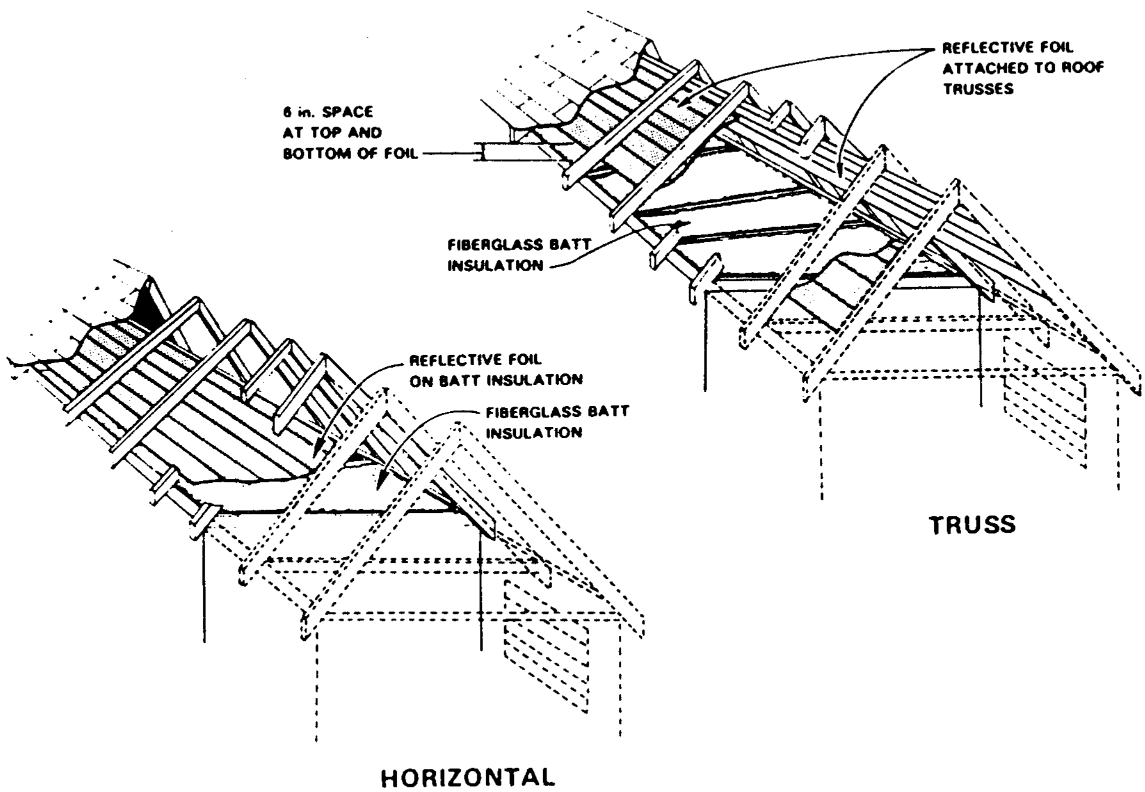

Fig. 3. Two types of radiant barrier installation.

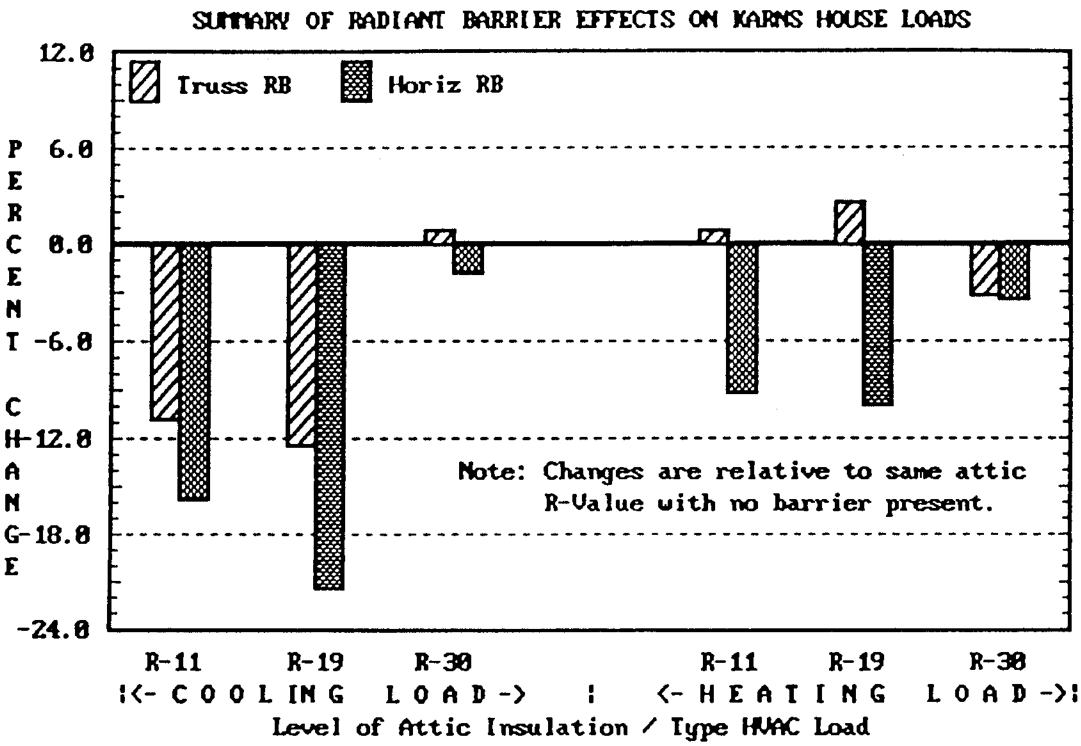

Fig. 4. Summary of measured radiant barrier effects on Karns house loads.

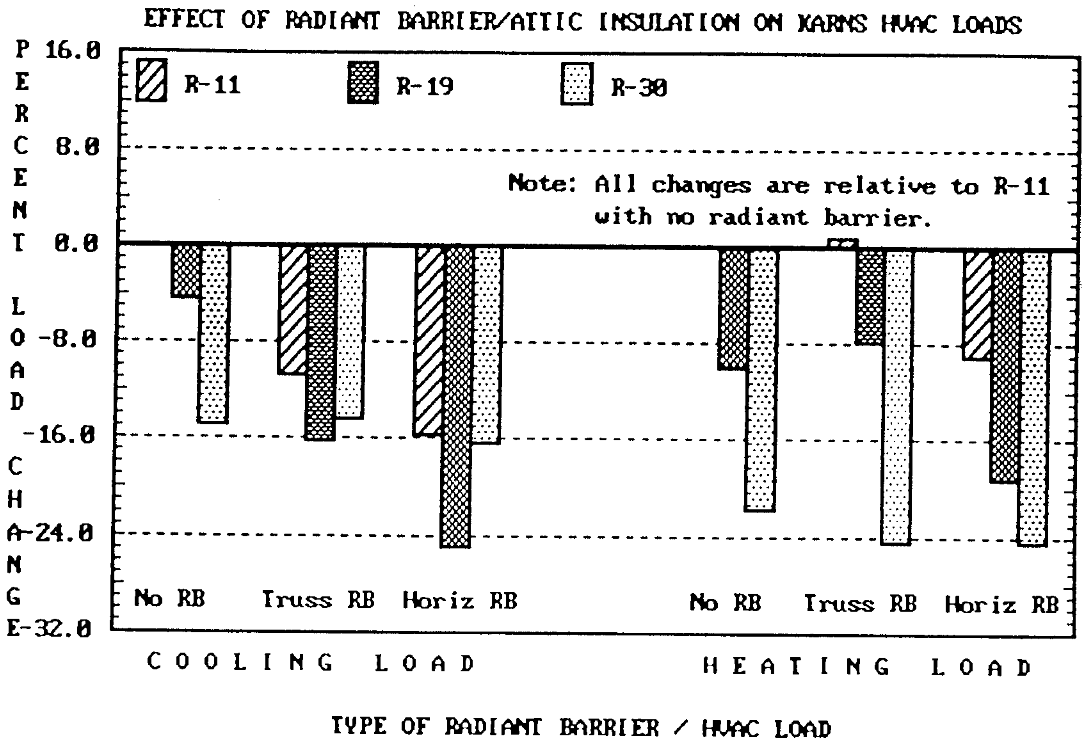

Fig. 5. Effect of radiant barrier/attic insulation on Karns HVAC loads. [Loads calculated using the DOE 2.1 program with measured radiant barrier data.]