RADIANT BARRIER INSULATION PERFORMANCE IN FULL SCALE ATTICS WITH SOFFIT AND RIDGE VENTING

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ABSTRACT

There is a limited data base on the full scale performance of radiant barrier insulation in attics. The performance of RBS have been shown to be dependent on attic ventilation characteristics. Tests have been conducted on a duplex located in Florida with soffit and ridge venting to measure attic performance.

The unique features of these experiments are accurate and extensive instrumentation with heat flow meters, field verification of HFM calibration, extensive characterization of the installed ceiling insulation, ventilation rate measurements and extensive temperature instrumentation. The attics are designed to facilitate experimental changes without damaging the installed insulation.

RBS performance has been measured for two natural ventilation levels for soffit and ridge venting. Previously, no full scale data have been developed for these test configurations. Test data for each of the test configurations was acquired for a minimum of two weeks with some acquired over a five week period. The R19 insulation performed as expected.

INTRODUCTION

The performance of reflective surfaces in attics was first investigated by Joy (1958) using a 12' X 13' laboratory test attic. Joy showed that attic ventilation is important in determining attic performance since it provides a cooling mechanism for the attic. The variables that affected the ceiling heat flux are ventilation rate, inlet air temperature, surface emittance and the ventilation method. McQuiston (1982) used field test results to verify an attic model which was then used to predict attic performance. Fairey (1982) performed tests in two unvented attic test cells under real time test conditions with foil installed against the roof deck. Fairey (1985), using a 52 square foot test cell with forced ventilation at 0 and 5 air changes per hour (ACH), found that foil installed under the roof deck performed as well as foil installed on top of the insulation. The 1985 unvented tests showed a 19% heat flow reduction for R19 plus foil versus R19 which was significantly lower than the 1982 unvented tests which showed a 42% reduction. The vented tests at 5ACH showed a 43% reduction, again showing the effect of attic ventilation.

The Tennessee Valley Authority (1985) used a Latin Square design in five 50 square foot naturally ventilated, outdoor test cells to investigate the effect of foil placement. Three foil locations were investigated (Figure 1): attached to the underside of the roof deck, attached to the bottoms of the rafters, and on top of the insulation. Heat flow reductions of 16%, 23% and 40% respectively for the three locations were measured showing that foil placement was another variable to be considered. Oak Ridge National Laboratory (1985, 1986) compared foil location and insulation level for three side by side houses in Karns, Tennessee. Their results showed that foil installed on top of the insulation performed better than foil installed under the roof deck. Insulation level also affected foil performance installed in an attic. Figure 1 shows the methods used to install the foil for the tests reviewed. In a brief review all of the characteristics, results and differences of the tests cannot be discussed.

Other than the ORNL Karns house tests, there have been no full scale test house studies of the performance of reflective insulation in attics. Another shortcoming in the previous tests was the lack of data on the actual natural ventilation rates that occur in attics. Joy showed that not only was the ventilation rate important but that the type of ventilation would also be important. The type of ventilation is important since it affects the rate that will be achieved in practice and since it affects the flow path in the attic. The two studies that had natural ventilation rates, (ORNL and TVA) used soffit and gable venting and did not measure the ventilation rate. The other experimenters used forced ventilation and approximated either gable/gable or soffit/ridge venting. Since the roof deck temperature will be the primary driving force for attic ventilation, under natural conditions the attic ventilation rate will not be constant but will vary on a diurnal cycle.

Another shortcoming of the field work has been the poor to nonexistent characterization of the ceiling insulation. All fibrous insulations are rated under the Federal Trade Commission Rule at a given R value at a stated thickness and are designed to recover to greater than the stated thickness. At thicknesses greater than the stated thickness, the R value is greater than the design. However, if the insulation is compressed to less than the design thickness, for instance, by placing boards over joist members to install foil in the attic, then the R values will be less than the nominal. Since all of the reported field results used side by side tests, it is important that the

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insulation level in the various attics be identical, or at the very least characterized, so that differences between attics can be attributed to the variable being tested rather than undetected differences in the attic insulation levels.

This problem is compounded when small heat flow meters are used to measure the ceiling heat flow. Fairey, TVA and ORNL all have used 2 1/4" X 2 1/4" heat flow meters. These measure such small areas of the insulation that differences can occur due to normal density/thickness variations in the product. Since the heat flow through insulating materials is dependent on the density, it is very difficult to characterize the thermal properties of a fiberglass batt over such a small area. Standard ASTM test equipment uses much larger sizes for the metering area to obtain adequate material characterization just for this reason.

The goal of our program was to characterize the performance of an attic with foil installed in the draped configuration under natural ventilation rates. The tests were designed to provide both side by side comparisons and data for model development. Two ventilation configurations were tested. The draped configuration was selected since it has not been previously tested and is one of two allowed installation methods in the Florida Energy Code. The Florida Energy Code requires full soffit and ridge venting with foil emissivity of less than 0.06. There have been no full scale test house results published for radiant barrier insulation performance in Florida.

TEST FACILITY

The test facility is a south facing duplex located in central Florida. The identical east and west units are mirror images of the other. Each unit is nominally 850 square feet (Table 1) with windows located on the north and south sides of the units. There is no glazing on the east or west walls. The ridge line runs east and west. Each unit has its own heat pump for cooling and heating.

The roof has gray shingles. Continuous soffit and ridge venting is provided for each unit. The ceiling is insulated with R-19 fiberglass insulation. Concrete block walls are insulated with 3/4" isocyanurate foam between furring strips on 24" centers. The floor of the house is concrete slab covered with carpet except in the kitchen and bathrooms.

A standard 6:12, 2X4, raised truss system on 24" centers is used. Additional cross members were added to the trusses above the insulation to provide unobstructed access to the attics. This prevented damage to the insulation when working in the attics. The two attics are separated by a R-30 wall. All joints in the wall were taped and caulked to prevent air flow between the attics of each unit. The gables have 3/4" foam sheathing covered with aluminum siding.

INSTRUMENTATION

The duplex is instrumented with approximately 150 sensors to measure temperatures, heat flows, air velocities, weather data and ventilation rates. The majority of the instrumentation is concentrated around the attics of both units with limited instrumentation located in the living units. Air velocities were measured with hotwire anemometers. Measured weather data included air temperature, horizontal solar radiation, wind speed and direction.

Each unit has five test sections (Figure 2) where the heat flow through the ceiling is measured. One test section is located in the center of the attic while the other four represent nominally equal areas of the attic. The locations were chosen to avoid anomalies due to ducts, registers, breaks in the sheet rock, framing or wiring. The locations were selected to determine the uniformity of heat flow through the ceiling both between the north/south and the east/west portions of the attic.

Each test section measures temperatures at the top of the ceiling (between the gypsum board and the insulation), on top of the insulation, the air temperature midway between the insulation and the roof deck and the inside of the roof deck (Figure 3). The center test section has additional air temperatures to determine the stratification of the attic air. Temperatures of the exterior roof, the divider between the two attics and the gables were measured. Temperature sensors are located along the north and south roof decks to measure the temperature gradients due to air flowing under the roof decks.

Five computer systems take the data at 15-40 second intervals, average the data over hourly periods and store the data on daily files. The files are then transferred to a central computer.

HEAT FLOW MEASUREMENTS

The heat flow at each test section is measured by 1' X 1' heat flow transducers (HFT)installed between the trusses. The HFT's were individually calibrated in equipment traceable to the National Bureau of Standards. The thermal properties of center 1' X 1' test sections of the batts above the test sections were also measured in the laboratory prior to installation in the duplex. This allows for an important check on the accuracy of the heat flow measurements and on the performance of the batts. Using the temperatures measured on both sides of the batts and the heat flow, the R values of the batts can be determined in the field. Table 2 shows that the R value measured in the field and that measured in the laboratory are within a few percent of each other under summertime conditions.

Considerable care was taken to insure that the thickness of the batts over the test sections was known and remained constant during the test. A light screen was used to maintain the batt thickness constant. Since the batts over-recovered, an average installed thickness of 7.0" was obtained instead of the nominal 6.5". This resulted in an assigned value of R-20.3 for the west unit and R-20.1 for the east unit rather than the nominal R-19 for the insulation between the trusses.

For the non-test section insulation, rulers were installed throughout the attic to measure the installed thickness. The initial installed thickness of 6.95" has increased by 0.2" over the test period. The constant thickness has been maintained because of the walkway system which allows work in the attic without damaging the insulation.

ATTIC VENTILATION RATE MEASUREMENTS

Attic ventilation rates were measured using a tracer gas decay method. A separate computer system controlled the tracer gas measurement and the injection of Sulfur Hexafluoride (SF6) into the attic. Sufficient SF6 was injected to use the full dynamic range of the tracer gas unit. The gas was injected at four locations within the attic while sampling was done at the center of the attic. Mixing fans were operated for a few seconds at 10 minute intervals to aid in uniform mixing.

Two levels of venting were investigated. To maintain adequate air flow from the soffits into the attic in attics with a low sloped roof, a baffle needs to be installed under the roof deck. This keeps the insulation from filling the space between the wall top plate and the underside of the roof deck which would block the air flow. To simulate this in the duplex attic, baffles were installed, and the space between the top of the wall and the bottom of the roof deck was filled with insulation. This is referred to as ventilation configuration #1.

Since the duplex has a raised truss, baffles are not required to keep this air passage open. After obtaining test data on the first configuration, the insulation between the top of the wall and the roof deck was removed to eliminate this flow restriction. This is referred to as ventilation configuration #2. Based on the tracer gas measurements, the attic ventilation rates were the same for both tests.

RADIANT BARRIER SYSTEM TESTS

The double sided radiant barrier with a measured emittance of 0.03 was installed in the draped configuration (Figure 4). A 6" gap was left at the peak and the soffit ends to allow air to circulate from the main attic air with the air flow along the roof deck. This has been the recommended practice by FSEC and was followed by TVA and ORNL. Foil was not installed on either the gable or the dividing wall between the attics. None of the literature has recommended covering vertical surfaces such as gables with foil.

Null tests were run at the beginning and end of the test periods. Table 3 shows the results of the tests. The average heat flows are integrated values for the entire week calculated by Equation 1.

$$Qave = \frac{\int Q(t)\,dt}{\int dt} \qquad \text{Eq (1)}$$

The null tests show that the attics are identical to within a few percent.

Starting with week 159, foil was installed in the west unit. The first test period had the venting in Configuration #1 and the set point at $70^{o}F$. For two weeks the average percentage heat flow reduction was approximately 20%. The average heat flow reduction is calculated by Equation 2.

$$\text{Percent Reduction} = \frac{\bar{Q}_{west} - \bar{Q}_{east}}{\bar{Q}_{east}} \times 100 \qquad \text{Eq (2)}$$

The set point temperature was then raised to $78^{o}F$ which increased the ceiling heat flow reduction to 22% for two weeks. For the next 5 weeks the set point was returned to $70^{o}F$ and the venting was changed to Configuration #2. The average heat flow reduction for the 5 week period was 20%. Finally a two week null test was conducted which showed that the average heat flow through the two ceilings is within +/- 1%.

DISCUSSION OF THE RESULTS

Comparing the two venting configurations shows that there is no difference in the percentage heat flow reduction caused by using baffles to maintain air flow with the space between the wall and the underside of the roof deck being filled with insulation. Tracer gas results confirmed that for these tests that both venting configurations had the same ventilation rate. It appears that the air flow resistance provided by the soffit and ridge vents is the dominant resistance and that the resistance offered by the baffles is small in comparison. Had the baffles not been present and the entire air space between the top of the wall and the roof deck been filled with insulation, the air flow would have been significantly reduced and the results would probably have been different. The important factor is the contribution that the baffle (or any other air flow resistance) has on the total air flow resistance of the attic. These factors have not been considered in previous work.

Table 4 shows the average daily peak heat flow reductions for 6 weeks. These are calculated using Equation 3.

$$\text{Peak Reduction} = \left[\frac{Q_{west} - Q_{east}}{Q_{east}}\right]_{peak} * 100 \qquad \text{Eq (3)}$$

The peak heat flow was reduced by 30%.

CONCLUSIONS

Full scale house tests for an attic with foil installed in the draped configuration with soffit and ridge venting show a 20% ceiling heat flow reduction over a period of 9 weeks. The test house meets the Florida Energy Code radiant barrier requirements and is located in central Florida. These tests show a much smaller average percentage heat flow reduction than has been previously reported although this particular installation method has never been tested. An increase in the house set point from $70^{o}F$ to $78^{o}F$ decreased the ceiling heat flux and slightly increased the percentage heat flow reduction. The field measured

R values for the nominal R-19 insulation were in excellent agreement with the laboratory measurements.

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Table 1. Test House Description
(One unit of duplex)

Outside Dimensions	31ft X 27ft
House Area	844 ft^2
Window Area	72 ft^2
Attic Vent Areas	
Ridge	2.4 ft^2
Soffit	5.6 ft^2
Ceiling Insulation Installed R-value	
West Unit	20.3
East Unit	20.1
Ceiling Insulation Installed thickness	
West Unit	6.9"
East Unit	7.0"

Table 2. Comparison of Laboratory and Field Measured Insulation R-values

Test Section	Laboratory Measured	Percent Difference Between Field and Laboratory R-values
1	20.40	2.4
2	19.65	3.0
3	19.43	1.2
4	20.83	1.0
5	21.26	1.6
6	19.91	0.4
7	19.88	1.5
8	21.21	4.9
9	19.41	-0.6
10	20.84	-1.4

R-value in (hr ft2 oF)/Btu

Table 3. Comparison of Ceiling Heat Flows

Julian Week	Test Parameters Foil Installed	House Temp	Average Heat Flux West	East	Percent Diff
159	Yes	70	0.744	0.956	22.2
166	Yes	70	0.831	1.022	18.8
187	Yes	78	0.628	0.813	22.7
194	Yes	78	0.466	0.595	21.7
208	Yes	70	0.725	0.871	16.7
215	Yes	70	0.889	1.111	20.5
222	Yes	70	0.581	0.720	19.3
229	Yes	70	0.833	1.035	19.5
236	Yes	70	0.886	1.118	20.7
244	No	70	0.600	0.604	-0.5
250	No	70	0.790	0.801	1.3

Heat flux in Btu/(hr ft2 hr)
Percent Diff = ((Qwest/Qeast)-1)*100

Table 4. Daily Average Peak Ceiling Heat Fluxes for East and West Units With Foil Installed

Julian Week	West Unit Average Peak	East Unit Average Peak	Percent Difference (W/E-1)*100
159	1.74	2.41	-27.7
166	1.63	2.35	-30.8
215	1.78	2.55	-30.0
222	1.31	1.92	-31.6
229	1.87	2.70	-30.5
236	1.94	2.80	-30.5

Heat flux in Btu/(hr ft^2 hr)

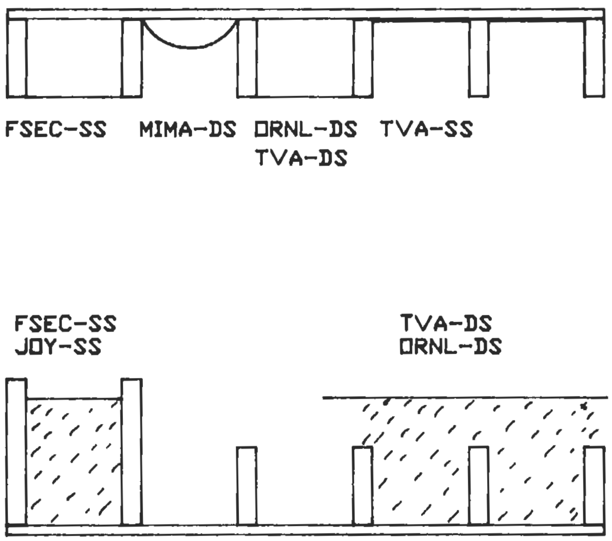

Figure 1. RBS Installation Methods
DS = Double Sided Foil
SS = Single Sided Foil

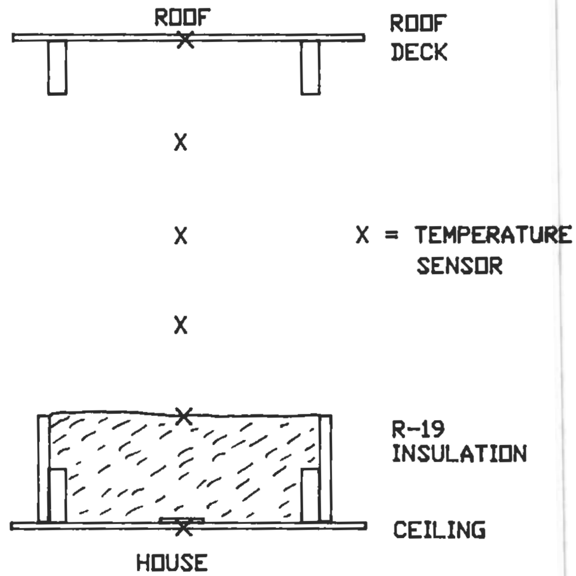

Figure 3. Typical Test Section

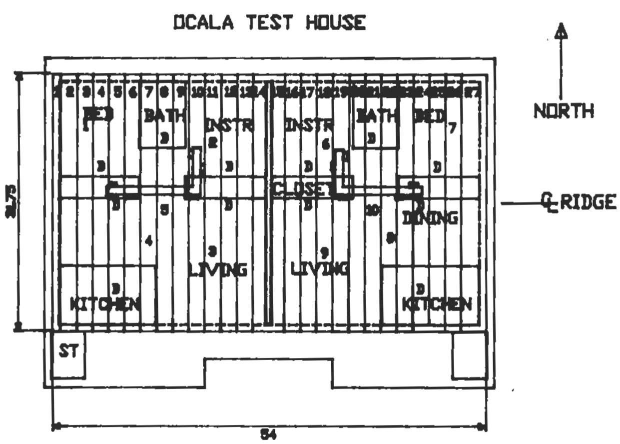

Figure 2. Plan View of Ocala Test Duplex

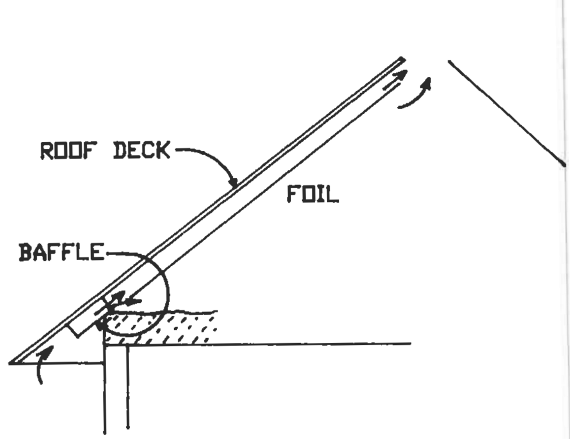

Figure 4. Radiant Barrier Installation Details