CH-99-11-5

Test and Evaluation of the Attic Temperature Reduction Potential of Plastic Roof Shakes

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ABSTRACT

While monitoring the comparative performance of two test houses in Pittsburgh, Pennsylvania, it was noticed that the attic air temperature of one house with a plastic shake roof was consistently 20°F (11°C) cooler than its twin with asphalt shingles during peak summer cooling periods. More detailed monitoring of the temperatures on the plastic shake, the roof deck, and the attic showed this effect to be largely due to the plastic shake and not to better roof venting or other heat loss mechanisms.

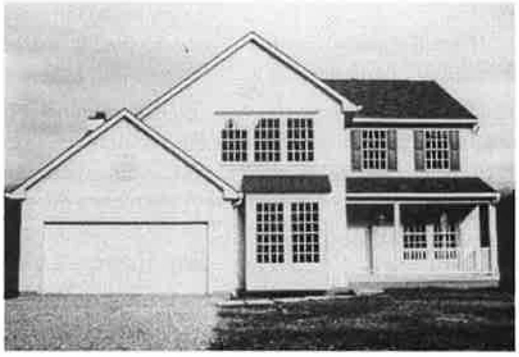
INTRODUCTION

In order to comparatively evaluate new home construction technology, two visually identical test houses have been constructed in Pittsburgh, Pennsylvania (Figure 1). Lab House A is a standard 2400 ft^2 (220 m^2) two-story house taken from a current builder line. Lab House B is identical in design and appearance, but all major components of the house have been revised for improved performance. Every component of the shell, HVAC, plumbing, electrical, finishes, and cabinetry has been modified. The topic of this paper is the modification done to the roof of Lab House B and the thermal performance that resulted from these changes.

LAB HOUSE B

The differences in roof construction between Lab House A and Lab House B are slight, but significant. They are detailed in Table 1. As part of the overall monitoring and evaluation of the two houses, attic temperatures have been recorded. Reviewing the data for summer conditions, an interesting performance difference was noted. On a hot summer day with strong solar radiation, the attic air temperature of Lab House B was nearly 20°F (11°C) cooler than Lab House A (Figure 2). Both houses have the same solar orientation and nearly the same dark brown shingle surface. They were both

Lab House A



Lab House B

Figure 1 Test houses.

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TABLE 1
Lab House A/B Roof Construction

Component	Lab House A	Lab House B
Trusses	Standard heel	Raised heel
Insulation	R-30, fiberglass	R-43, cellulose
Ceiling	5/8 in.(16 mm) gypsum	5/8 in. (16 mm) gypsum
Air barrier	Ceiling plane	Continuous ceiling plane
Eave vent baffles	Single styrofoam	Full width cardboard
Vent path openings	Approx. 1 in. × 12 in. (25 mm × 305 mm) 11 in.^{2} (72 cm^2), net free area	Approx. 1 in. × 22 in. (25 mm × 560 mm) 22 in.^{2} (142 cm^2), net free area
Eave vent	Continuous, perforated, 1:.334, 18 in.^{2} (116 cm^2), net free area	Continuous, perforated, 1:.334, 18 in.^{2} (116 cm^2) net free area
Ridge vent	Continuous, 1:.187, 36 in.^{2} (232 cm^2), net free area	Continuous, 1:.187, 36 in.^{2} (232 cm^2), net free area
Roof deck	7/16 in. (11 mm) OSB	7/16 in. (11 mm) OSB
Shingles	Composition (approx. 1.97 lb/ft^2)(9.6 kg/m^2)	Plastic shakes (approx. 0.73 lb/ft^2)(3.5 kg/m^2)

experiencing the same solar radiation and wind conditions. In order to better understand the mechanism behind this performance, it was decided to conduct a more detailed investigation of the temperature conditions in the roof of Lab House B.

Considerable research has been done on attic/roof interactions, looking at the effects of surface color, venting, and house/attic moisture relationships. Our interest was principally in investigating what thermal performance differences might be attributable to the unusual characteristics of the plastic shake roofing material. It is a molded panel, lightweight and mounted with numerous gaps and openings between panels.

Studies conducted on concrete tile roofing (Beal and Chandra 1995) concluded that the tile roofs studied reduced the heat flux to the house interior by 40% to 50%. This reduction was attributed to the mass of the tile, which kept the

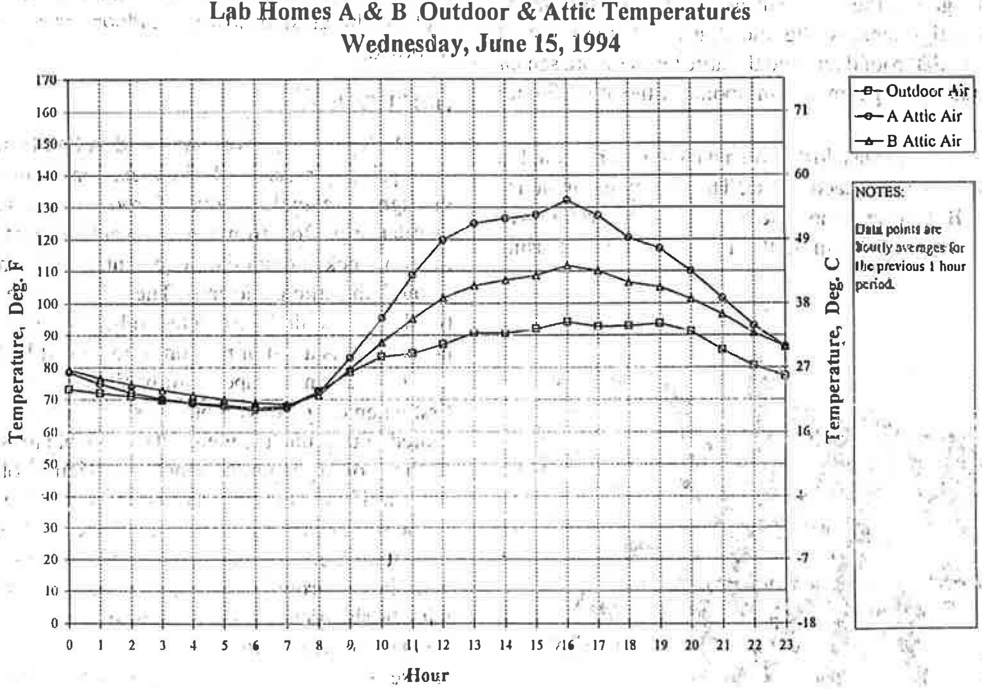

Figure 2 Examination period 1, June 15, 1994.

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TABLE 2
Lab House B Roof Monitoring Chronology

• Plastic roof installed (original roof)	1993
• Attic temp. sensor (attic T) placed	Jan. 1994
• Roof sensors (shingle T, sheathing T) installed	10/6/95
• Datalogger reconfigured for STEM test, then temporarily removed from service. Sensor on underside of shake stopped recording correctly during this time. It may have dropped loose from the shake surface.	1/20/96
• Datalogger back up and running	3/19/96
• Datalogger instrumentation decommissioned	7/2/96
• House B re-roofed with asphalt shingles	8/1/96
• New shingle, sheathing, attic, and outdoor sensors installed	8/23/96
• Pocketlogger instrumentation up and running	9/6/96
• Pocketlogger instrumentation removed	11/11/97

temperature of the back surface of the tile quite low, and to the air space under the tile due to the tile's barrel shape. Some variation of this air space was studied, and improved thermal flux reduction was found with greater air space behind the tile.

The plastic shake roofing that is the subject of this study bears some relationship to this research in that the roofing is composed of shaped, overlapped elements. There are significant differences in that the elements, shakes, are much lighter in weight and are a flatter shape.

The chronology of this investigation is listed in Table 2. Thermocouples (type T, standard limit of error ±1°C) were placed tight against the undersurface of the plastic shake (Figure 3) and tight against the undersurface of the oriented strand board (OSB) roof deck, and the attic temperature sensor was suspended at the geometric midpoint of the attic (Figure 4).

The data logging was done with a data logger mounted in an insulated box, inside each house. The equipment in house A and House B was the same. The reference temperature was established for each system at the multiplexer panel using thermistors. The thermistors measured the reference temperature for all thermocouple measurements.

Figure 3 *Plastic shake roofing (w/skylights).*

Temperature data were logged from October 1995 until July 1996, at which time the plastic shake roof was removed (due to attachment problems) and a conventional asphalt composition shingle roof was installed. Temperature sensors were again installed in the same locations on the asphalt shingle roof: against the underside of the shingle and the underside of the OSB deck and in the center of the attic. During the first monitoring period, October 1995 to July 1996, a weather station recorded data at the house including solar radiation. Solar radiation data were not available after the change to asphalt shingles; however, outdoor air temperatures were recorded.

DISCUSSION

With an attic as well insulated as Lab House B, there are three primary means of losing heat. One is the heat exchange through the shingles above the roof deck, a second is by the ventilation airflow from the eave vents across the underside of the roof deck and out the ridge vent, and the third is heat loss through the attic gable ends. The gable end heat loss from the two houses could be expected to be nearly the same for both houses and is a minor portion of total heat loss.

By tracking temperature performance of the roof deck, first when covered with plastic shakes and, second, when re-roofed with asphalt shingles, it is possible to isolate the effect of the roofing material alone. A particular objective was to discern, if possible, any thermal performance characteristics of the plastic shakes that might be due to their unusual lightweight molded form. There was the opportunity for air movement in and around the shake surfaces that was not possible with the shingles. Note that the asphalt shingles used to re-roof Lab House B are virtually the same as those installed on Lab House A.

As so often happens, there was a glitch in the experiment. Sometime between January 20, 1996, and March 19, 1996, the

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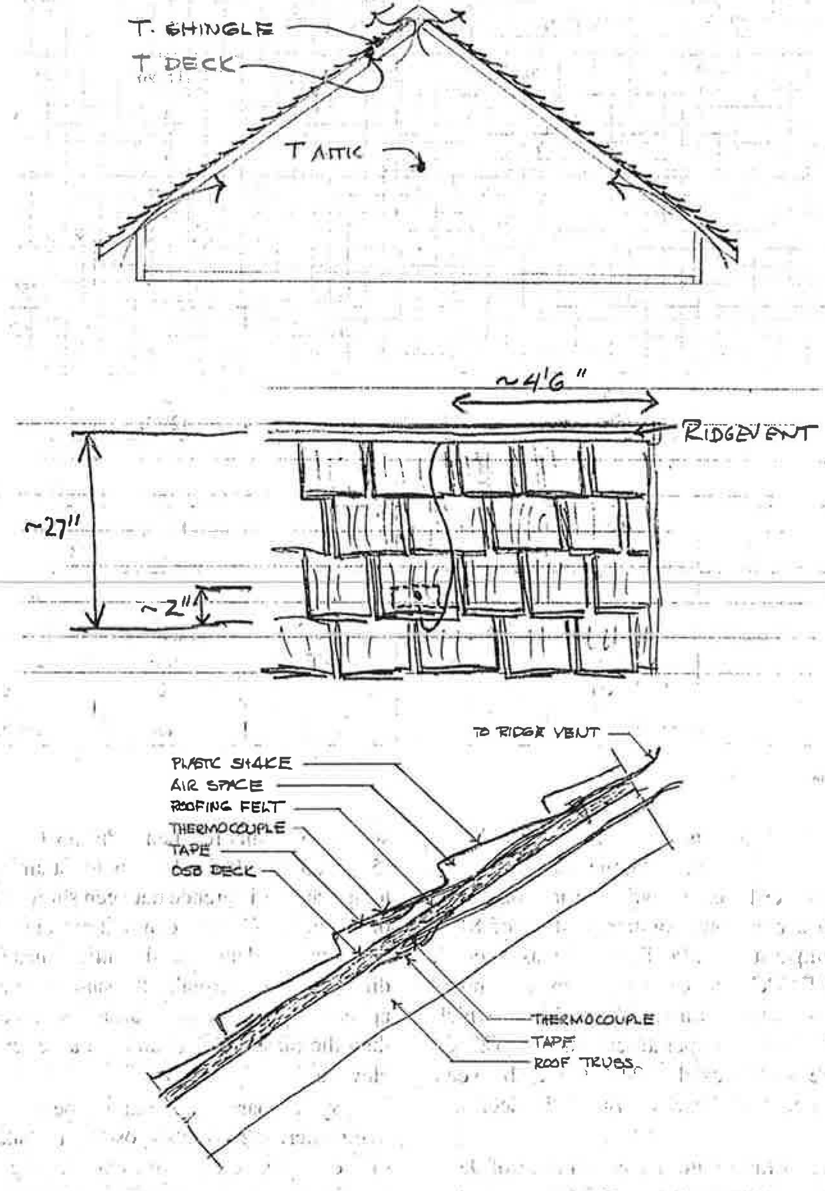

Figure 4 Lab House B, temperature sensor locations.

sensor attached to the undersurface of the plastic shake ceased to provide reliable data, indicating temperatures virtually the same as the attic interior. This remained the case until the house was re-roofed in August 1996. It is postulated that the sensor may have worked loose from its attachment to the shake, cloth tape, perhaps due to repeated heating and cooling, and dropped down into the air space between the shake and the roof deck. Nevertheless, the critical attic and outdoor temperatures were continuously monitored.

The thermal performance of the roofs was examined four times (Figures 5 through 8) and then comparatively (Figure 9) in order to develop an understanding of the behavior of the two forms of roofing: asphalt shingles and plastic shakes.

Figure 2 presents data for both Lab House A and Lab House B on June 15, 1994, examination period 1. The thermally significant differences in the attic/roof construction of the two houses are the roof surface and the eave venting cross-sectional area. Both will be discussed subsequently. This was a hot day for Pittsburgh in which we saw the distinct attic temperature difference between the two roof systems. The summary in Table 3 indicates that on this 94°F (37°C) day the attic air of Lab House A, with asphalt shingles, was 38°F (21°C) hotter than the outdoor temperature, while the attic air of Lab House B, with plastic shakes, was 18°F (10°C) hotter than the outdoor temperature. The attic of Lab House B was 20°F (11°C) cooler than Lab House A.

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TABLE 3
Lab House A/B, Comparative Performance of Roofing Systems

	6/15/94		10/12/95	6/16/96	6/24/97	96/97 diff.
	A	B	B	B	B	
Examination period	1		2	3	4	
Max. outdoor temp.	94°F (37°C)	94°F (37°C)	81°F (27°C)	92°F (33°C)	91°F (33°C)	0°
Max. shingle temp.	--	--	130°F (55°C)	110°F* (43°C)	168°F (75°C)	--
Max. deck temp.	--	--	106°F (41°C)	122°F (50°C)	142°F (61°C)	20°F (11°C)
Max. attic temp.	132°F (55°C)	112°F (44°C)	90°F (32°C)	108°F (42°C)	126°F (52°C)	18°F (10°C)
Shingle/deck difference			24°F (13°C)	--	26°F (14°C)	
Deck/attic difference			16°F (9°C)	14°F (8°C)	16°F (9°C)	
Shingle/attic difference			40°F (22°C)	--	42°F (23°C)	
Attic/outdoor difference	38°F (21°C)	18°F (10°C)	9°F (5°C)	16°F (9°C)	35°F (19°C)	19°F (10°C)
Roof type	asph.	plas.	plas.	plas.	asph.	plas./asph.

* Sensor believed to have come loose from shake undersurface.

After installing the temperature sensors to the plastic shakes and roof deck on October 6, 1995, the warmest day in the fall of 1995 was October 12, examination period 2 (Figures 5 and 6). Here, with a peak outdoor temperature of 81°F (27°C), an attic air temperature of 90°F (32°C) was reached. The attic is peaking 9°F (5°C) above outdoor ambient temperatures. The plastic shake temperature is 130°F (55°C), which is 40°F (22°C) above the attic temperature. This 40°F (22°C) temperature difference is composed of 24°F (13°C) between the shake and the deck and 16°F (9°C) between the deck and the attic.

On June 16, 1996, a high outdoor temperature of 92°F (33°C) was recorded in examination period 3 (Figure 7). On such days in Pittsburgh, solar radiation is always at relatively high levels. Due to the problem with the sensor on the plastic shake, the reading of 110°F (43°C) is unrealistically low, only deck and attic temperatures can be evaluated. On this hot summer day, the attic air temperature of 108°F (42°C) was 16°F (9°C) above outdoor ambient air temperature. The portion between the deck and the attic was 14°F (8°C), almost the same as the previous (October 12, 1995) examination period.

Shortly after the June 16, 1996, examination period 3, the plastic shakes were removed and Lab House B was re-roofed with asphalt composition shingles. High temperatures were not recorded on this roof until the summer of 1997. The final examination period 4 is June 24, 1997 (Figure 8). On this hot summer day that reached 91°F (33°C), the attic rose to 126°F (52°C), 35°F (19°C) above outdoor ambient. The 42°F (23°C) temperature difference between shingle and attic is composed of 26°F (14°C) between shingle and deck and 16°F (9°C) between the deck and the attic. These relative temperature differences are virtually the same as for the plastic shakes. It appears that the shingle surface becomes considerably hotter than the plastic shake, and the attic temperature is similarly elevated.

By comparing examination period 4 to house A in examination period 2, it is also possible to make some determination of the influence of eave-ridge venting. These two roofs are identical except for the difference in eave vent cross-sectional area. The maximum outdoor temperatures are 3°F (1.6°C) different and the attic/outdoor temperature difference is also 3°F (1.6°C). This suggests that any attic ventilation difference plays a very small role in the heat loss characteristics of the roof assembly. Attic ventilation certainly provides for part of the heat removal from the attics of both houses, but the difference in vent area between the two houses seems to have little or no effect on comparisons between the two houses under summer conditions.

It should be noted that everything about the roof of Lab House B was held constant during the test and evaluation period except for the changeout of the roofing surface. Even this surface retained the same dark brown color from plastic shake to asphalt shingle when re-roofed.

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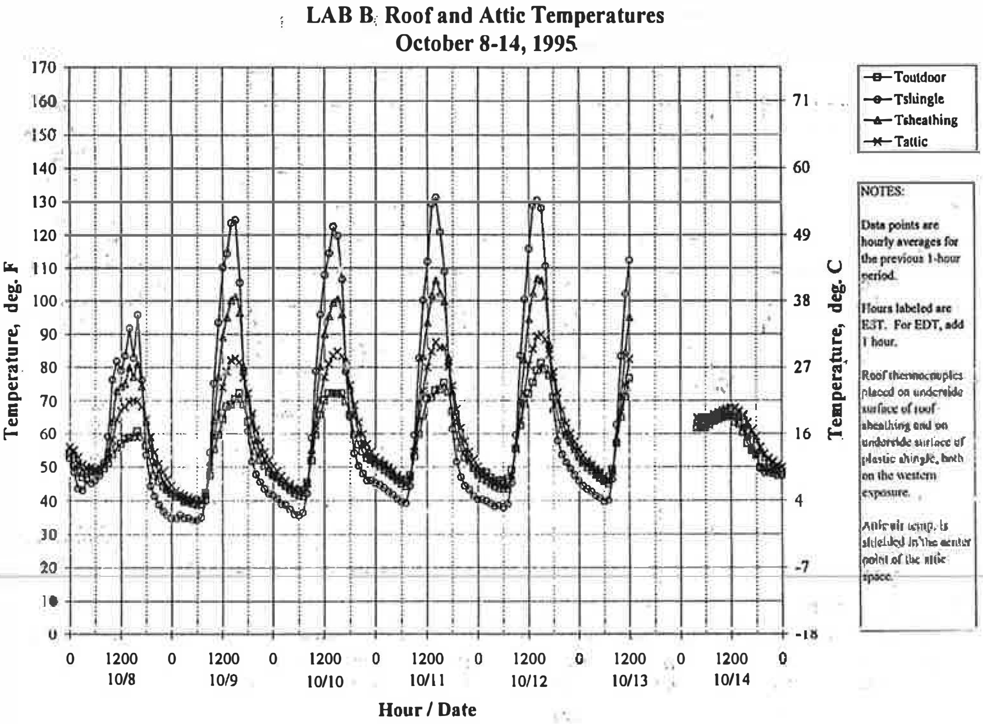


NOTES:

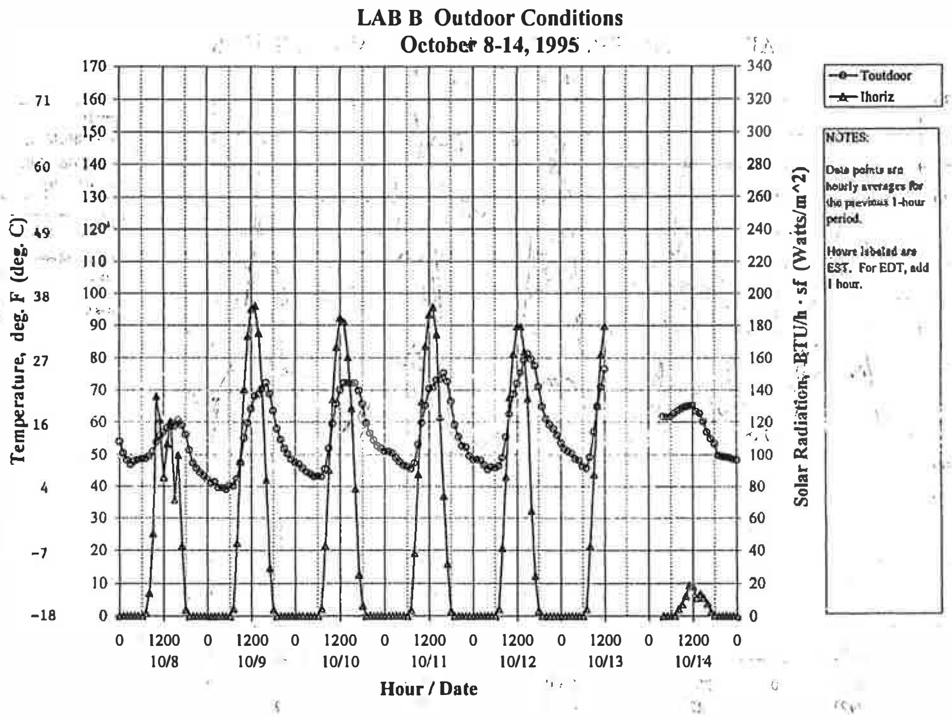
Data points are hourly averages for the previous 1-hour period.

Hours labeled are EST. For EDT, add 1 hour.

Roof thermocouples placed on underside surface of roof sheathing and on underside surface of plastic shingle, both on the western exposure.

Attic air temp. is shielded in the center point of the attic space.

Figure 5 *Examination period 2, October 12, 1995.*



NOTES:

Data points are hourly averages for the previous 1-hour period.

Hours labeled are EST. For EDT, add 1 hour.

Figure 6 *Examination period 2, October 12, 1995.*

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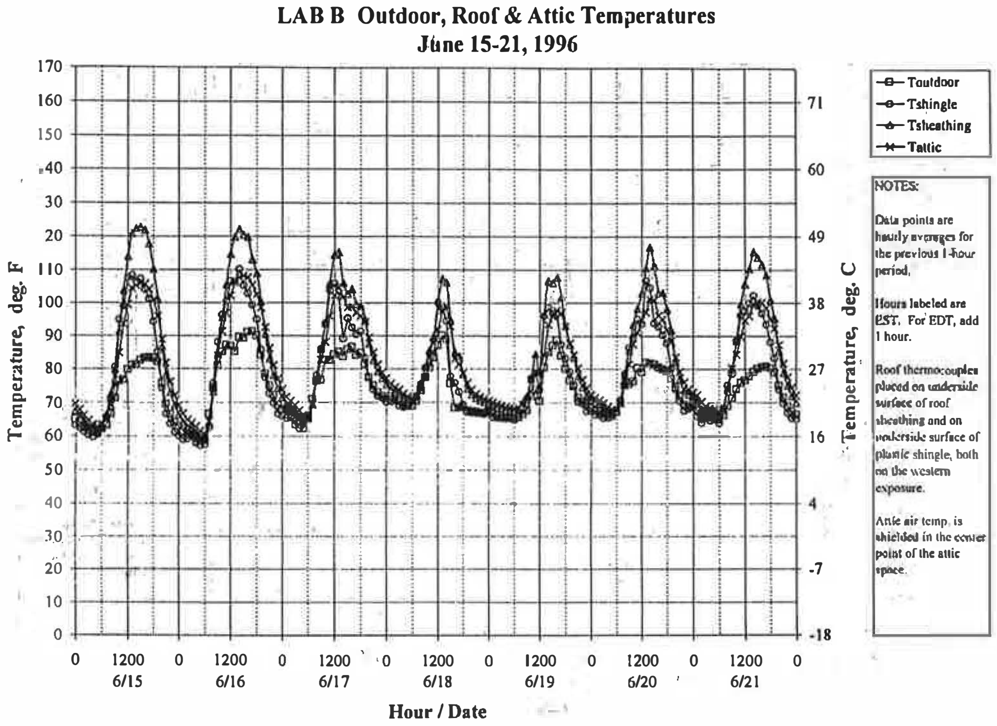

Figure 7 *Examination period 3, June 16, 1996.*

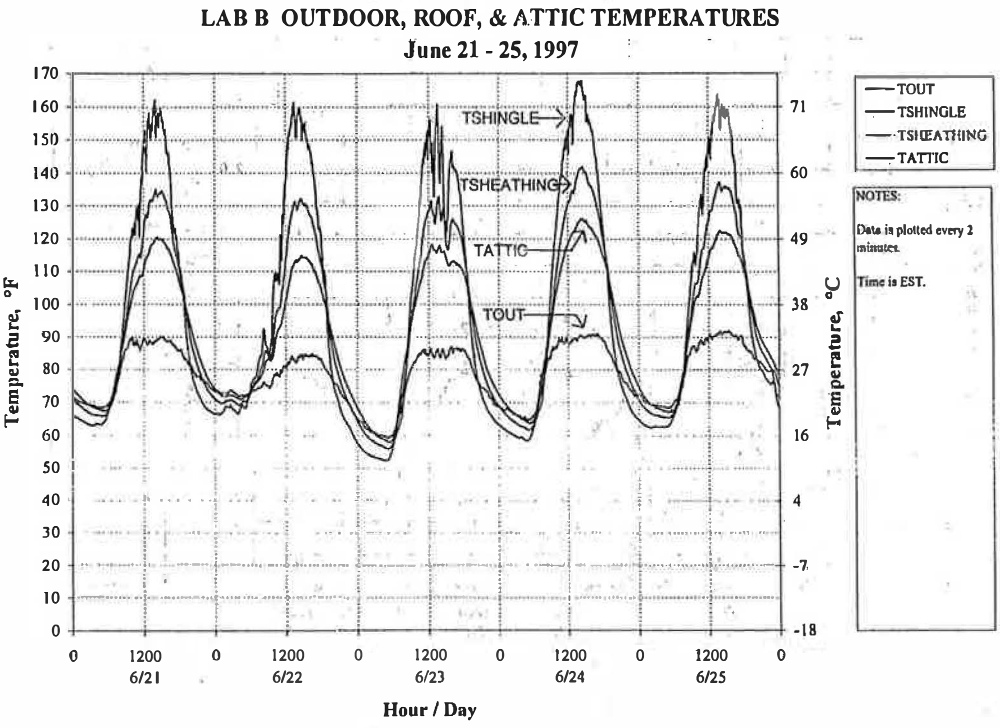

Figure 8 *Examination period 4, June 24, 1997.*

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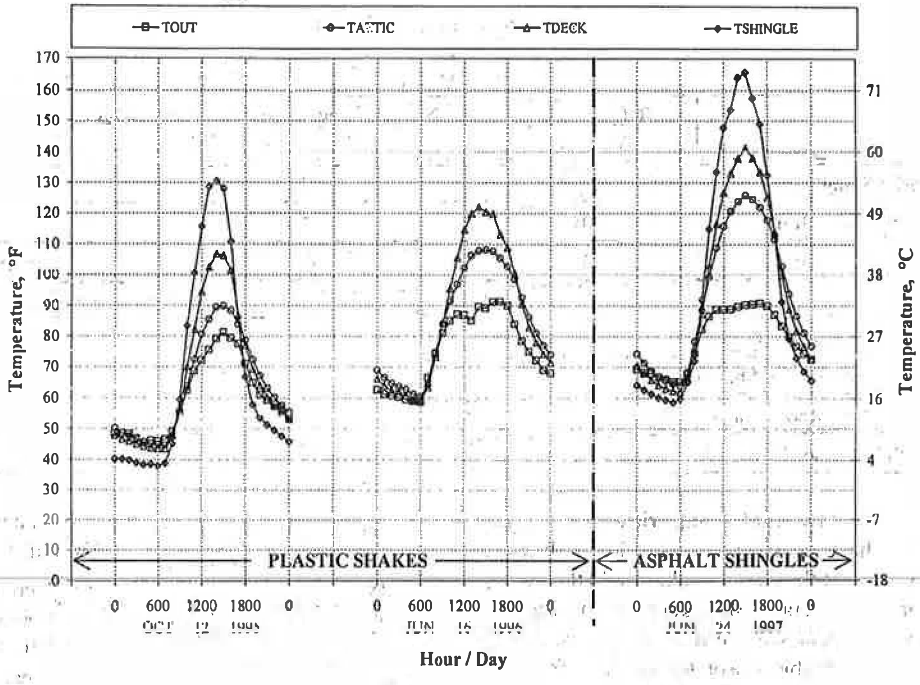

Figure 9 *Lab B roof temperature comparisons.*

In the sequence of ownership of the two houses, Lab House A was sold before the detailed sensor installation could be done on Lab House B, and the unfortunate shake temperature sensor failure made comparative assessment a challenge. Nevertheless, the data as summarized in Table 3 and Figure 9 and assessed in examination periods 1 through 4 do suggest some performance difference between the plastic shakes and the composition shingles.

The examination periods may be summarized as follows:

- *Period 1*—This period demonstrates that the House B attic is 20°F (11°C) cooler than the House A attic under peak summer conditions. The operative differences could be in the roof surface or in the eave vent area.
- *Period 2*—This period provides the breakdown of the attic to plastic shake temperature range in relation to outdoor temperature with temperatures for the shake, the roof deck, and the attic. It shows that 60% of the temperature gradient is between shake and deck and 40% between deck and attic. This was determined with an outdoor temperature of 81°F (27°C).
- *Period 3*—The plastic shake roof is subject to peak summer conditions with outdoor temperature of 92°F (33°C). The outdoor and attic temperatures are very similar to what is seen for House B in examination period 1. Comparing period 3 to period 2, the gradient from attic to roof deck is nearly identical, suggesting that the big gradient is again from deck to shake.
- *Period 4*—On the same house (House B), under the same summer conditions (91°F-92°F [32°C-33°C]), the composition shingles now result in an attic temperature 18°F (10°C) higher than the plastic shakes in period 3, indicating that the plastic shakes are likely responsible for the observed beneficial lower attic temperatures of period 3.

Further comparing period 4 to House A in period 1 shows quite similar attic/outdoor and maximum outdoor temperature differences, suggesting that eave ventilation differences have little impact on the comparison of House A to House B. So it seems plausible that the plastic shake alone is primarily responsible for the lower attic temperatures when compared to composition shingles.

The attractive thermal performance of the plastic shakes compared to the shingle roof could be due to one or more mechanisms:

- High solar reflectivity
- Greater convective loss
- Thermal storage and nocturnal re-radiation

Thermal storage of any magnitude is highly unlikely, as the plastic shakes are a molded sheet that is quite thin and lightweight. To assess comparative solar reflectivity, samples of each of the roofing materials were laboratory tested. The solar properties in Table 4 were determined from actual samples of the plastic shake and composition shingles that were applied to House B. The testing was done using industry standard procedures for roofing materials (DSET 1998). Results of these tests (Table 4) indicate the hemispherical

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TABLE 4
Roofing Materials Test Results

Emittance			
Specimen Code	Reflectance (ρ) Measured	Near-Normal Emittance (ε) Calculated	Hemispherical Emittance (ε) Calculated
Composite Shingle	.05	.95	.90
Plastic Roof Shake—Top	.05	.95	.90
Plastic Roof Shake—Bottom	.06	.94	.89

Reflectance	
Specimen Code	% Reflectance
Composite Shingle	9.6
Plastic Roof Shake—Top	8.8
Plastic Roof Shake—Bottom	15.8

spectral reflectance of the two roofing materials is quite similar, with the plastic shake approximately 8% lower than the shingle. This suggests that the plastic shake would thus reject less solar radiation by reflectance than does the composition shingle. Ruling out thermal storage and reflectance leaves convective loss as the probable reason the heat loss from the plastic shakes is greater than that of the conventional shingles. Convective loss may, of course, occur across both the exterior and interior surface of the plastic shake, while convection can occur only across the exterior surface of the shingle.

CONCLUSIONS

Examination of the performance characteristics of the two types of roofing through the test period suggests the following conclusions:

1. Under peak summer conditions (90°F-94°F [32°C-34°C]), attic air temperatures under the roof with plastic shakes is 18°F-20°F (10°C-11°C) lower than under the roof with shingles.
2. This temperature difference appears to be a difference in the shingle/shake temperature itself as measured at the undersurface of the shingle or plastic shake.
3. When both roofs were surfaced with asphalt shingles on June 15, 1994 (House A), and June 24, 1997 (House B), and were exposed to peak summer conditions (94°F and 91°F [34°C and 33°C]), there was little difference in attic air to outdoor temperature rise. House A has a 38°F (21°C) difference, while House B has a 35°F (19°C) difference. This would suggest that attic ventilation effects were virtually the same for both roofs.
4. Hemispherical spectral reflectance from the plastic shake (8.8) is 8% lower than for the shingle (9.6). Thus, greater solar reflectance cannot be a reason the plastic shakes are cooler.
5. The plastic shake weighs approximately 0.73 lb/ft^2, while the shingles weigh approximately 1.97 lb/ft^2. The lighter weight shake would not appear to offer any thermal performance advantage due to storage/re-radiation effects.
6. By eliminating the probability of reflectivity, mass, or roof ventilation as reasons that the plastic roof shakes are cooler than the shingles under identical conditions, the most likely explanation is increased convective heat loss. This could entail convection across both interior and exterior surfaces.
7. The gaps between plastic shake panels and the void space underneath would appear to provide good pathways for convective airflow and heat transfer.
8. Comparison of plastic shakes to metal roofing would be useful. Ribbed metal roofing is lightweight like the plastic shake but does not have the air space behind. Metal shingles would be the closest in configuration and weight.
9. Further investigation of plastic roof shakes for beneficial cooling season performance seems desirable. Aspects to study might include surface color and sheen, gap configurations, and other molded forms such as slate and tile styles.

ACKNOWLEDGMENT

This work was done with support from the U.S. Department of Energy, Building America Program, through the National Renewable Energy Laboratory. Data logging was done with a Campbell Scientific datalogger. Thermistors were supplied by Campbell Scientific.

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