COOLING ENERGY MEASUREMENTS OF HOUSES WITH ATTICS CONTAINING RADIANT BARRIERS[1]

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ABSTRACT

Tests were conducted by Oak Ridge National Laboratory (ORNL) to determine the magnitude of the energy savings brought about by installing radiant barriers in the attics of single-family houses. The radiant barrier used for this test was a product with two reflective aluminum surfaces on a kraft paper base. The radiant barrier has the potential to reduce the radiant heat transfer component impinging on the fiberglass attic insulation. Working as a system in conjunction with an air space, the radiant barrier could theoretically block up to 95% of far-infrared radiation heat transfer.

The experiment was conducted in three unoccupied research houses that are operated by ORNL. One house was used as the control house (no barrier was installed), while the other two were used to test the two different methods for installing the radiant barriers. In one house, the barrier was laid on top of the attic fiberglass batt insulation, and in the other house, the barrier was attached to the underside of the roof trusses. The attics of all three houses were insulated with kraft paper faced nominal R-19 fiberglass batt insulation.

The results showed a savings in the cooling loads of 21% when the radiant barrier was laid on top of the attic fiberglass insulation and 13% with the radiant barrier attached to the underside of the roof trusses. The savings in electrical consumption was 17% and 9%, respectively. The electrical consumption data and the cooling load data indicated that the most effective way of installing the foil was to lay it on top of the fiberglass batt insulation. The radiant barriers reduced the measured peak ceiling heat fluxes by 39% for the case where the barrier was laid on top of the attic fiberglass insulation. The radiant barrier reduced the integrated heat flows from the attic to house by approximately 30-35% over a 7-day time period.

INTRODUCTION

The U.S. Department of Energy (DOE) and the Tennessee Valley Authority (TVA) jointly sponsored the first full-scale attic experiment to measure the energy performance of radiant barriers installed in attics of single-family houses. The experiment was conducted by Oak Ridge National Laboratory (ORNL) in three unoccupied houses located near Oak Ridge, Tennessee, during the summer of 1985. Since the purpose of the radiant barrier was to reduce the radiant heat transfer component impinging on the fiberglass insulation, it was expected that a reduction in the total heat transfer through the ceiling would occur.

The radiant barriers tested in this experiment had a kraft paper center with a thin aluminum coating on each side. They were used to minimize the radiation heat transfer into the attic insulation. Since roof temperatures could exceed 150°F during periods of peak insulation in the summer months, radiation heat transfer between the underside of the attic roof and the fiberglass insulation could be significant. Prior research indicated that radiant barriers appeared to have the potential to reduce radiation heat transfer and to reduce cooling energy use. The objective of this project was to determine experimentally the magnitude of the cooling energy

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savings attributed to the installation of the radiant barriers.

DESCRIPTION OF RADIANT BARRIER EXPERIMENT

The location chosen for this experiment was the Karns Houses Research Facility consisting of three unoccupied houses which are located in the Karns Community, between Oak Ridge and Knoxville, Tennessee. The three single-family test houses are classified as 1200-sq-ft ranch style. The conditioned space (roughly 40 x 30 feet) included a 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 floor plans for all three houses were identical. The heat pumps were positioned on the west side of the houses, and insulated ductwork was located in the crawl space.

Two variations on the installation of radiant barriers were studied. House #1 was used as a control house; the other two were used to test the two different methods for installing radiant barriers. In house #2, the barrier was laid horizontally on top of the nominal R-19 (6-1/4-inch) attic fiberglass batt insulation. In house #3, the barrier was attached to the underside of the roof trusses. The barrier was attached with staples in both cases. Both installation methods are illustrated in Fig. 1. One difference between the installations in the two houses was that the foil only extended over the living area and not the garage for house #2 (none of the garages had ceiling insulation). In house #3,

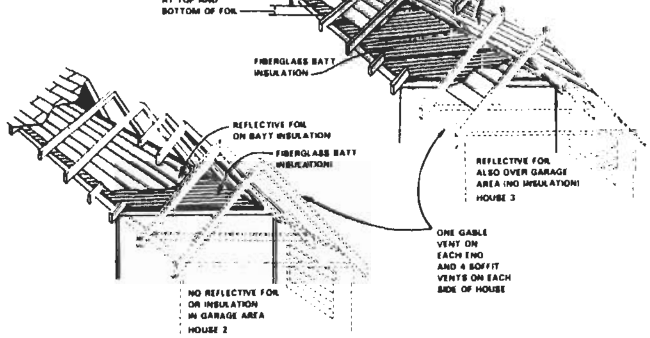

Fig. 1. Location of radiant barriers.

the barrier extended the entire length of the attic, including the garage. The installation of the barrier on top of the insulation was relatively easy, was inexpensive,[2] and also could allow possible do-it-yourself installation by homeowners. The installation on the underside of the roof trusses was slightly more complex. An approximate 6-inch air gap was left on both extremes of the barrier (i.e., between the top of the batt insulation and the barrier and between the peak of the roof and the barrier). This allowed the possibility for accumulated heat to be carried away by natural convection from the soffit vents to the gable vents.

The experimental design specified the houses to be operated for three weeks before the radiant barriers were installed. This was a calibration period to allow for comparison of the energy use and cooling loads between the houses. The calibration period served two purposes: (1) to evaluate cooling loads of the houses so any differences could be noted and factored out, and (2) to evaluate the performance of the air conditioners so any differences could be noted and factored out. House #1 was used as a control house. The radiant barriers were installed after the calibration period in houses #2 and #3.

DATA COLLECTION

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

Most temperature sensors were copper-constantan (type T) thermocouples, while pulse-generating watt-hour meters were used to measure electrical consumption.

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[2]Note: The material cost of the radiant barriers was 4¢/sq ft using 1200 sq ft per house. The installation labor averaged to $100.00 per house.

The sensors used to monitor the sensible cooling load are rather unique. The design was developed by the Instrumentation and Controls Division of ORNL, and several were used to monitor both the heating and sensible cooling loads for previous ORNL projects (1). The device is called a "Btu meter" and consists of three sensors and an electronic logic interface card. Two of the sensors are averaging platinum RTDs (resistance temperature detectors). One RTD is located on the inlet side of the evaporator (cooling) coil, and one is located on the outlet side of the evaporator. Each is coiled in a helix in the cross-sectional area of the duct so that the average air temperature entering and leaving the evaporator coil is measured. The outputs of the RTDs are inputs to the logic card. A small anemometer is also located in the ductwork 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 result by the anemometer input and sends a digital (pulse) output to the data logger which is a measure of the sensible cooling energy (Btus).

The latent load was measured by collecting the condensate from the evaporator coil and metering it through an accurately calibrated solenoid (positive displacement) pump in small (approximately 25 ml) batches. Each stroke of the solenoid pump (1 ml of condensate pumped) generated a pulse which was sent to the proper data logger input channel.

DATA ANALYSIS

The sums of the hourly values of the various data channels over an approximate 3-week period were used to compare energy usage and cooling load differences between the three houses. Since house #1 was the control house for both the before-barrier and the after-barrier tests, the ambient weather effects were factored out by making the results relative to the control house.

Since both the measured cooling loads of the three houses and the heat pump cooling mode efficiency of each house were not identical, it was necessary to normalize the results of the experimental measurements. The results were normalized by first deriving relative values for both the house cooling loads and HVAC electrical consumption before the barrier was added, with house #1 being the common denominator. The value obtained for each house was used as a calibration factor for that house, i.e., its load or electrical consumption relative to house #1, the control house. The equations used for calibration factors were the following:

For house #1:

$$CF_1 = \frac{H_1}{H_1}_{\text{No barrier}} = 1.0 \;;$$

For house #2:

$$CF_2 = \frac{H_2}{H_1}_{\text{No barrier}} \;;$$

For house #3:

$$CF_3 = \frac{H_3}{H_1}_{\text{No barrier}} \;.$$

where CF was the calibration factor for the respective house and the H's were either the house cooling loads or electrical consumption. The subscripts in the equations signified the house numbers.

The measured cooling loads and HVAC electrical consumption after the foil was added to houses #2 and #3 were made relative to house #1 again, and this result was divided by the calibration factor in order to obtain the normalized results. The equations used for normalization were the following:

For house #2:

$$NC_2 = \frac{1}{CF_2} \times \frac{H_2}{H_1}_{\text{With barrier}} \,,$$

For house #3:

$$NC_3 = \frac{1}{CF_3} \times \frac{H_3}{H_1}_{\text{With barrier}} \,,$$

where NC was the normalized consumption (either the house cooling loads or electricity consumption).

This normalizing procedure allowed comparison between slightly different entities. Since all three houses were undergoing the same ambient weather conditions at all times, weather effects were effectively factored out and the normalized results presented a true comparison between house #1 and house #2, house #1 and house #3, and accordingly between house #2 and house #3.

ELECTRICAL AND COOLING LOAD EXPERIMENTAL DATA

The houses were operated in the comparison mode from July 8 to July 31, 1985. This was a calibration period to allow for the comparison of energy use among the three houses. Calibration factors were calculated for both cooling loads and the HVAC electricity consumption. The electric energy consumption for the three houses was 522 kWh for house #1 (the control house), 582 kWh for house #2, and 529 kWh for house #3 (Table 1). The raw consumption data indicated that house #2 consumed approximately 11% more HVAC cooling electricity during the three-week period than the control house. House #3 consumed about 1-1/2% more than the control house. Possible reasons for the variation of electrical usages included differences in performance of the duct work (higher leakage rates), differences in the integrity of the envelopes, and differences in performance of HVAC systems. Since the data were normalized, differences in consumptions were not critical factors. The savings of a retrofit, such as radiant barriers, could be measured accurately by first comparing the data with respect to the control house and then normalizing the energy use in each house with respect to energy use before and after the retrofit. The calibration factors calculated using pre-retrofit data were divided into the calibration factors using post-retrofit data. Both the cooling load and the HVAC electricity were normalized in this manner.

The cooling loads data for the three-week pre-retrofit period for house #2 were approximately 11% higher than the control house (Fig. 2). The loads data for house #3, for the same period, were 5% lower than the control house data (Table 1). The reason that the electric consumption in house #3 was higher than that of the control house was that the COP of the heat pump was lower in house #3 than the control house. The COP was consistently lower for each testing period from July 8 to July 31. The shorter time periods also showed the same trends for both the electric consumption and the total loads as those presented for the total three-week time period.

The two houses were retrofitted with radiant barriers during the week of August 4, 1985. Measurements with the foil installed were taken from August 13 through September 4, 1985. House #2 had the foil laid on top of the fiberglass insulation and house #3 had the foil

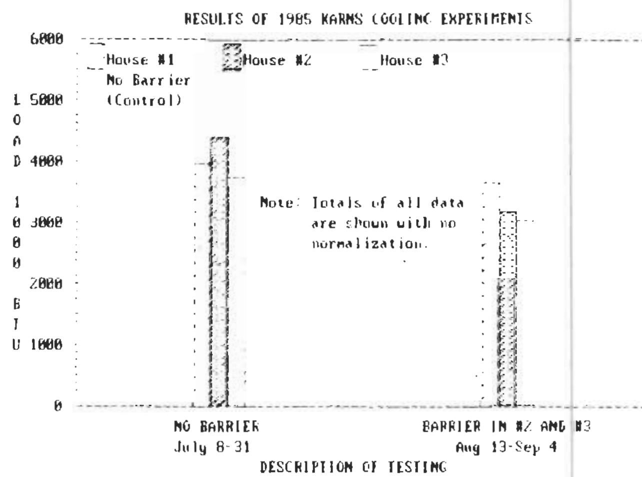

Fig. 2. Cooling loads comparison with and without the radiant barriers.

Table 1. Karns Houses Calibration Data - No Radiant Barrier Installed

House number	Dates from–to	Sensible Btu	Latent Btu	Total Btu	Electrical watt-h	Cooling COP	Total hours
			Average hourly values				
1	7/08–7/10	8,490	1,444	9,934	1,329	2.190	55
2	7/08–7/10	9,218	1,678	10,896	1,464	2.180	55
3	7/08–7/10	8,208	1,170	9,379	1,353	2.031	55
1	7/13–7/16	6,888	1,281	8,169	1,055	2.269	85
2	7/13–7/16	7,458	1,312	8,770	1,152	2.231	85
3	7/13–7/16	6,616	1,036	7,652	1,067	2.101	85
1	7/16–7/23	8,128	1,318	9,446	1,261	2.195	165
2	7/16–7/23	8,832	1,424	10,255	1,373	2.189	165
3	7/16–7/23	7,795	1,070	8,865	1,253	2.073	165
1	7/23–7/28	5,571	941	6,512	848	2.250	119
2	7/23–7/28	6,160	1,115	7,274	961	2.218	119
3	7/23–7/28	5,494	748	6,241	878	2.082	119
1	7/29–7/31	6,117	1,193	7,310	945	2.268	54
2	7/29–7/31	7,447	1,554	9,001	1,165	2.263	54
3	7/29–7/31	6,020	944	6,964	978	2.086	54
			TOTALS are sums of hourly values × hours for each period				
1	TOTALS	3,386,704	582,231	3,968,935	522,749	2.225	478
2	TOTALS	3,733,294	655,254	4,388,548	582,218	2.209	478
3	TOTALS	3,278,827	468,915	3,747,742	529,202	2.075	478

Note: Power outage caused incomplete data from 7/10–13 attached to the underside of the trusses. The raw data (Table 2) showed that the electrical consumption in house #2, for the three-week period, was 8% lower than the control house. The consumption in house #3 was also 8% lower than the control house. The unnormalized cooling loads in houses #2 and #3 were 13% and 17% lower than the control house, respectively. The raw data indicated that the radiant barriers in house #2 and #3 saved energy during the three-week test period.

Table 2. Karns Houses 1985 Data for Radiant Barrier Testing

House number	Dates from–to	Sensible Btu	Latent Btu	Total Btu	Electrical watt-h	Cooling COP	Total hours
			Average hourly values				
1	8/13–8/20	6,621	1,449	8,069	1,007	2.348	163
2	8/13–8/20	6,002	1,034	7,036	946	2.179	163
3	8/13–8/20	5,879	821	6,700	940	2.089	163
1	8/20–8/27	4,501	907	5,408	674	2.352	169
2	8/20–8/27	3,901	675	4,576	620	2.164	169
3	8/20–8/27	3,869	536	4,404	618	2.089	169
1	8/27–9/03	6,122	1,266	7,388	936	2.314	162
2	8/27–9/01	5,490	913	6,403	847	2.214	162
3	8/27–9/03	5,322	752	6,073	858	2.074	162
1	9/03–9/04	7,484	1,436	8,920	1,182	2.211	24
2	9/03–9/04	7,263	1,144	8,407	1,105	2.229	24
3	9/03–9/04	6,887	926	7,813	1,116	2.051	24
		TOTALS are sums of hourly values × hours for each period					
1	TOTALS	3,011,266	628,968	3,640,233	457,949	2.329	518
2	TOTALS	2,701,250	458,055	3,159,304	422,727	2.190	518
3	TOTALS	2,639,392	368,432	3,007,825	423,361	2.082	518

Note: House No. 1 is the control house—it has NO barrier. House No. 2 has the barrier installed atop attic insulation. House No. 3 has the barrier installed along the roof trusses.

The raw data were then normalized with respect to the performance of each house during the July calibration period. The normalized HVAC electric energy consumption data showed that house #2 saved 17% (Table 3 and Fig. 3). The HVAC electrical savings of house #3 was 9%. The reduction in the cooling loads for

Table 3. Comparison of Load and Electrical Data With and Without Barriers

	Before barrier			With barrier		
	House No. 1	House No. 2	House No. 3	House No. 1	House No. 2	House No. 3
Sensible (1000 Btu)	3,386.7	3,733.3	3,278.8	3,011.3	2,701.3	2,639.4
Latent (1000 Btu)	582.2	655.3	468.9	629.0	458.1	368.4
Total (1000 Btu)	3,968.9	4,388.5	3,747.7	3,640.2	3,159.3	3,007.8
% latent	14.67	14.93	12.51	17.28	14.50	12.25
Relative total	1.000	1.106	0.944	1.000	0.868	0.826
Normalized total				1.000	0.785	0.875
Relative latent	1.000	1.125	0.805	1.000	0.728	0.586
Normalized latent				1.000	0.647	0.727
Relative sensible	1.000	1.102	0.968	1.000	0.897	0.877
Normalized sensible				1.000	0.814	0.905
Electrical input (kWh)	522.7	582.2	529.2	457.9	422.7	423.4
Relative electrical	1.000	1.114	1.012	1.000	0.923	0.924
Normalized electrical				1.000	0.829	0.913

*House No. 1 (control house) did not contain a barrier during test period.

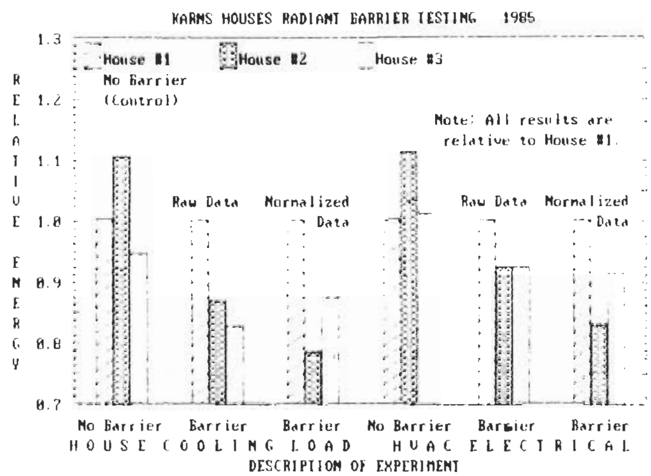

Fig. 3. Comparison of loads and electrical data with and without the radiant barriers.

the two houses were 21% and 13%, respectively. The normalized data showed that the house with the foil laid on top of the ceiling insulation saved more energy than the house with the foil attached to the underside of the roof trusses.

TEMPERATURE DATA

Temperature data were collected at various points in all three houses. Roof shingle temperatures, attic air temperatures, temperatures on the top and on the bottom of the insulation, and house air temperatures are shown in Fig. 4 for house #1 (control house – no

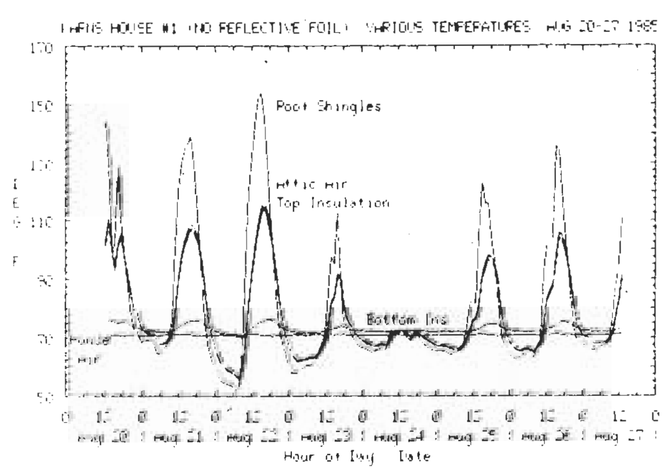

Fig. 4. Various temperatures in Karns House #1 (Control House).

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barrier). The plot was for the time period August 20-27, 1985. August 24 was a very mild day with minimal insulation. August 22 was the hottest day, and during the peak hour, house #1 had shingle temperatures of about 155°F. The attic air temperatures and the temperatures on top of the insulation were almost identical at about 118°F. The peak temperature on the bottom side of the insulation was about 80°F. The peak shingle temperature for house #1 was about 165°F and occurred on September 1, 1985.

House #2 with the horizontal barrier had an additional temperature measurement on top of the barrier (Fig. 5). For the

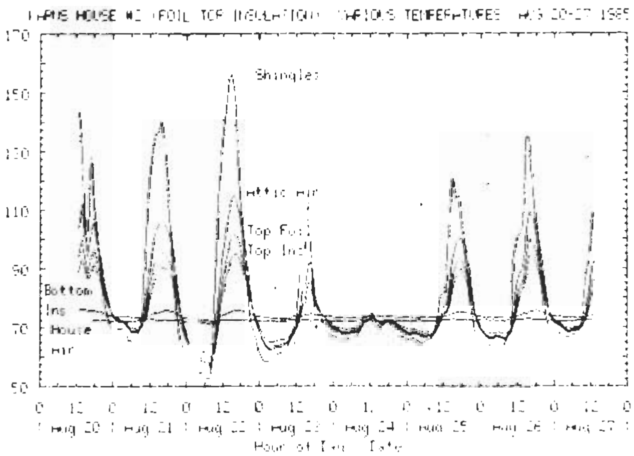

Fig. 5. Various temperatures in the house with radiant barrier installed on top of fiberglass insulation.

peak period on August 22 there was a large temperature difference between the attic air temperature and the temperature on top of the insulation. House #3 with the truss barrier had a temperature measurement for the air between the barrier and the roof (Fig. 6). This measurement was done in place of the temperature measurement on top of the barrier as in house #2. For house #3 there was a large temperature difference between the barrier/roof air temperature and the attic air temperature.

More important was the comparison of temperature data among the three houses (Fig. 7). For the peak hour on August 22, the shingle temperatures of house #3 were 10°F higher than the shingle temperatures of the control house. The

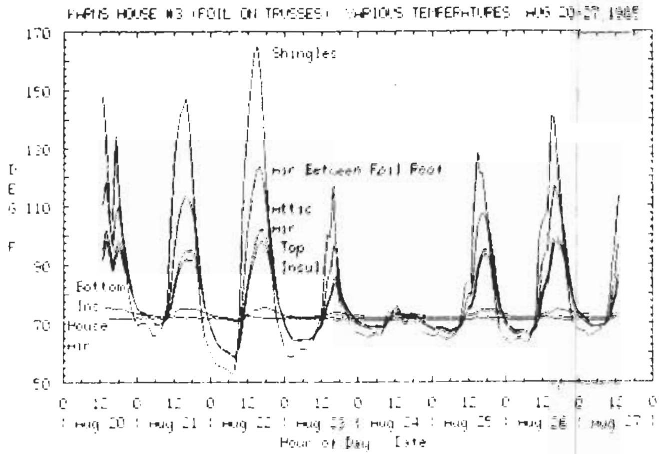

Fig. 6. Various temperatures in the house with radiant barrier attached to underside of roof trusses.

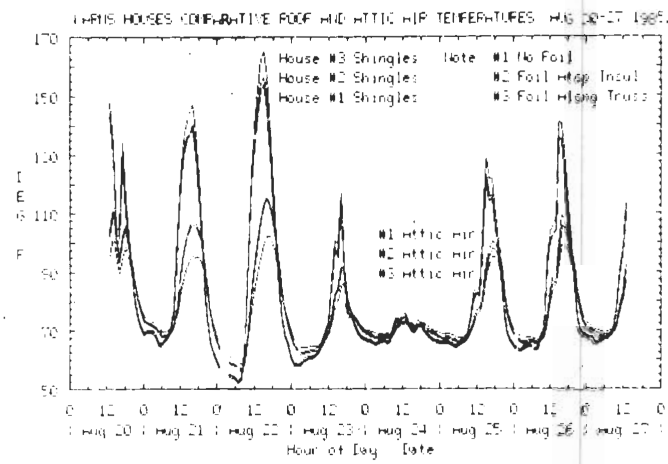

Fig. 7. Comparison of temperature data between three houses.

shingle temperatures of house #2 (horizontal barrier) was only slightly higher than the shingle temperatures of the control house. The reverse was shown on the attic air temperatures. House #3 had the lowest attic air temperature. The attic temperatures of house #1 and house #2 were about the same. The peak shingle temperature for house #3 was about 175°F and occurred on September 1, 1985. This was also 10°F higher than the shingle temperature of the control house.

HEAT FLOW DATA

Heat flow data were collected from heat flux sensors (size 2-1/4 in. x 2-1/4 in.) installed on the attic side of the ceiling underneath the fiberglass batt insulation. The heat flow data were presented for the same time period, August 20-27, 1985, as the temperature data (Fig. 8). The peak flow occurred on August 22, 1985, the same day as the highest shingle temperatures. The peak heat flow in the control house was approximately 2.4 Btu/h/ft^2. The peak heat flows in the house #2 with the radiant barrier were both about 1.47 Btu/h/ft^2, or 39% less than the heat flows in the control house.

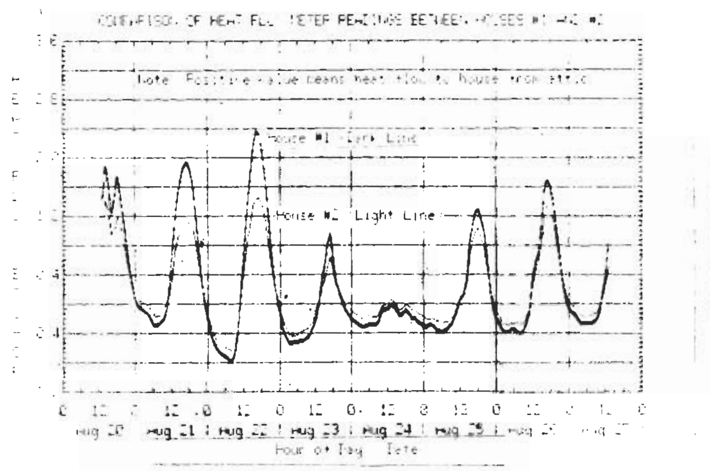

Fig. 8. Comparison of heat flux measurements between house #1 and house #2.

The heat flows were then integrated over the seven-day time period for each heat flow sensor (Table 4). During the day the heat flow was usually from the attic to the house (positive heat flow), and during the night the heat flow was from the house to the attic (negative heat flow). A comparison between house #1 and house #2 (Fig. 8) showed that the house with the radiant barrier had a lower heat flow during peak daily hours, but also had slightly less heat loss during the late evening/early morning hours. This negative impact of the radiant barrier during the late evening/early morning was not overly significant because of the small cooling load during these hours. The time-integrated heat flows in Table 4 present values for both the heat flow from the attic to the house and the heat flow from the house to the attic. House #2 showed a lower integrated heat flow of about 35% than the control house. House #3 had a lower heat flow from the attic to the house of about 30% than the heat flows in the control house. In summary, the peak heat flows and the time-integrated flows were lower in the houses with the radiant barriers than in the control house.

Table 4. Integrated Heat Flow Measurements (Aug. 20-27, 1985)

	Heat flow attic to house (Btu/ft^2)	% change comparison of house #1	Heat flow house to attic (Btu/ft^2)	% change comparison of house #1
House No. 1				
Meter No. 1	61.7		27.4	
Meter No. 2	68.7		28.3	
Average	65.2		27.8	
House No. 2				
Meter No. 1	43.0		19.7	
Meter No. 2	41.6		21.5	
Average	42.3	−35.1%	20.6	−25.9%
House No. 3				
Meter No. 1	43.3		21.9	
Meter No. 2	47.7		19.4	
Average	45.5	−30.2%	20.6	−25.9%

ELECTRICAL USAGE DATA

The measured cumulative energy consumed by the HVAC systems of the three houses from August 13 to September 4, 1985 is shown in Fig. 9. Houses #2 and #3 had radiant barriers installed and showed a gradually increasing energy savings compared to house #1. A composite 24-hour HVAC energy usage profile derived by using averaged hourly data from the three-week test period (Aug. 14 - Sept. 4, 1985) is shown in Fig. 10. The control house average peak usage of 1732

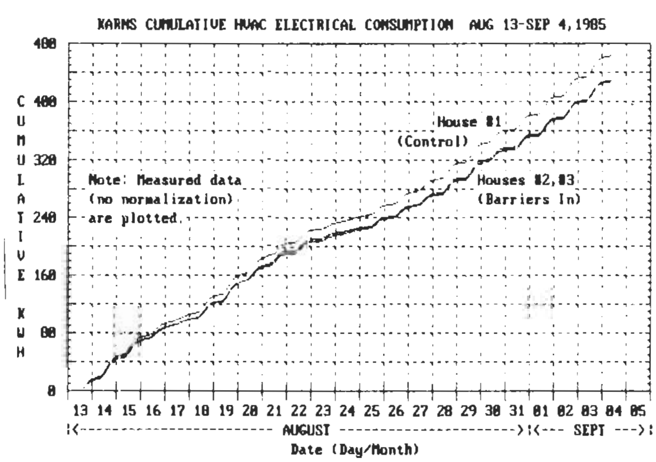

Fig. 9. Cumulative HVAC electrical consumption using average hourly data from Aug. 13 - Sept. 4, 1985.

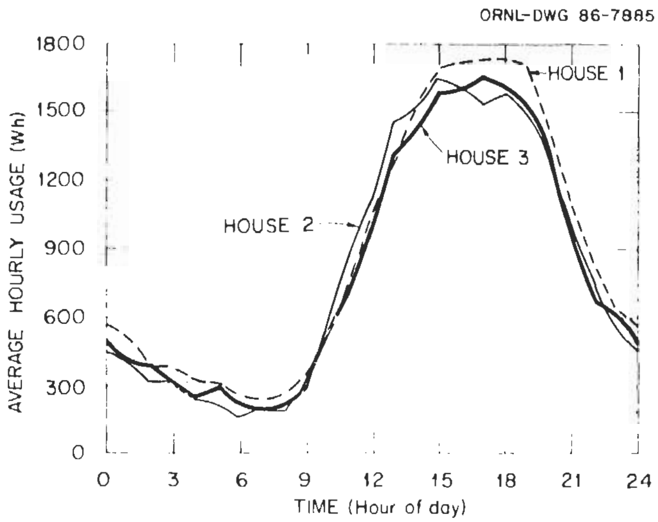

Fig. 10. Composite hourly HVAC energy usage (Aug. 14 - Sept. 4, 1985).

watt-hours at 1800 hours was reduced by 151 watt hours (8.7%) by the presence of a barrier in house #2, compared to an overall average reduction of 7.4%. The reduction over the 24-hour profile, however, appeared to be relatively uniform on a percentage basis, with no drastic reductions taking place.

SUMMARY AND CONCLUSIONS

Radiant barriers in attics were tested to determine the cooling energy savings resulting from their installation. The experiment was conducted by ORNL in three unoccupied houses. The radiant barriers used for this test were products with two reflective aluminum surfaces. The purpose of the radiant barrier was to reduce the radiant heat transfer that impinges on the fiberglass insulation. House #1 was used as the control house and the other two houses were used to test two different methods for installing the radiant barrier. In house #2 the foil was laid horizontally on top of the nominal R-19 attic fiberglass insulation, and in house #3 the foil was attached to the underside of the roof trusses. The houses were highly instrumented with sophisticated data-gathering systems. The data collected included air temperatures within the houses, outside air temperatures, wind speed and direction, total horizontal insulation, attic air temperatures and humidities, crawl space air temperatures and humidities, outside earth temperatures, electrical consumption by the house and by the HVAC system, and both sensible and latent heat removed by the HVAC system.

The first phase of the test, July 8-31, 1985, was a calibration period to allow for the comparison of energy use among the three houses without radiant barriers. After the completion of this three-week test, two houses were retrofitted with radiant barriers. Measurements were then taken for an additional three weeks, August 13 - September 4, 1985, with the barriers installed.

The data with the barriers installed were then normalized with respect to the calibration period and compared to the control house. The normalized cooling electric consumption data showed that the house with the horizontal barrier saved 17%, while the electrical savings for the house with the truss barrier was 9%. The reductions in the cooling loads for the two houses were 21% and 13%, respectively. The data showed that the horizontal barrier saves more energy than the house with the truss barrier. Also, the barrier decreased the cooling loads by a larger percentage than it decreased the electrical consumption because of changes in the heat pump COPs.

The temperature data also showed the impact of the radiant barriers. The house with the truss barrier had lower peak attic air temperatures (10-15°F) than the control house or the house with the horizontal barrier. The house with the truss barrier had peak shingle temperatures that were 10°F higher than the control house. The house with the horizontal barrier had only slightly higher peak shingle temperatures than the control house.

The heat flow data followed the trend of the results of both the energy consumption data and the temperature data. The peak heat flows in the houses with the barriers were both approximately 39% less than the heat flows in the control house. The time-integrated heat flows for the house with the horizontal barrier were 35% lower than those in the control house. The house with the truss barrier had time-integrated heat flows 30% lower than those in the control house. The heat flow measurements were consistent with the energy consumption data which also showed that the house with the horizontal barrier saved more energy than the house with the truss barrier.

Radiant barriers in attics have the potential to save HVAC cooling energy. The most promising method of installation appeared to be when the foil was laid horizontally on top of the fiberglass ceiling insulation. It was relatively easy to install, and it showed greater savings than a barrier installed along the roof trusses.

REFERENCE

CONFERENCE PROCEEDINGS

1. Baxter, V. D., "Data Acquisition and Testing at the Tennessee Energy Conservation In-Housing (TECH) Complex," Procedures of DOE Field Data Acquisition for Buildings and Equipment Energy Use Monitoring, CONF-8510218, October 16-18, 1985, pages 173-179.

APPENDIX A

Table A1. List of Data Channels

Channel number	Slot number	Instrumentation information: Number	Instrumentation information: Location and/or description	Range	Accuracy (+ or −)
000	001	TE-014	Outside air temp (rear)	0–200°F	1°F
001	002	TE-082	Great room wet bulb	0–200°F	1°F
002	003	TE-083	Great room dry bulb	0–200°F	1°F
003	004	RE-070	Pyranometer (roof solar)	0–500 Btu/ft^2	3%
004	005	TE	HP I-O RTD delta MV	0–50 MV	0.02 MV
005	006	TE-086	No. 2 bedroom wet bulb	0–200°F	1°F
006	007	TE-087	No. 2 bedroom dry bulb	0–200°F	1°F
007	008	TE-088	No. 3 bedroom wet bulb	0–200°F	1°F
008	009	TE-089	No. 3 bedroom dry bulb	0–200°F	1°F
009	010	TE-001	Crawl space air temp	0–200°F	1°F
010	011	TE-002	Crawl space earth 6 in.	0–200°F	1°F
011	012	HFT1	Heat flux meter No. 1 temp	0–200°F	1°F
012	013	HFM1	Heat flux meter No. 1	+/− 40 Btu/ft^2/h	5%
013	014	HFT2	Heat flux meter No. 2 temp	0–200°F	1°F
014	015	HFM2	Heat flux meter No. 2	+/−40 Btu/ft^2/h	5%
015	016	TE-026	Outside earth 36 in.	0-200°F	1°F
016	017	TE-028	Hall closet (carpet top).	0–200°F	1°F
017	018	TE-029	Top of floor insulation	0–200°F	1°F
018	019	TE-030	Bottom of floor insulation	0–200°F	1°F
019	020	TE-033	Garage inside wall	0-200°F	1°F
020	021	TE-034	Great room wall	0–200°F	1°F
021	022	TE-035	Kitchen air	0-200°F	1°F
022	023	RT1	Roof (under shingles)	0–200°F	1°F
023	024	TE-037	Attic top of insulation	0–200°F	1°F
024	025	TE-038	Attic top of foil	0–200°F	1°F
025	026	TE-039	Attic air above foil	0–200°F	1°F
026	027	XE-044	Wind direction house No. 2	0–360 deg	5%
027	028	XE-043	Wind speed (house No. 2 only)	0–30 mph	5%
028	029	TE-005	HP outside unit inlet air	0 200°F	1°F
029	030	TE-007	HP outside unit exhaust air	0-200°F	1°F
030 ↓ 039			Channels not used		
040	HWI	ME-040	Outside relative humidity	10–95%	5%
041	HWI	ME-041	Crawl space rel humidity	10–95%	5%
042	HWI	ME-042	Hallway relative humidity	10-95%	5%
043 ↓ 049			Channels not used		
050	031	TE	Attic temp (RH probe) house No. 2 only	10–95%	5%
051	032	ME-242	Attic relative humidity house No. 2	10–95%	5%
052	033		Not used		
053	034		Not used		
054	035	TE-031	HP indoor unit return air	0–200°F	1°F
055	036	TE-032	HP indoor unit supply air	0–200°F	1°F
056	037	TE-027	Thermostat (hall air)	0–200°F	1°F
057	038	TE-023	Front entrance outside air	0–200°F	1°F
058	039		Not used		
059	040		Not used		
060	HWI		Not used		
061	HWI	JE-060	Total house w-h		<0.5%
062	HWI	JE-061	Total heat pump w-h		<0.5%
063	HWI	JE-062	Total resistance w-h		<0.5%
064	HWI	JE-063	Heat pump defrost/cooling run time		1 sec
065	HWI	JE-064	Heat pump heating run time		1 sec
066	HWI	JE-065	Heat pump defrost/cooling w-h		<0.5%
067	HWI	JE-066	Heat pump heating w-h		<0.5%
068	HWI	JE-067	Resistance defrost w-h		<0.5%
069	HWI	JE-068	Resistace normal w-h		<0.5%
070	HWI	JE-069	Sensible heat/cool delivered		1%
071	HWI		Latent heat (condensate)		1%

APPENDIX B

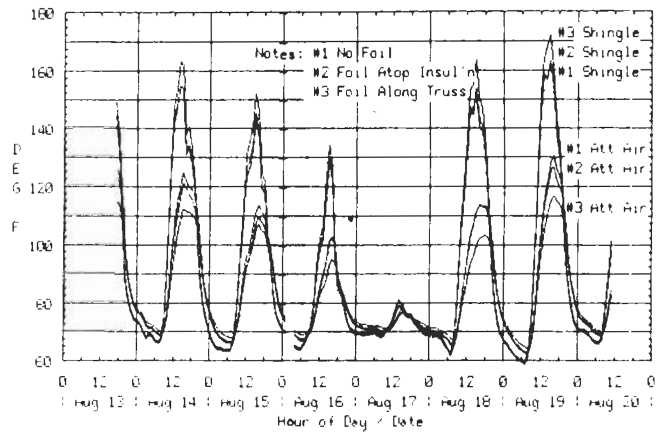

Fig. B1. Effect of Reflective Foil on Shingle and Attic Temperatures: Aug. 13-20, 1985.

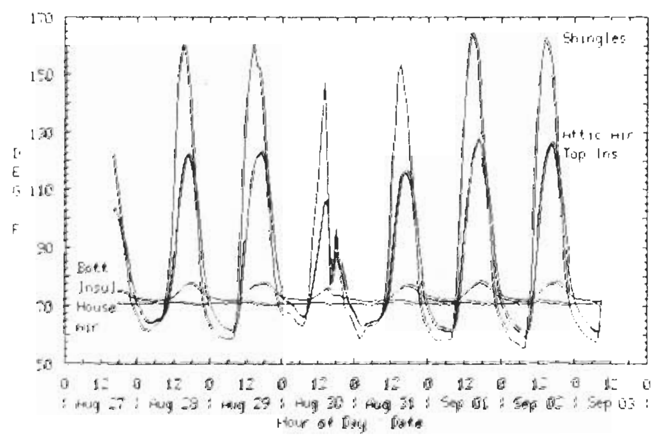

Fig. B2. Karns House #1 (No Reflective Foil) Various Temperatures: Aug. 27-Sept. 3, 1985.

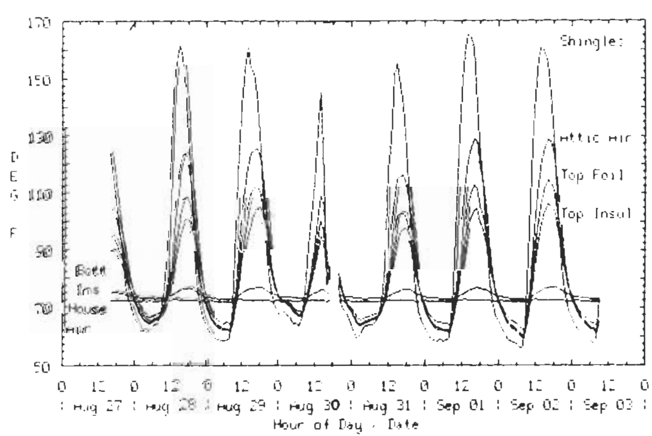

Fig. B3. Karns House #2 (Foil atop Insulation) Various Temperatures: Aug. 27-Sept. 3, 1985.

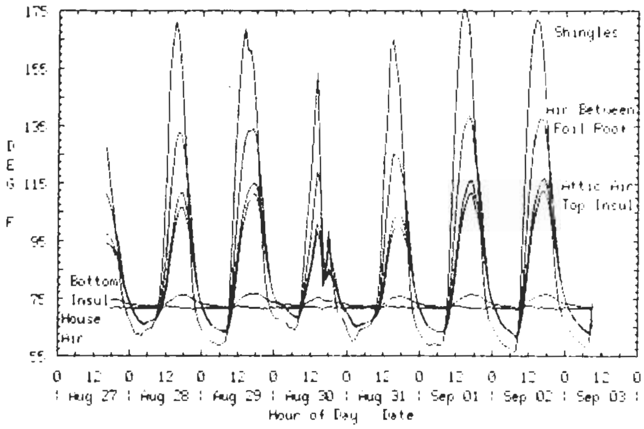

Fig. B4. Karns House #3 (Foil on Trusses) Various Temperatures: Aug. 27-Sept. 3, 1985.

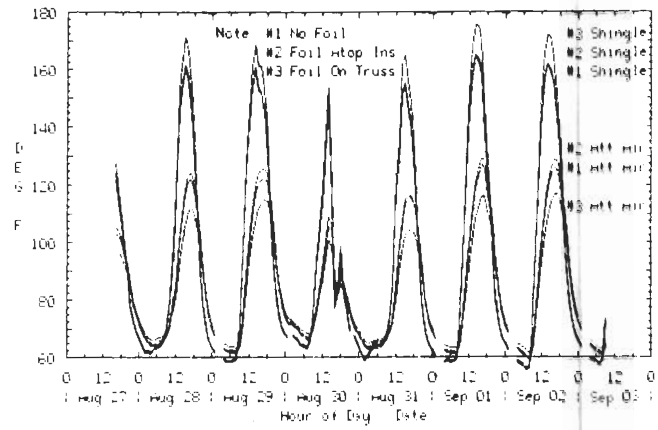

Fig. B5. Karns Houses Comparative Roof and Attic Air Temperatures: Aug. 27-Sept. 3, 1985.