Full-Scale Radiant Barrier Tests in Ocala, Florida: Summer 1988

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ABSTRACT

Full-scale tests were conducted in a duplex located in Ocala, FL during the summer of 1988. The duplex was well instrumented with temperature, heat flow, wind speed, wind direction, solar, and humidity sensors. Attic ventilation rates were measured with a tracer gas system.

Previous tests were performed on foil installed in the draped configuration during 1987. The results from the summer of 1987 indicated that additional testing was needed. For the summer of 1988, two foil installation methods (draped and covering the bottom of the top chords of the trusses) were tested with and without foil installed on the gables. The performance of R-30 vs. R-19 with no foil and with foil installed in the draped configuration was also investigated. Data for foil installed horizontally on top of the insulation are reported.

Null tests performed during 1987 and 1988 showed that the two units are identical. The 1988 results extend the results from 1987 and support conclusions reached previously.

INTRODUCTION

Radiant barrier (RB) performance has been investigated by Joy (1958), McQuiston (1984), Fairey (1982, 1985), Hall (1986, 1988), and Levins (1986, 1987) and others. These investigations were performed with different test equipment in several climates and with different methods of foil installation (Figure 1). In terms of percentage ceiling heat flow reductions, Hall and Levins concluded that foil performed better installed on top of the R-19 insulation (35% to 40% reductions), rather than under the roof deck (16% to 30% reductions) while Fairey found that foil performance is independent of location (42% reduction). Levins' whole-house data also show that foil performs better on top of the insulation.

Since 1986, the Florida Energy Code has incorporated a radiant barrier credit that allows foil to be installed under the roof deck either draped or covering the bottom of the rafters. No data existed for the draped configuration. Ober (1988) obtained a 20% ceiling heat flow reduction with R-19 insulation for the draped configuration over a nine-week period in 1987. Based on these results and the discrepancy concerning foil location, additional tests were conducted in 1988. This paper presents those test results.

TEST FACILITY

The test facility is an unoccupied, single-story, south-facing duplex located in central Florida. The identical east and west units are mirror images of the other. Each unit is nominally 850 ft^2 (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-in. isocyanurate foam between furring strips on 24-in. centers. The floor of the house is a concrete slab covered with carpet except in the kitchen and bathrooms.

A standard 6:12, 2 by 4, raised truss system on 24-in. 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 an 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-in. foam sheathing covered with aluminum siding.

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After the 1987 tests it was discovered that the builder had blocked about 14% of the ridge vent with roofing paper. This was removed for the 1988 tests to provide full ventilation. The effect of the reduced vent area had a minor effect on the 1987 results.

INSTRUMENTATION

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

The heat flow at each test section is measured by 1 ft by 1 ft heat flow transducers (HFT) installed between the trusses. The HFTs were individually calibrated in ASTM C-518 equipment traceable to the National Institute of Standards and Technology.

The same R-19 batts were used for these tests as in the summer of 1987. For some tests, R-30 insulation was used. This was achieved by adding R-11 over the existing R-19 in the east attic. The thermal conductivity of the 1 ft by 1 ft section of each batt above the heat flow meter was measured in the laboratory using ASTM C-518 at the nominal thickness. This value was then adjusted to obtain the R-value at the installed thickness and density. Considerable care was taken to ensure that the thickness of the batts over the test sections was known and remained constant during the test. A lightweight screen was used to maintain a constant batt thickness.

For the non-test section insulation, rulers were installed throughout the attic to measure the installed thickness. The initial installed thickness of 6.95 in. has increased by 0.1 in. over a period of seven months. The constant thickness has been maintained because of the walkway system, which allows work in the attic without damaging the insulation.

Five computer systems took the data at 15- to 40-second intervals, averaged the data over hourly periods, and stored the data on daily files. The files were then transferred to a central computer.

The following conventions have been used in our work for heat flow directions. Positive heat flows mean heat is flowing from the attic, through the ceiling, and into the house. These heat flows contribute to air-conditioner loads. Negative heat flows are from the house into the attic.

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 (SF_6) into the attic. Sufficient SF_6 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. The temperature measurements indicated that the attic air was thermally stratified.

TABLES SUMMARIZING THE 1988 SUMMER RESULTS

Table 3 summarizes the weather data for the summer 1988 test period. The results for all of the tests for the summer of 1988 are shown in Table 4. The first column, labeled Base, is the base insulation case to which the alternative (Alt) insulation strategy is being compared. This table calculates the average heat flow reduction for each test and shows the number of days used in the calculations. For the first test, R-19 plus foil draped (the alternative case) vs. R-19 (the base case), 20 days of data were available for the calculations and an average heat flow reduction of 25.7% was measured. This test will be discussed later.

The weather during May and June resulted in negative heat flows during the night. The percentage heat flow reductions presented in Table 4 are averages over the 24-hour periods and thus include the effects of the negative heat flows on the data analysis. Data with negative heat flows are marked by an asterisk in the tables and tend to inflate the percentage ceiling heat flow reductions.

Table 5 presents similiar data as Table 4 for peak ceiling heat flow reductions. The peak heat flow reduction is based on the difference between the average highest peak heat flows for each attic during the test period. This table also includes the starting date for each test. The data in Tables 3, 4, and 5 are shown in chronological order.

NULL TESTS - SUMMER 1988

A null test comparing the two attics with R-19 insulation and no radiant barriers was run in July for two weeks. The heat flow between the two attics was within 1%. Previous null tests at the beginning and end of the 1987 tests showed similiar agreement. These results indicate that direct comparisons can be made between the two attics without any corrections.

PERFORMANCE OF INSULATION

For the R-19 batts the average installed thickness was 7.0 in. instead of the nominal 6.5 in. due to over-recovery of the insulation. This resulted in an assigned R-value for the insulation between the trusses of R-20.3 for the west unit and R-20.1 for the east unit rather than the nominal R-19. 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.

Laboratory- and field-measured R-values for R-19 insulation were found to agree within 5% for the 1987 summer data. This holds true for the 1988 data as well. The results are not repeated here since they are essentially the same as the 1987 results.

In 1988, R-30 insulation was installed for six weeks in the east attic. Table 2 compares the field-measured data with the assigned R-values based on laboratory data. The average difference between assigned and field-measured R-values was 2.4%, while the largest difference is 7.3%. Thus, excellent agreement is obtained with the R-30, showing that the insulation performs as expected and that the heat flow measurements are accurate.

R-30 vs. R-19 (Test 88-7)

Most of the comparisons of the performance of radiant barrier insulation have compared R-19 plus foil vs. R-19. In these comparisons, alternative energy-conserving strategies are not discussed. One exception is the limited test results from Fairey (1985), which showed that R-19 plus foil performs better than R-30 in a small-scale test cell.

For the R-30 vs. R-19 test, R-30 insulation reduced the ceiling heat flux by 33% over R-19. This is very close to that obtained by calculating the ceiling/attic R values for R-19 and R-30 (in this case R-20.4 and R-30.1).

R-30 reduced peak ceiling heat flows by 38% over R19.

PERFORMANCE OF RADIANT BARRIERS - SUMMER 1988

This series of tests was designed to:

1) repeat the 1987 test for foil draped
2) study the effect of foil installed on the gables
3) test foil installed covering the bottom of the top chords of the trusses
4) test foil installed on top of the insulation
5) compare the performance of R-30 insulation to R-19
6) compare the performance of R-30 insulation to R-19 with foil draped.

R19 Plus Foil Draped vs. R-19 (Test 88-1)

This test repeats the configuration tested for most of the summer of 1987. Two changes were made from 1987 which ensured that full venting was achieved. The ridge vent change was discussed earlier.

The test facility in Ocala has continuous soffit venting, which includes soffit vents along the 1 ft overhang at the gable ends. For the 1987 tests, the foil installation blocked most of the gable vents (the soffit vents were fully open). For the 1988 tests, the foil was installed to obtain full venting from the gable vents.

A 26% ceiling heat flow reduction was obtained. This compares with a 20% heat flow reduction obtained in 1987. The greater heat flow reduction may be due either to better performance of the attic due to increased ventilation or to the presence of negative heat flows during the 1988 tests. In reviewing the data, it appears that negative heat flows are the more likely reason.

Peak ceiling heat flows were reduced by 32%. In 1987, peak heat flows were reduced by 30% to 32%. Using peak heat flows, there appears to be very little difference between the 1987 and 1988 tests for the draped configuration. Note that the analysis of the peak heat flows is not affected by the negative heat flows that were present at night, which do affect the 24-hour averages.

<u>R-19 Plus Foil Covering the Rafters vs. R-19</u> (Test 88-4)

Foil was installed covering the bottom of the top chords of the trusses for this test. This allows for a lower effective emissivity than foil installed in the draped configuration and should result in better performance. A 25% average ceiling heat flow reduction was measured with reductions of 34% for the peak heat flows. The comparison of the peak heat flow reductions shows that this configuration is slightly more effective than the draped configuration. Again, negative heat flows mask the small differences in the average reductions. Modeling will be necessary to separate the effects.

<u>R-19 Plus Foil Draped with Foil on the Gables vs. R-19</u> (Test 88-2)

For this test, foil was installed in the draped configuration with foil added to the west gable and the center divider (which acts as the east gable). This resulted in a 24% ceiling heat flow reduction. Peak heat flow was reduced by 33%.

<u>R-19 Plus Foil Covering the Rafters, Foil on the Gables vs. R-19</u> (Test 88-3)

Foil was installed covering the bottom of the top chords of the trusses for this test. Foil was also installed on the gables. A 22% ceiling heat flow reduction was measured. Due to equipment problems, only two days were available for analysis. Peak heat flow was reduced by 33%.

<u>R-30 vs. R-19 Plus Foil Draped</u> (Test 88-8)

R-30 was installed in the east attic, as previously described. In the west attic, foil was installed in the draped configuration. Foil was not installed on the gables. The R-30 resulted in 15% less heat flow through the ceiling than R-19 plus foil. Peak heat flow was reduced by 9%.

<u>R-19 Plus Foil Installed on Top of the Insulation vs. R-19</u> (Test 88-6)

Foil was installed on top of the insulation. A 35% ceiling heat flow reduction was measured with a 39% peak ceiling heat flow reduction. This is in good agreement for one week of data starting September 14, 1987. The ceiling heat flows for this period were reduced by 36%. These data are for newly installed, clean foil.

<u>Summary of Results</u>

It is instructive to compare the performance of various insulation alternatives for upgrading R-19 insulation in an attic. One alternative is to add R-11 insulation to the R-19, which results in a total of R-30 insulation. The performance of R-30 compared to R-19 insulation with no foil installed in either attic results in a 33% reduction in ceiling heat flow.

An alternative strategy is to install foil under the roof deck. Two methods have been tested; foil draped and foil covering the bottom of the rafters. Both result in 20% to 25% ceiling heat flow reductions. Adding foil to the gables does not substantially improve the performance over gables without foil. Thus foil installed under the roof deck (with R-19 attic insulation) does not perform as well as R-30 insulation with no foil. This is confirmed by directly comparing R-19 + foil draped with R-30. R-30 reduced the ceiling heat flow by 15% over the R-19 plus foil draped.

Another alternative is to install foil on top of the insulation (horizontal application). Initially this results in a 35% ceiling heat flow reduction. However, this application is susceptible to dust accumulation, which will increase the emittance of the foil. Work by Cook (1989) estimates that after four years of dust accumulation, the average emittance will increase to 0.23, which will reduce the horizontal performance to 16%. Additional dust accumulation will reduce the performance further.

CONCLUSION

These tests with foil installed under the roof deck in two configurations show a 20% to 25% reduction in summer ceiling heat flow for R-19 plus foil vs. R-19. Adding foil to the gables did not substantially improve the performance of the foil under the roof deck. Clean foil installed on top of the insulation resulted in a 35% ceiling heat flow reduction. While these tests show that foil installed horizontally performs better initially, after four years, dust accumulation will significantly reduce the performance of horizontal foil.

Table 6 compares the data from this paper with data from Levins (1986), Hall (1986, 1988), Fairey (1985), and Ober (1988) for R-19 insulation plus a radiant barrier vs. R-19. For foil installed under the roof deck the TVA/ORNL/MIMA data show a 16% to 30% ceiling heat flow reduction. For clean foil installed on top of the insulation, the TVA/ORNL/MIMA data resulted in a 35% to 40% reduction. Based on these tests, foil installed on top of the insulation performs better than foil installed under the roof deck. The FSEC data indicate that foil performs equally well installed in either location, resulting in a 42% reduction in ceiling heat flow.

Comparing test results for R-30 insulation vs. R-19, we measured a 33% ceiling heat flow reduction, while Hall (1987) measured a 27% reduction. Simple calculations ratioing ceiling R-values would result in a 35% reduction.

ACKNOWLEDGMENTS

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Table 1

Test House Description
(One unit of duplex)

Outside Dimensions	31ft by 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 $hr{\cdot}ft^2{\cdot}°F/Btu$
East Unit	20.1 $hr{\cdot}ft^2{\cdot}°F/Btu$
Ceiling Insulation Installed thickness	
West Unit	6.9"
East Unit	7.0"

Table 2

Comparison of R-Values Measured in the Field and Assigned R-Values For R-30 Insulation

Test Section	R-Values (hr·ft²·°F/Btu) Assigned	Measured by Weeks (1988) 8/8	8/15	8/22	8/29	9/5	9/12
6	31.0	31.1	31.4	30.7	31.5	31.3	31.6
7	30.2	31.8	32.4	31.7	32.4	32.0	32.3
8	32.1	33.6	34.3	33.5	34.2	34.0	33.9
9	30.4	29.0	29.7	28.9	29.7	29.3	29.5
10	32.0	32.9	33.2	32.5	33.3	33.1	33.2

Table 3

1988 WEEKLY WEATHER DATA, OCALA, FLORIDA

	TEMPERATURE°F			SOLAR		WIND SPEED			WIND DIRECTION
WEEK	AVG.	AVG. MAX	AVG. MIN	AVG.	AVG MAX	AVG.	AVG MAX	ABS. MAX	AVG.
495	72.6	83.7	62.6	62	233	0.7	2.0	3.7	179
502	77.0	91.9	64.9	76	263	0.7	2.3	2.9	201
509	74.4	87.0	63.1	69	245	0.8	2.9	4.0	161
516	77.0	90.6	64.9	74	255	1.2	3.4	5.0	135
523	77.1	86.1	71.1	62	234	1.1	3.1	4.0	173
530	77.4	88.6	66.6	75	244	0.8	2.4	3.6	116
537	79.0	90.2	72.4	57	239	0.5	2.7	5.5	144
544	80.7	88.4	74.1	61	232	0.7	2.2	3.1	182
551	79.0	90.0	0.9	74	262	1.0	2.9	4.2	115
558	80.9	92.4	74.0	72	264	0.5	2.2	2.8	
565	77.4	87.9	71.7	51	237	0.5	2.0	4.2	.
572	81.1	92.7	72.7	73	284	.	.	.	.
579	81.0	94.9	73.3	76	286	.	.	.	.
586	78.6	88.9	63.1	60	234	.	.	.	.
593	80.3	91.6	63.4	72	277	.	.	.	152
600	80.0	88.9	74.3	46	178	0.6	2.2	5.5	182
607	80.4	90.7	74.4	66	254	1.1	3.6	5.5	131
614	77.9	83.7	74.3	36	144	1.3	3.0	5.2	137
621	81.6	90.9	75.7	61	241	1.3	3.7	4.9	120
628	79.4	91.0	70.9	68	247	0.6	1.4	2.4	160

Week 495 starts on May 9, 1988.

Table 4

COMPARISON OF HEAT FLOWS BETWEEN BASE AND ALTERNATIVE UNITS

Test	Base	Alt.	No. of days	Base ΔT	Alt. ΔT	Base Average (Btu/ft^{2}hr)	Alt. Average (Btu/ft^{2}hr)	% Difference (1 - ALT/BASE)100
88-1	R19(E)	R19+FD	20	14.8	11.6	0.744	0.553	25.7*
88-2	R19(E)	R19+FDG	15	15.0	12.0	0.738	0.559	24.3*
88-3	R19(E)	R19+FCRG	2	17.7	14.3	0.883	0.695	21.3*
88-4	R19(E)	R19+FCR	9	16.7	13.0	0.828	0.624	24.6*
88-5	R19(E)	R19	10	18.5	18.5	0.912	0.911	0.1
88-6	R19(E)	R19+FTI	12	19.8	14.0	0.994	0.648	34.8
88-7	R19(W)	R30	13	19.2	20.3	0.949	0.637	32.9
88-8	R19+FD (W)	R30	21	13.2	17.3	0.637	0.540	15.2

Table 5

AVERAGE PEAK HEAT FLUXES FOR BASE AND ALTERNATIVE UNITS

Base	Alt.	Start of Test	No. of. Days	Base Peak Average (Btu/ft^{2}hr)	Alt. Peak Average (Btu/ft^{2}hr)	% Difference Average (1 - ALT/BASE)100
R19(E)	R19+FD	5/9	20	2.289	1.551	32.2
R19(E)	R19+FDG	6/4	15	1.991	1.340	32.7
R19(E)	R19+FCRG	6/27	2	2.025	1.365	32.6
R19(E)	R19+FCR	6/30	9	2.032	1.332	34.4
R19(E)	R19	7/10	10	2.438	2.480	-1.7
R19(E)	R19+FTI	7/25	12	2.568	1.573	38.8
R19(W)	R30	8/10	13	2.411	1.486	38.4
R19+FD(W)	R30	8/29	21	1.335	1.219	8.7

Notes for Tables 4 and 5:

(E) = EAST UNIT
(W) = WEST UNIT
ΔT = AVERAGE TEMPERATURE DIFFERENCE ACROSS INSULATION FOR TEST PERIOD
* = NEGATIVE Q IS PRESENT

FD = Foil Draped
FDG = Foil Draped, Foil on Gables
FCRG = Foil Covering Rafters, Foil on Gables
FCR = Foil Covering Rafters
FTI = Foil on Top of Insulation

Table 6

Comparison of Average Ceiling Heat Flow Reductions for R19 Plus a Radiant Barrier versus R19

RB Location	TVA 1985	TVA 1987	ORNL 1985	MIMA 1987	FSEC 1985 0ACH	FSEC 1985 5ACH
Deck	16%	-	-	-	-	42%
Draped	-	-	-	20%	-	-
Bet Rafters	-	-	-	-	19%	42%
Over Rafters	24%	30%	30%	24%	-	-
Top of Insul	40%	-	35%	35%	-	42%

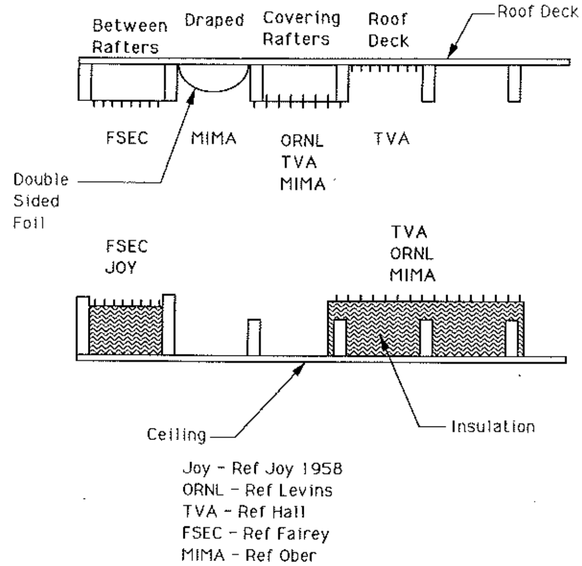

Figure 1. Radiant barrier installation methods

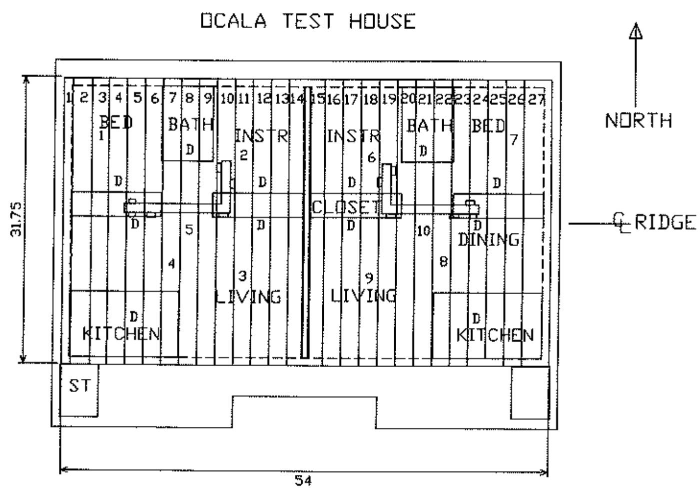

Figure 2. Ocala test house layout

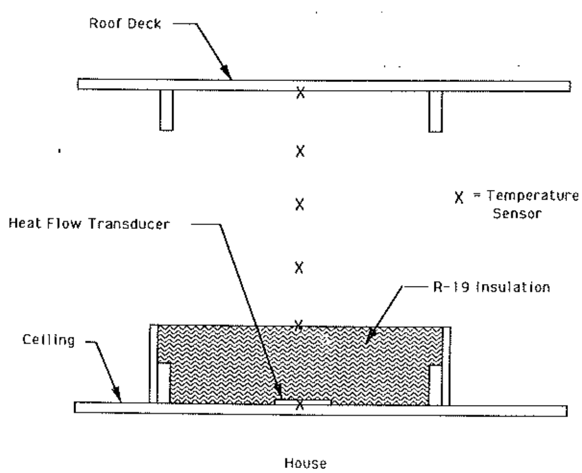

Figure 3. Typical test section