U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Roof and Attic Design Guidelines for Hot Climates

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ROOF AND ATTIC DESIGN GUIDELINES FOR HOT CLIMATES

EXECUTIVE SUMMARY

Design guidelines for hot climates are provided here to help builders and homeowners make informed decisions on the most economical and best practices for the renovation of a home's roof and attic.

This guide builds on the results of DOE Building Technology research to develop next-generation roofs and attics. Roof and attic heating and cooling loads comprise a significant portion of total building heating and cooling loads, which are the largest end uses in the buildings sector and consume about 1 Quad of primary energy each year. The new roof and attic designs can potentially reduce the cooling and heating loads attributable to residential roofs and attics by 35% of the roof and attic load generated by a home built to IECC (2006) standards. If ducts are also eliminated from the attic the loads drop by 90% of an IECC home's roof and attic load, which potentially reduces the whole building energy use by about 20%.

ORNL field-tested three new designs that are applicable to new and retrofit construction. The new designs use a combination of strategies including infrared-reflective cool roofs, radiant barriers, above-sheathing ventilation, low-emittance (low-e) surfaces, insulation, and thermal mass to reduce the attic air temperature and thus the heat transfer into the home. The salient features of the three new designs are as follows:

1. Insulated and ventilated shingle roof. Conventional or cool color shingle; 1-in. (0.0254-m) air space made by profiled and foil-faced 1-in. (0.0254-m) EPS insulation placed above deck (retrofit practice) or fitted between roof rafters (new construction); two low-e surfaces; passive ventilation from soffit and attic providing cool make-up air to the inclined air space.

2. Offset-mounted metal roof with phase-change materials (PCMs). Painted metal roof exploits cool color pigments; above-sheathing ventilation with a 1½-in. (0.038-m) inclined air space fitted with a low-e surface and a sheathing impregnated with paraffin hydrocarbon PCMs.

3. Insulated and ventilated tile roof. High-profile clay tile that is highly reflective; the tile's high profile provides above-sheathing ventilation; a 1¼-in. (0.032-m) expanded polystyrene (EPS) insulation is placed on top of the deck, and a spray urethane foam adheres the tile and EPS assembly firmly to a fully adhered peel-and-stick, ice-and-water guard membrane.

A review of the field data on the new roof and attic designs is included as the Appendix to this guide. Field results were benchmarked against ORNL's attic computer tool ASTM (2004) and simulations made to compute energy cost savings from the designs for hot climates.

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ROOF AND ATTIC DESIGN GUIDELINES FOR HOT CLIMATES

1. INTRODUCTION

Residential and commercial buildings combined consume 72% of the electricity generated in the United States and about 54% of the natural gas. The roof and attic are responsible for about 15-20% of the energy consumed by homes built before 1990. This design guide is focused on improving roofs and attics in hot regions in ASHRAE Climate Zones 1, 2, and 3, as shown in the map in Figure 1.

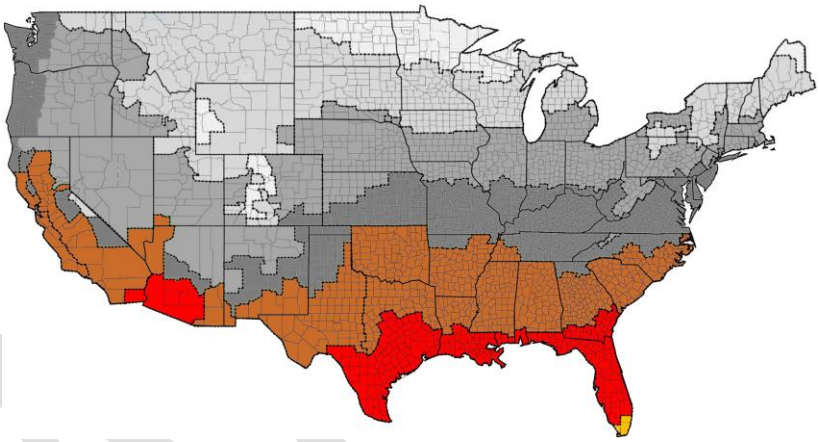

FIGURE 1 The design guide is aimed at buildings in the colored areas — ASHRAE Climate Zones 1 (yellow), 2 (red), and 3 (orange), from south to north. (Zone 1 includes Hawaii, Guam, Puerto Rico and the Virgin Islands).

Over the last five years the Department of Energy has sponsored research to examine advanced roof and attic designs, focused on reducing the energy flow between the attic and the conditioned space to the lowest achievable values. No single action can provide such savings — it takes a combination of technologies in an "Integrated Roof Design." The results of this research tell us what the maximum savings can be, and also which elements of the integrated designs are most effective. Where budgets won't stretch to the "greenest" possible roof, the results of this research enable the homeowner or builder to optimize the energy savings for each dollar spent.

The attic is defined broadly to include the roof as well as the space between the roof and the finished ceiling below, which can include ducts for the heating, ventilating, and air-conditioning (HVAC) system. Benefits of energy retrofits and strategies for roofs and attics depend on climate, attic geometry, duct arrangements, and other building parameters. Improving an attic or roof can be done at any time during the life of a home, though factors such as cost and climate will be considerations.

Heat flows naturally from a warmer space to a colder space. Heat that flows into the building is called heat gain, while heat that flows out of the building is called heat loss. When too much heat gain or loss occurs, the building's air conditioning or heating system has to use more energy to keep the space comfortable. A large amount of heat gain and loss in buildings can be attributed to roofs and attics.

Increasing the resistance of the roof and attic to heat gains and losses saves energy and money because the roof is subjected to greater temperature extremes than any other part of the building. This guide describes roof and attic designs for new and retrofit applications that are energy efficient and economically viable. The better the design of the roof and attic, the lower will be the energy bill.

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2. CONVENTIONAL BUILDING PRACTICE

Conventional practices are often not the best choice for homeowners who want to save energy and lower their energy bills because many builders continue to install HVAC ducts in the attic, and the ducts are not well insulated or properly sealed to limit air leakage. Homeowners typically pay an added $275 per year because of leaky and poorly insulated air conditioning ducts operating in a hot and leaky attic. Energy costs are also increased if the attic floor leaks air to or from the home. Duct location and sealing the attic floor are of paramount importance and should take precedence over other energy efficient roof and attic strategies.

Figure 2 illustrates why these renovations should be a priority component of a building program, whether for retrofit work or for building a new home. The dark blue bars represent a dark roof and attic that contains poorly insulated and leaky ducts and a leaky attic floor. The orange bars show energy use where the practitioner repaired the leaks in the attic and he sealed and rewrapped the ducts in R_{US}-8 (R_{SI}- 1.4) insulation. The light blue bars are for a new-design roof and attic assembly with the ductwork and attic floor repaired for leakage. The green bars represent a renovated attic where the homeowner had the leaky attic floor repaired and the ducts completely removed from the attic.

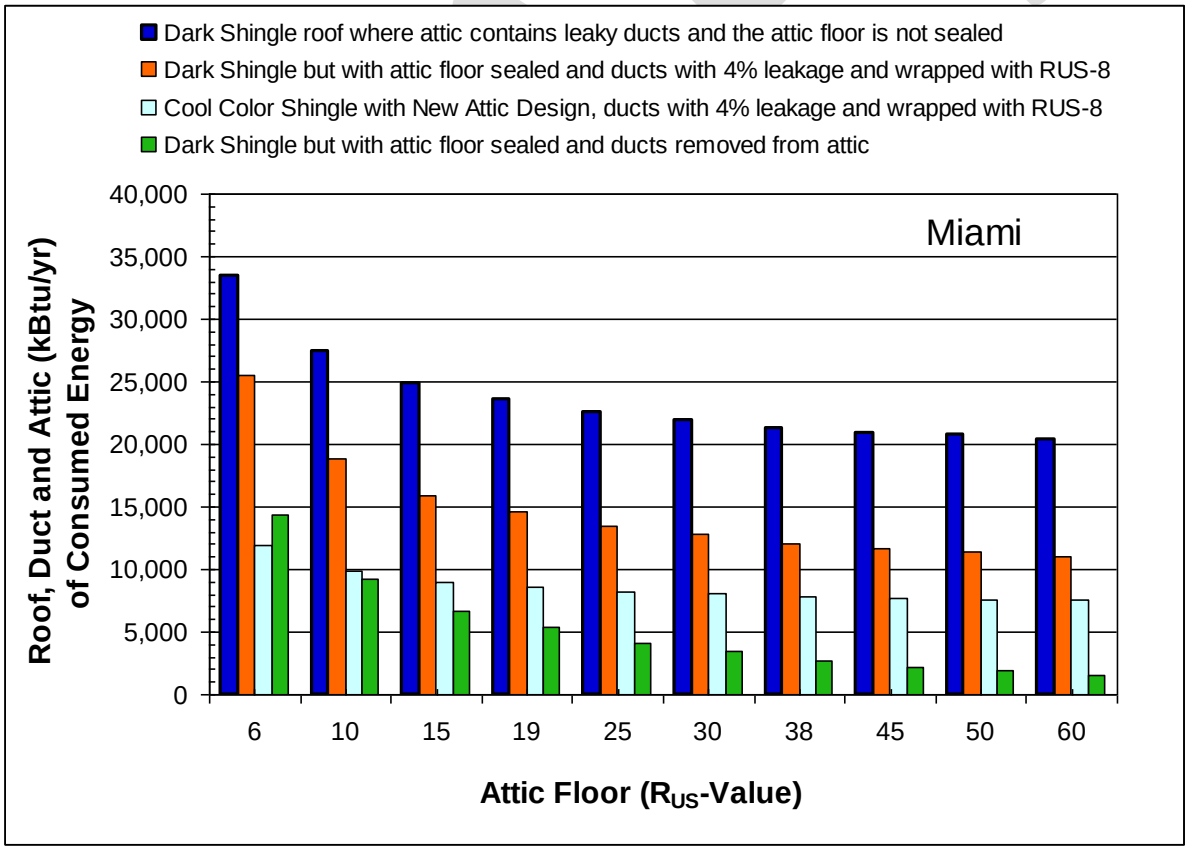

Figure 2. Comparison of energy impacts of leaky ducts in attic space, sealing attic floors, insulating attic floors, and eliminating energy losses from HVAC ducts in unconditioned attics.

Adding insulation reduces your energy bill for all assemblies represented in Figure 2. However, the energy savings achieved with more insulation does not counterbalance the energy lost by the ducts. Sealing all duct joints with mastic and wrapping the ducts with R_{US}-8 (R_{SI}-1.4) insulation drops the energy losses through ducts in the attic by roughly 40% (Fig. 2 dark blue bars compared to orange bars). An attic with R_{US}-60 (R_{SI}-10.6) floor insulation but with leaky ducts and leaky floor (Fig. 2 dark blue bar) has 30% more heat energy losses than an attic with just R_{US}-5 (R_{SI}-0.9) floor insulation but with no ducts and no air leakage across the attic floor (Fig. 2 green bars). In many homes, the ductwork increases air-conditioner energy use by roughly 18% for moderately leaky ducts in a well-insulated attic (Cummings et al. 1990; Parker, Fairey, and Gu 1993).

After repairing HVAC ducts, sealing the attic floor, and adding insulation, what's next? Installing a new roof design (light blue bars, Fig. 2) will recoup about $200 of that $275 lost by the ducts and leaky attic. However, because of the magnitude of duct losses, the new roof designs do not fully compensate for the inefficiency of the ducts if floor insulation exceeds R_{US}-10 (R_{SI}-1.8). Therefore, the recommendation is to always install HVAC ducts in the conditioned space of the residence rather than in the unconditioned attic. For older homes, repair the ductwork, and if this is done in combination with the new roof and attic designs, the assembly can potentially reduce the cooling and heating loads attributable to residential roofs and attics by 65%. In comparison, moving the ductwork from the attic to the conditioned space lowers the roof and attic energy by 85%. This shows how the new roof and attic designs compensate for much of the energy lost where air conditioning ducts cannot be moved into conditioned spaces (see Section 5.1).

3. ENERGY-SAVING STRATEGIES MERGED INTO NEW ROOF DESIGNS

Field testing and simulations have shown that three new integrated roof designs yield substantial energy savings. The integrated roof designs use a combination of strategies and technologies to reduce attic air temperatures and heat transfer into homes, including thermal insulation, ventilation, cool roofs, duct location, sealed attics, radiant barriers, PCMs, vapor retarders, and airflow retarders. The three new integrated roof assemblies tested by ORNL are described below, and their energy performance is summarized in Table 1.

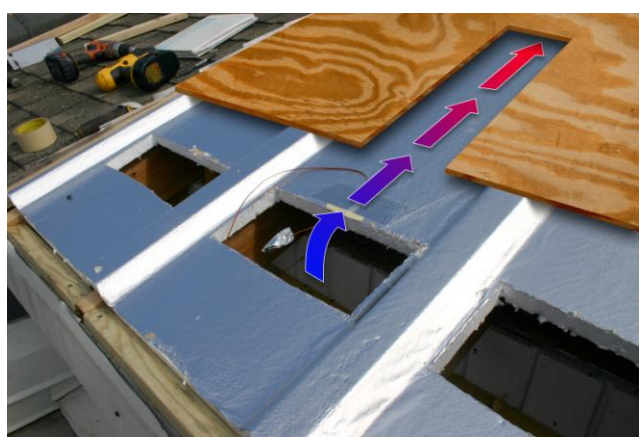

Figure 3. The air in the 1-inch air space is heated as the shingles absorb solar energy. The hot air rises out the ridge vent, pulling in cooler makeup air from the soffit and attic.

1. Insulated and ventilated shingle roof. The new design for a shingle roof assembly has a profiled and foil-faced EPS insulation that fits over the rafters. Its design (Fig. 3) uses convection, radiation shields, and insulation to retard the flow of heat into the attic. It uses a unique soffit opening to pull the coolest air from the soffit and attic into an inclined air space, which further enhances its ability to decrease heat transfer crossing into the attic. A ridge vent

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expels the hot air from the space back to the outdoors. The ventilation design keeps the air intake internal to the attic, which eliminates any threat of burning embers entering the inclined air space, which makes this system adaptable to regions susceptible to wildfires. This system is manufactured and marketed in Texas and is available to the general public. The design saves about $120 per year as compared to a 1500-sq-ft home built in Miami to IECC (2006) standards (Table 1). The yearly cost savings are estimated at about $190 for Austin and about $260 for Atlanta.

Table 1. The simulated yearly cost of energy attributed to roofs and attics for new homes.

(The EIA (2008) average annual bill for Florida is $1,570.)

Location	New house[1] compliant with IECC 2006	IECC house[1] with cool color shingle	New design 1— EPS insulation	New Design 2— Cool color metal	New Design 3 — High-profile tile
	$ per year per square (100 sq ft)				
Miami	$8.54	$8.14	$0.66	$0.71	$0.64
Austin	$15.04	$14.73	$2.31	$2.51	$2.41
Atlanta	$22.05	$22.04	$4.67	$4.97	$4.84

[1] IECC-compliant home has ducts in attic. Ducts wrapped with R_{US}-8 (R_{SI}-1.4) insulation; duct leakage 4%.

Design 1: Foil-faced 1-in. (0.0254-m) EPS insulation fitted between roof rafters; ventilation from soffit and attic to the inclined air space; radiant barrier in attic, 2 low-e surfaces in air space.

Design 2: Cool color metal roof offset-mounted from roof deck 1½-in. (0.038-m); low-e surface in inclined air space covers PCM membrane; radiant barrier in attic.

Design 3: Peel-and-stick, ice-and-water guard membrane, 1¼ -in. (0.032-m) EPS insulation above deck with high-profile tile; spray foam adhered EPS foam and tile to roof deck (no fasteners required).

2. Offset-mounted metal roof. A painted metal roof (Figure 4) exploits the use of cool color pigments. The roof is offset-mounted from the roof deck to provide an above-sheathing ventilation path for carrying heated air away from the attic space. The paint finish is warranted to not fade for 30 years, and field studies have shown it to be impervious to climatic soiling even after 30 years of weathering. The system also incorporates PCMs placed just below the sheathing on the roof deck. These materials store the heat from the sun during the day and release that energy during the cooler nights, so that less heat penetrates into the attic or house. Field studies showed the design to perform just as well as the new tile roof design; however, ASTM C 1340-04[1] does not include the effects of the PCM tested in the field. Compared to an IECC-

Figure 4. Offset-mounted metal roof painted with cool color pigments field tested and benchmarked against computer tools developed at ORNL.

[1] The response factor approach used by ASTM C1340 cannot be used to simulate transients due to PCMs. Future work will use Energy Plus, which has algorithms to model the effect of the PCMs.

compliant, 1500-sq-ft house, this design saves about $120 per year in Miami, $190 in Austin, and $260 in Atlanta (Table 1).

3. Self-ventilating, insulated, clay tile roof. A high-profile clay tile with cool color pigments was also tested (Figure 5). The assembly has a fully adhered peel-and-stick membrane on the deck and 1¼ inch of EPS foam board that is attached by spray adhesive to the membrane, and in turn the concrete or clay tile is adhered to the EPS foam board using a polyurethane spray adhesive. The EPS foam board is grooved on its underside to enhance its attachment and to provide a drainage plane for condensate to run off the roof. The peel-and-stick membrane is waterproof and is firmly adhered to the oriented strand board (OSB) deck to seal it from air and moisture infiltration. This assembly is available on the open market from a major manufacturer of building products. The assembly passed roof-attachment testing in Dade County, FL. In field tests conducted under a user agreement at ORNL, the attic air temperature never exceeded the outdoor air temperature during east Tennessee's hot summer months. The mass of the clay tile works like PCMs, storing the sun's energy during the day and releasing it as night-sky radiation later on at night. The assembly's performance was almost the same as the painted metal assembly, and this is an excellent selection for the hot and dry climates in the southwest.

Figure 5. High-profile clay tile adhered to EPS insulation using a polyurethane foam adhesive.

Building America's best practice calls for R_{US}-50 (R_{SI}-8.8) attic floor insulation and for the ducts to be located in the conditioned space (BA 2003). That best practice reduces the energy loss through the attic to a very small amount. The integrated roof designs described here are able to reduce that energy loss by another 50% (see Appendix A, Fig. A8).

4. CONVENTIONAL PRACTICES FOR SAVING ENERGY — RETROFIT APPLICATIONS

Conventional best practices are often the best choice for homeowners who want to save energy and lower their energy bills. This section covers measures that homeowners and builders will want to consider first when contemplating roof and attic retrofits. The attics of the homes used to estimate these savings, which represent those built between 1980 and 1990, have R_{US}-15 (R_{SI}-2.6) or less insulation on the attic floor and at best R_{US}-5.5 (R_{SI}-0.97) insulation wrapped around leaky ducts operating in the attic (in compliance with the ASHRAE 90 standard published in 1980). Air leakage of the ductwork is unknown; however, for demonstration purposes, simulations assumed air losses of 10% of supply airflow for uninspected ductwork and 4% leakage for inspected, well-installed ductwork (Cummings et al. 1990; CEC 2005).

4.1 Renovated Ducts in the Attic

Table 2 compares the energy performance of the roof and attic of a home built according to ASHRAE 90 (1980) standards (Table 2, line 1) to retrofitted roof and attic systems. Repairing the leaks to the ducts

and the attic floor will net savings of about $8.2 per year per 100 sq ft ("square") of the home's footprint (compare row 1 to row 2 in Table 2).

4.2 Ceiling Insulation

With the HVAC ducts and attic floor leaks repaired, add insulation to at least IECC R_{US}-30 (R_{SI}-5.3), which will increase savings to $11.1 per square (line 3). The incremental cost for the added R_{US}-15 (R_{SI}-2.6) insulation of $13.2 per square (BNI 2009) when divided by the incremental cost of saved energy ($11.1 – $8.2) yields a payback of about 5 years for adding the R_{US}-15 (R_{SI}-2.6) insulation.

4.3 Cool Color Shingles

F.W. Dodge (2002) reported that about 85% of homes in the United States have replaced existing worn-out roofs with asphalt shingles. Simulations for a home in Miami with cool color shingles on the roof (Table 2, Line 4) show a reduction in the cooling load but also a slight increase in heating load, which results in a net annual savings of just $0.65 per square. Attics with code levels of floor insulation will exhibit low savings. In Atlanta or Austin the net savings for a cool roof are respectively $0.10 and $0.50 per square, assuming R_{US}-30 (R_{SI}-5.3) on the attic floor. The cost premium for cool color shingles according to local distributors installing the product is about $50 per square (Mullenax 2010). Therefore, there is no positive payback for homes having code levels of insulation.

Table 2. Simulated heat transfer, energy costs, and energy savings from roof and attic retrofits in Miami, FL. [1]

Roof		Attic[2]			Duct system		Load[3] due to roof and attic		Roof and attic annual energy costs		What you save
ID	Assembly	Floor R_{US}-value	Floor air leakage	Radiant barrier	R_{US}-value	Air leakage	Cooling (kWh/sq)	Heat (kWh/sq)	Cooling $/sq	Heating $/sq	$/sq /year
1	Conventional asphalt shingle	15	10%	No	5.5	10%	171.51	11.39	$21	$1	
2	Renovated duct and attic	15	0%	No	8	4%	110.59	6.96	$14	$0.9	$8.2
3	Add floor insulation	30	0%	No	8	4%	88.27	5.86	$11	$0.7	$11.1
4	Cool color shingle (SR 0.25)	30	0%	No	8	4%	83.07	5.90	$10	$0.7	$11.8
5	Attic radiant barrier	30	0%	Yes	8	4%	67.74	5.91	$8	$0.7	$13.7
6	Sealed attic[4]	15	0%	No	8	4%	76.39	4.26	$10	$0.5	$12.8

[1]Comparison is to homes built in 1980 – 1990 to 1980 ASHRAE 90 standards (line 1) and having SEER-8.6, HSPF-11.2, 1990 equipment; assumes electricity costs of $0.1252/kWh, as estimated by Energy Information Administration (EIA 2008).
[2]Attic ventilation set at 1:300 with exception of sealed attic (line 6).
[3] Annual loads based on attic footprint of 1539 sq ft (143 m^2).
[4] Roof deck is 2 × 6 rafter construction sealed with 5½ in. of low-density urethane spray foam insulation (R_{US}-20).

4.4 Radiant Barriers

One could opt to install a radiant barrier in the attic, and installing it on the underside of the roof rafters is recommended, if feasible, so that the foil acts as both a radiation shield and a channel for directing buoyant driven heat from the soffit to the ridge. The radiant barrier nets about $2.6 per square of added savings (subtract line 3 from line 5 in the "What You Save" column of Table 2). The radiant barrier increases savings by an estimated $4.4 per square in Austin and about $2.5 per square in Atlanta. The radiant barrier foil costs about $15 per square of material, and the labor to attach the foil directly to the underside of the roof rafters is estimated at $26 per square of coverage for a 4:12 pitch roof. Therefore,

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retrofitting the attic with a radiant barrier would cost about $42 per square of attic footprint, and the shield pays for itself in about 9 to 15 years, even with code levels of insulation existing in the attic.

4.5 Sealing the Attic

Sealing the roof deck and gables of an attic with spray polyurethane foam insulation has gained popularity among many builders and code officials. Often a sealed attic is made part of the conditioned space to help guard against unwanted moisture entering the space. The foam is sprayed between the roof rafters and over the gable ends of the attic to literally seal the attic. Simulations for Miami (Table 2) were run for R_{US}-20 (R_{SI}-3.5) low-density urethane sprayed between 2 × 6 rafters supporting the roof deck. Attic floor insulation was left at R_{US}-15 (R_{SI}-2.6). Results showed that the cooling and heating loads for attics sealed in this way were very similar to those for the shingle roof with code level of floor insulation and radiant barrier in this hot climate (compare loads for line 5 and line 6 in Table 2). The material and labor cost for sealing an attic is estimated at about $0.78 per square foot per inch depth of foam [R_{US}-4 (R_{SI}-0.70)]; a 2-in. depth costs $1.29 per square foot (BNI 2009; Faulkner 2010). Therefore, to fill the cavity made by 2 × 6 rafters would cost about $3 per square foot of coverage for a 5½-in. (0.14-m) depth of foam [R_{US}-22 (R_{SI}-3.9)]. The application yields savings of about $12.8 per square (Table 2, line 6). Annual savings are about $197 for a 1500-sq-ft home, and the total cost for foam material and labor amounts to about $5,000. Sealing the attic therefore yields a payback of about 25 years, which would not be acceptable to many homeowners.

5. USING NEW INTEGRATED ROOF DESIGNS IN HOME RETROFITS

The three prototype roof and attic assemblies on houses without HVAC energy losses through ducting in unconditioned attic space save roughly $200 per year per square (Table 3).

5.1 EPS Foil-Faced Roof Assembly for Retrofit Construction

ORNL field-tested the insulated and ventilated shingle roof assembly in retrofit construction. Retrofitting a roof with the foil-faced EPS assembly puts the EPS insulation in direct contact with the existing shingle roof. Here the EPS is foil-faced only on its top side. A builder would basically install a new roof on the existing roof by attaching furring strips to the existing shingle roof as a nail board to hold the EPS foam and new deck to the roof. It is foil-faced only on its top side to serve as a low-e surface facing into the inclined air space. The EPS insulation is profiled to provide a 1-in. (0.0254-m) air space. OSB with or without a foil facing can be placed on top of the insulation to provide an additional low-e surface. Just one low-e surface will eliminate 88% of the radiation crossing the inclined air space. The second low-e surface is optional; the two low-e surfaces lower the radiation heat transfer by about 92%.

A slot is cut near the eave just above the soffit vent into the existing shingle and old deck to provide make-up air from the soffit vent and attic space. Buoyant air moves up the inclined air space and creates a negative pressure at the eave, which pulls cool air from the soffit and attic to enhance thermal performance in the inclined air space. The design puts the opening to the air space within the soffit

Figure 6. Furring strips are nailed to the existing roof, and the EPS board with new OSB deck and shingles are attached on top of the existing roof. Vents are cut into the old roof deck just above the soffit.

enclosure, which helps block any burning embers from entering the space and thereby improves the fire protection design of the roof. The air heated in the inclined air space is rejected out a ridge vent.

Compared to a standard builder's house of 1500 sq ft, built to IECC 2006 standards (Table 3, line 1), the roof prototype with foil-faced EPS insulation (line 2) saves about $15.6 per square per year and lowers the utility bill by about $234 per year. Of the three prototypes, this one, which uses the insulation to reduce convection, conduction, and radiation through the roof deck, may be the most economical, although its costs is almost double the cost of a conventional shingle roof. Assuming a roof replacement would occur in any case, the incremental cost is about $100 per square for materials and labor. Labor and materials for the R_{US}-15 (R_{SI}-2.6) insulation cost about $100 per square, and sealing the attic floor costs about $450 ($30 per square). Therefore, the unique EPS sheathing pays for itself in about 15 years.

Table 3. Simulated heat transfer, energy costs, and energy savings from roof and attic retrofits in Miami, FL. [1]

Roof		Attic[2]			Duct system		Load[3] due to roof & attic		Roof and attic annual energy costs		What you save
ID	Assembly	Floor R_{US}-value	Floor air leakage	Radiant Barrier	R_{US}-value	Air leakage	Cooling (kWh/sq)	Heat (kWh/sq)	Cooling $/sq	Heating $/sq	$/sq /year
1	Conventional asphalt shingle	15	10%	No	5.5	10%	171.51	11.39	$21	$1	
2	Asphalt shingle	30	0%	Yes	8	4%	53.16	5.43	$7	$0.7	$15.6
3	Cool color metal	30	0%	Yes	8	4%	59.28	5.55	$7	$0.7	$14.8
4	High-profile tile	30	0%	Yes	8	4%	55.17	5.47	$7	$0.7	$15.3
5	Eliminate ducts	30	0%	No	NA	NA	24.05	1.27	$3	$0.2	$19.7

[1]Comparison is to 1980-1990 home having SEER-8.658, HSPF-11.22, 1990 equipment; assumes EIA (2008) electricity cost of $0.1252/kWh.
[2]Attic ventilation set at 1:300.
[3] Annual loads based on attic footprint of 1539 sq ft (143 m^2).

5.2 Cool Color Metal Roof

Painted metal roofing is capturing more and more of the residential and commercial market; however, painted metal can cost at least three times as much as a shingle roof, except in states that charge fees for the disposal of shingle debris in landfills. Metal roofs are durable and fade resistant and strongly resist wind uplift, and the metal is recyclable. If you like metal roofs because of their look, durability, or strength against gale-force winds, then consider a cool color metal roof. ORNL simulated steep-slope roofs fitted with a 1½-in. (0.0254-m) air space above the sheathing and observed that including a low-e surface placed in the inclined air space yields similar performance to the previously discussed shingle roof with radiant barrier (compare line 5 in Table 2 to line 3 in Table 3). Field testing showed that the addition of PCM to the metal roof assembly resulted in thermal performance very similar to the high-profile clay tile assembly (see Appendix, Fig. A4).

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5.3 Clay and Concrete Tile Roof Assembly

The thermal mass of clay and concrete tile makes these products an excellent selection for hot climates. The thermal mass of the tile acts as a capacitance and absorbs heat during the day and releases it at night as night-sky radiation. Field tests of concrete and clay tile were conducted for the tile industry and showed exemplary performance in a unique roof system (Table 3, line 4). A high-profile clay tile and a high-profile concrete tile were each placed on 1¼ in. (0.032 m) of EPS insulation attached to the roof deck using a spray polyurethane adhesive. The additional R_{US}-4.8 (R_{SI}-0.85) of EPS insulation under the high-profile tiles helped lower peak-day heat transfer by 85% compared to the control shingle roof. In fact, the heat transfer crossing the deck of the clay tile roof was the lowest observed of all tested tile roofs: deck heat flow dropped by 90% compared to that measured around solar noon for the control shingle roof on a hot August day in East Tennessee. (See Appendix, Fig. A3.)

Computations of the system simulated for Miami (Table 3, line 4) show that the high-profile, cool color, clay tile placed on EPS insulation reduces the cooling load by 70% of the IECC base assembly, saving about $15.3 per square, and therefore performs slightly better than the EPS foil-faced assembly.

The high-profile tile roof with EPS insulation on the deck and the painted metal roof both have cool color pigments, and each roof has its niche markets. Either is an excellent selection for hot climates. Installation cost for clay roofs is about $250 per square; concrete tile is about $200 per square. Installation cost for metal roofs can be as high as $700 per square. Therefore, consumers generally choose these roofs based more on aesthetic preference, durability, fire protection, and location than on cost.

5.4 Eliminating The Energy Waste From HVAC Ducts in Unconditioned Attics

The most cost-effective retrofits for an attic are repairing the leaks through the attic floor and in the HVAC ducts, adding insulation to the attic floor, and installing a radiant barrier inside the attic. However, eliminating the energy waste from running HVAC ducts through the attic saves a substantial $19.7 per year per square (Line 5 in Table 3). To accomplish the job dictates removal of the ducts, and possibly installation of a new ductless HVAC system such as the wall-mounted, mini-split heat pumps that are becoming more and more popular. A 2-ton mini-split system costs about $3,500 for equipment and the labor to install it. Labor and material costs for installing the R_{US}-15 (R_{SI}-2.6) insulation are about $1,300, and $450 ($30 per square) for sealing the attic floor. Taking these measures for a 1500-square-foot home would save about $300 per year and pay for a mini-split system, the insulation, and the sealing of the attic floor in about 17 years.

6. MAKE YOUR OWN ASSESSMENTS

Several energy savings calculator tools developed by ORNL are available on line to help homeowners and builders estimate savings from energy retrofits and building strategies. Go to the ORNL Building Technologies Research and Integration Center web page for a look at the various tools (http://www.ornl.gov/sci/roofs+walls/calculators/index.html).

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A new shareware tool, the Roof Savings Calculator (RSC), is commissioned under beta testing for use by the public. It is available at www.roofcalc.com/. The RSC tool focuses on the roof and attic, but also conducts whole-building simulations for more accurate results. Work progresses to benchmark the RSC tool against the multiplicity of roof and attic design strategies simulated for hot climates and your input is welcome to help improve the tool.

Future work will investigate roof and attic designs in cold climates, where the priority is limiting heat loss through the attic and cool roofs do not save energy. Efforts will continue to benchmark the RSC tool against field data, which will distinguish RSC from all similar whole-building energy calculators.

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GLOSSARY OF TECHNOLOGY OPTIONS FOR ENERGY-EFFICIENT ROOFS AND ATTICS

(this material will be used for linked pop-up boxes in the web version)

Thermal Insulation

Thermal insulation saves energy by providing effective resistance to heat flow through the building envelope, reducing heat gains and losses and the heating or cooling needed to maintain comfortable indoor temperatures. Insulation is rated in terms of thermal resistance, called R-value. The higher the R-value, the more effective the insulation is. The R-value of thermal insulation depends on the type of material, its thickness, and its density. In calculating the R-value of a multi-layered installation, the R-values of the individual layers are added together for the final R-value.

Thermal insulation being applied to the underside of an attic roof.

Thermal insulation can greatly reduce the amount of heat lost or gained through a roof system and may be used with other retrofitting techniques to gain maximum benefits. Adding insulation is often the first priority for homeowners. Because of its comparatively low cost, thermal insulation offers the best return on investment of many energy-saving strategies. Most local building codes require that buildings have a minimum amount of insulation. When determining how much insulation is needed, check with your town building official to make sure that you are satisfying their requirements.

Ventilation

Attic ventilation has been built into buildings for centuries in the United States and around the world. Ventilation helps to keep the attic cool in hot climates and can also prevent moisture accumulation. Air movement can carry moisture from a wet foundation through the envelope and into the attic, which may cause damage to the roof if the moisture isn't removed by venting. Venting is also proven to lower the temperature of dark roofs, which reduces cooling loads and can lengthen the service life of temperature-sensitive roofing materials.

Power ventilation is useful in very hot climates. Power vents are used to blow outside air through a ventilated attic and are typically controlled by thermostats to run only when the attic temperature is much hotter than the outside air. Power ventilation must be applied with caution in humid climates because of the moisture potentially carried into the attic by outdoor air.

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Above-Sheathing Ventilation

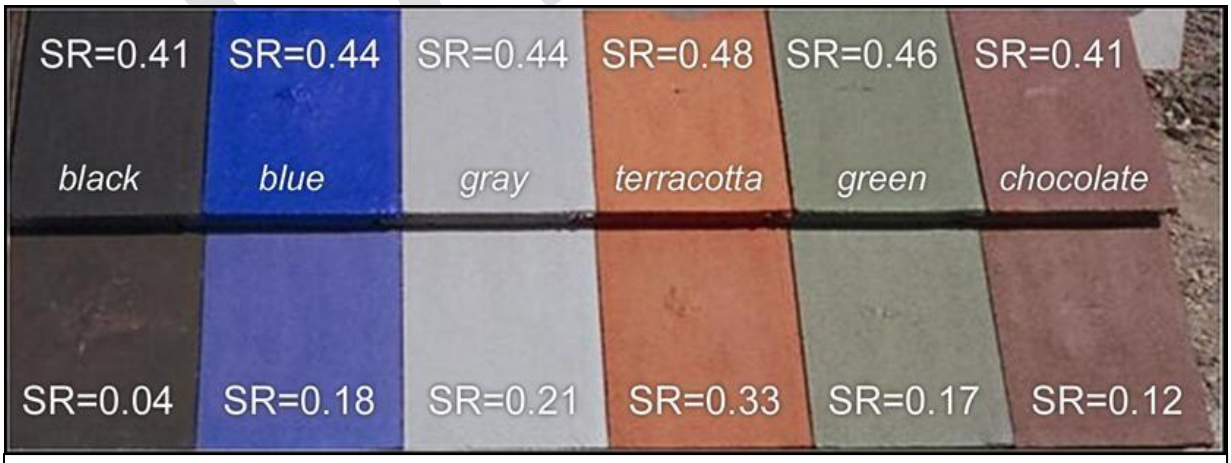
Above-sheathing ventilation (ASV) is applied by creating an inclined air space by installing battens or wood strips between the roof deck (the sheathing, or lower roof) and the waterproofing material (e.g., shingles) on the top. The extra air space provides a channel for air movement to removes heat and moisture from the lower roof. When sunlight strikes the top surface of the roof, this heating causes air to flow in this inclined air channel. At night, the airflow is reduced and the airspace acts as a thermal insulator to provide additional energy savings. Keeping the roof dry improves its durability and thermal performance.

Cool Roofs

Cool roofs use white or colored solar-reflective surfaces to make roof temperatures lower than those of traditional dark roofs, which strongly absorb sunlight and heat. White or special "cool color" roofs absorb less sunlight, stay cooler in summer, and transmit less heat into the building than dark-colored roofs. The "coolness" of a roof is determined by solar reflectance (sunlight reflected from the roof) and thermal emittance (the radiating efficiency by which a roof cools itself). Both of these properties are measured on a scale from 0 to 1; the higher the value, the cooler the roof.

Traditional dark roofs can reach 150°F or higher in the summer, but a cool roof under similar conditions could stay more than 50°F cooler. Some cool roofs cost no more and require no more maintenance than a traditional roof. On a clear day up to 80% of sunlight reflected from a cool roof can leave the Earth's atmosphere without warming the atmosphere. Most dark roof materials only reflect 5 to 20% of incoming sunlight, while light colored roofs typically reflect 25 to 50%. White cool roofs tend to reflect the most sunlight, but colored cool roofs still reflect far more energy than conventional dark roofs.

Cool roofs can reduce energy bills by decreasing air conditioning needs, improve indoor thermal comfort for spaces that are not air conditioned, and potentially extend roof service life. Cool roofs also benefit the environment by reducing local air temperatures, improving air quality, reducing global warming by reflecting more sunlight back into space, and reducing summer peak electric power demand by reducing cooling energy use in buildings.



Cool roofing materials come in a range of colors.

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Energy savings from cool roofs depend on the local climate, the amount of insulation in the roof assembly, energy prices, and the efficiency of the building's heating and cooling systems.

Most existing roofs can also be made into cool roofs by applying coatings and replacing certain elements with "cooler" elements. Cool roof coatings can also be applied to dark roofs. When installing a cool roof, it is important to consider the reflectance of different colors and surfaces to see which roof would provide the greatest savings.

Location of Heating, Ventilating, and Air-Conditioning (HVAC) Ducts

HVAC ducts are often installed in the attic, especially in warm climates, where many houses are built on slab foundations. Inefficiencies in air distribution systems are a major source of energy losses — an estimated 30-40% of the energy delivered to the ducts passing through an unconditioned space may be lost through air leakage, conduction, convection, and radiation of heat through the duct walls unless ducts are properly insulated and sealed. For the average home built in the 1980s, moderately leaky ducts in a well insulated attic can increase total air-conditioner energy use by almost 20%.

HVAC equipment is commonly found in attics.

In warmer climates, temperatures inside an attic space can exceed 150°F while conditioned air at 55°F is being sent through HVAC ducts for cooling. If the ducts are not well insulated, a considerable amount of heat can be conducted from the attic into the ducts, thereby warming the air that is delivered to the conditioned space. If the supply ducts are leaky, then some of the conditioned air is wasted entirely in the attic space. Similarly, if return ducts are leaky, hot air can leak into the ducts, raising the temperature of the air returning to the air conditioning coil from the living space.

Heat losses and gains through conduction and leakage may significantly compromise the efficiency of an air distribution system located in an unconditioned space, especially an attic. Proper installation of ductwork and attention to connection and insulation detail can substantially reduce problems associated with locating ducts in attics, but will not eliminate them.

Sealed Attics

Ventilation can be a great way to deal with humidity problems, but in hot and humid climates, vents can allow humid air into an attic, causing condensation of moisture on cold surfaces such as HVAC system ducts. Sealing the attic and eliminating exterior vents is a good way to exclude moist outside air from the inside, but the sealing must be done right or a dark attic can become a damp breeding ground for mold. Sealing the attic can also recapture the energy losses from the air distribution system.

While moving ducts out of the attic and into the conditioned space is difficult and costly, moisture condensation in attics can be eliminated in hot and humid climates by sealing the attic to prevent infiltration of outside air. With sealed attics, it is important to think about the placement and type of insulation that will be used. Remember to move the insulation to the underside of the roof instead of on the attic floor. Sealing the attic in with the rest of the house makes it an integral part of the conditioned space and leaves the roof available to vent while the rest of the spaces are tightly sealed off from unwanted outside air. Sealed attics also offer an easily constructed alternative for air leakage control for homes.

Eliminating leaks from the attic floor prevents attic heat from entering conditioned spaces below.

Builders are likely to place ductwork in attics because it is economically expedient and it provides satisfactory cool air distribution for hot climates. Besides the energy loss due to heat transfer through duct walls and air leaks through duct connections, additional energy losses occur through all the openings through the building envelope made to connect the ductwork to the conditioned space. If ductwork is leaking inside the conditioned space, the leaked air is not lost as it would be if the ducts were placed in the attic. Simulation results show that improvements to ductwork should be a priority in any home (re)design. Simply placing ductwork inside the conditioned space yields relatively high energy and cost savings.

Radiant Barriers

Radiant barriers are thin sheets or panels with a bright metal foil on at least one surface. There are also special coating products that can act as radiant barriers that are preinstalled on roof sheathing materials. They are typically installed on the underside of the roof. Many radiant barrier products are available for use in roofs to reduce the flow of heat into a building. When used in attics, radiant barriers can significantly drop the cooling load in summer when compared to a conventional roof with no radiant barrier. Radiant barriers, as their name implies, stop the flow of radiant energy from the underside of the roof into the attic space. The energy that would have otherwise warmed your house will instead

This radiant barrier is attached to the underside of the roof and the shiny surface is visible on the inside of the attic. Proper installation and orientation of radiant barriers is necessary to achieve the best results.

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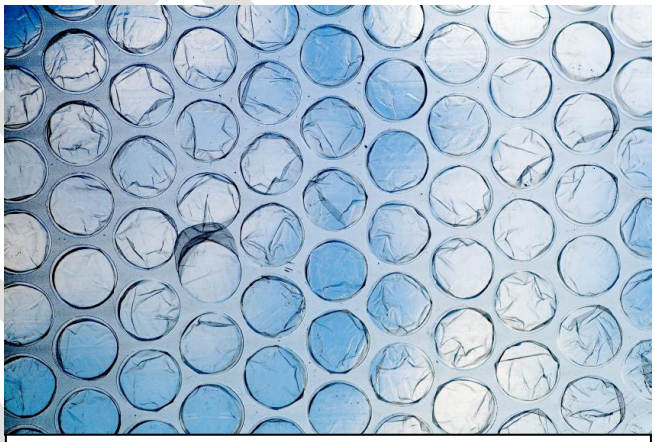
increase the temperature of the roof surface so that the heat can escape to the outdoors. This is why radiant barriers are most useful and cost effective in hot climates. All materials give off, or emit, energy by thermal radiation. The amount of energy emitted depends on the surface temperature and a property called the thermal emittance. The thermal emittance is a number between zero and one. The lower the thermal emittance, the more effective will be the radiant barrier material.

The energy savings attributable to radiant barriers are calculated using a computer model. The savings estimates are most sensitive, in order, to climate zone, location of ductwork, condition of ductwork, and effectiveness of roof covering. In hot climates, radiant barriers provide the best opportunity for a good return on investment.

Phase Change Materials

Phase change is a simple concept that can also be applied to save you money when (re)designing your home. Many materials, such as water, change from one phase to another, going from solid to liquid to gas. Phase change materials (PCMs) have melting temperatures that are selected to help you take advantage of the difference between day- and night-time outdoor temperatures.



Phase-change materials incorporated into roof designs can absorb heat during the hottest part of the day to keep it from entering the attic.

Due to its ability to store energy, the PCM maintains room temperature within the human comfort zone for long periods of time even after the heating or cooling system is turned off. Studies have shown that PCM can yield up to 35-40% peak cooling load reductions.

By melting during hot days and freezing during cooler nights, phase change material stores energy until it is ready to be used in your home (in the form of heat during winter) or released back into the environment (during cool summer nights). This increases comfort by decreasing the frequency of the HVAC system to turn on and off due to the temperature balance that PCMs can maintain. If the HVAC system is still needed, the demand can be lessened significantly and shifted to an off-peak electricity period. In hot climates with cooler nights, PCMs are extremely attractive, providing free cooling by releasing the day's heat to the cooler night-time environment. PCMs are still relatively new and have been incorporated into only a few building components.

Vapor Retarders and Airflow Retarders

Vapor retarders and airflow retarders can be used to control the movement of moisture and air into a building. They function differently but often times a single component may serve both functions. Many moisture and condensation problems are caused by excessive leakage of outside air into the building

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envelope. Airflow retarders and vapor retarders are both important, especially when dealing with moisture control.

Vapor retarders take up very little space within the building envelope, but installing them in the correct location is important and depends on climate and construction type. Vapor retarders, if used, must be placed on the warm side of roof construction to stop the diffusion of water vapor to the colder parts of the construction where condensation may occur. In hot climates, the vapor retarder should be placed on the outside of the roof sheathing and insulation. Without a vapor retarder, water vapor that happens to enter the construction can flow to the inside of the building and be removed by the air conditioning system instead of accumulating in the walls and roof. Vapor retarders also help protect insulation by keeping it dry, reducing the cooling load and preventing structural damage to insulation due to rotting, corrosion, and expansion of freezing water.

Air leaking into a building envelope can carry a significant amount of moisture and can have a huge impact on the roof's energy performance. Like vapor retarders, airflow retarders provide protection from excessive moisture accumulation in the building envelope and can also reduce energy consumption by eliminating the flow of unconditioned air from the outside into the roof. In all climates, airflow retarders are best placed on the outside of the envelope assembly. The effectiveness of an airflow retarder can be reduced immensely by even the slightest openings in the material. Openings can be caused by poor craftsmanship during installation, poorly sealed edges and improper design among others. Since the air retarders resist airflow, they must also withstand pressures exerted by external forces such as wind, and be protected during construction when damage can easily occur.

Many building codes have requirements associated with vapor retarders.

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APPENDIX: REVIEW OF FIELD DATA FOR NEW ROOF AND ATTIC DESIGNS

A combined experimental and analytical study documented the thermal performance of cool roofs in combination with other roof and attic strategies. Cool color roofs are a first line of defense against heat transfer penetrating the conditioned space. However, radiant barriers, above-sheathing ventilation, low-emittance (low-e) surfaces in an inclined air space above the roof deck, insulation, and conventional and advanced thermal mass (i.e., phase-change materials, or PCMs) can all potentially enhance cool roof and attic performance.

The field data were used to validate the attic simulation model ASTM C 1340 (2004). Ceiling insulation in the test assemblies was purposely set low at RUS-5.1 $h \cdot ft^2 \cdot {}^\circ F/Btu$ [RSI-0.9 $m^2 \cdot K/W$] to help reduce the experimental uncertainty in measured heat flux. Hence, the discussions of field data in this Appendix focus on the measured heat flux crossing the roof deck of the attic, and simulations provided in the Design Guidelines are for computed heat flux crossing the attic floor and the subsequent energy consumption associated with attics having code-compliant levels of insulation.

Clay and Concrete Tile Field Data

Concrete and clay tile roof and attic assemblies were field tested at ORNL to assess the effects of cool color roofs, thermal mass, and placement of batten and double-batten systems under the tile (Fig. A1). A clay tile was manufactured with cool color pigments; its measured solar reflectance was 0.54 and its thermal emittance was 0.90, abbreviated herein as SR54E90. Two medium-profile concrete tiles were coated in the field with pigments boosting solar reflectance from 0.08 for the conventionally painted tile to 0.40 for the coated tile. Salient features of the different tile roofs are provided in Fig. A2.

(8) (7) (6) (5) (4) (3) (2) (1)

Figure A1. Field-testing of clay and concrete tile roofs on ORNL's Envelope Systems Research Apparatus. Pictured test roofs:

1) Medium-profile concrete on double battens (SR10E93)
2) Medium-profile concrete fastened directly to deck (SR37E93), infrared-reflecting (IRR) coating
3) Medium-profile concrete on battens (SR37E93), IRR coating
4) Flat concrete tile fastened directly to deck (SR13E83)
5) High-profile concrete tile on battens; terra-cotta (SR34E83)
6) High-profile concrete tile; fastened by spray foam to deck; splotchy terra-cotta (SR26E86)
7) High-profile concrete tile; fastened directly to EPS foam; splotchy terra-cotta (SR26E86)
8) High profile clay tile fastened directly to EPS foam (SR54E90), IRR pigments

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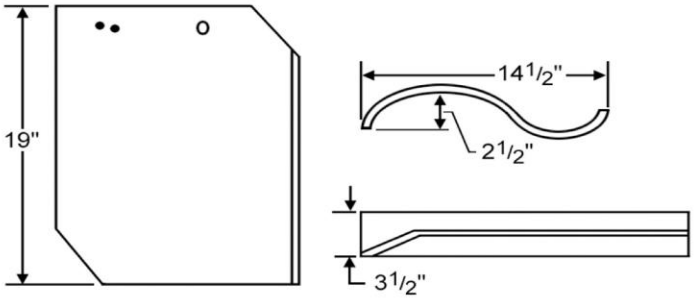
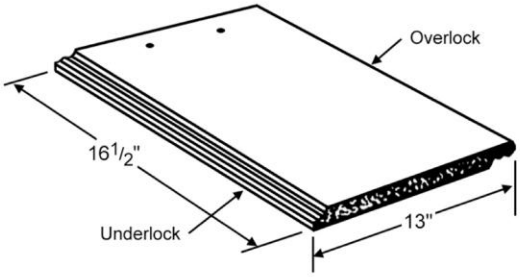
High profile Clay (SR54E90) Direct-to-EPS foam

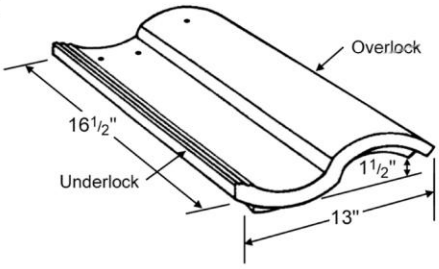


Flat Concrete (SR13E83) Direct-to-Deck



High profile Concrete (SR26E86)

- Direct-to-EPS foam
- Spray foam to deck
- On Battens



Medium profile Concrete

- (SR37E93) Direct-to-Deck
- (SR10E93) Double Batten
- (SR37E93) Batten

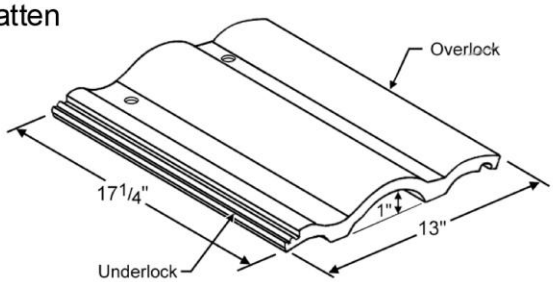


Fig. A2. Schematics and descriptions of tile roofs tested by ORNL.

High-Profile Tile

A high-profile tile with conventional terra-cotta color pigments (SR34E83) was tested on nominal 1 by 1 wood battens. The terra-cotta tile slightly outperformed all medium-profile tile configurations (Fig. A3). Two other roofs — one with high-profile concrete tile having a splotchy terra-cotta finish (SR26E86) and the other with a high-profile clay tile with cool color pigments (SR54E90) — were each placed on 1¼ in. (0.032 m) of expanded polystyrene (EPS) insulation adhered to the deck using a spray polyurethane adhesive . The additional R_{US}-4.8 (R_{SI}-0.85) of EPS insulation under the high-profile splotchy terra-cotta tile helped lower peak-day heat transfer by 85% of that measured for the control shingle roof. Further reductions in deck heat transfer were observed with the clay tile because its solar reflectance was double that of the splotchy terra-cotta tile. In fact, the heat transfer crossing the deck of the clay tile roof was the lowest observed of all tested tile roofs: deck heat flow dropped by 90% of that measured around solar noon for the control shingle roof on this hot August day (Fig. A3).

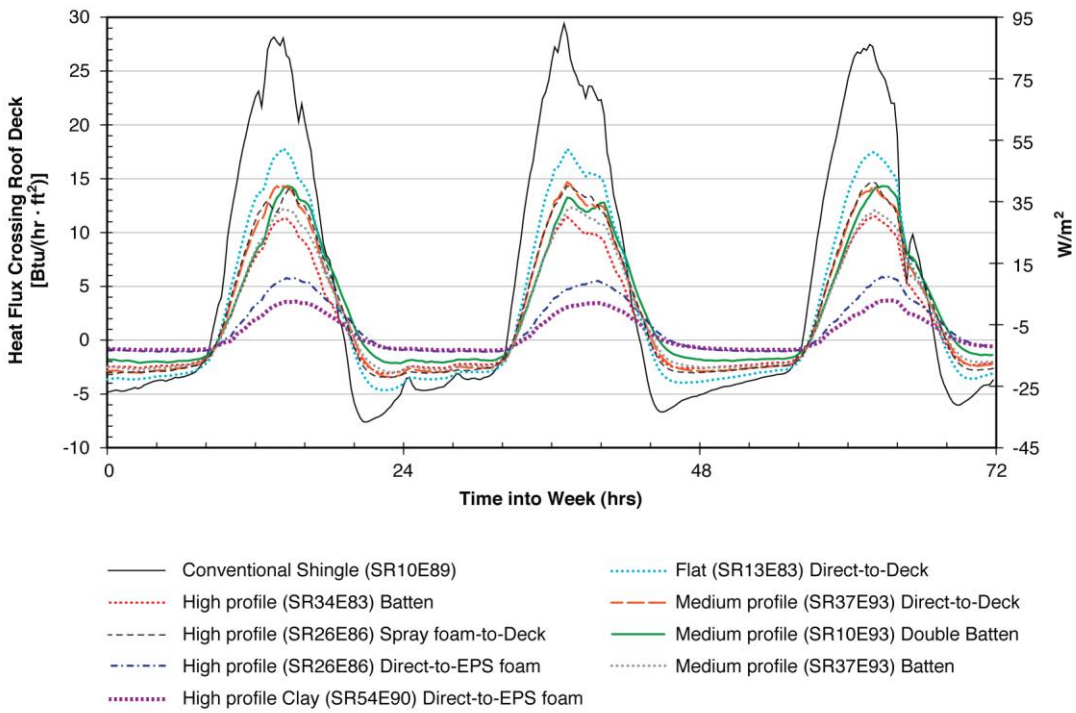


Figure A3. Field data for the heat flow crossing the roof deck for attic assemblies having concrete and clay tile roofs. August 2007 data benchmarked against AtticSim.

Computations using AtticSim deduced that the high-profile clay tile placed on 1¼ in. (0.032 m) of EPS insulation is about R_{US}-8.9 (R_{SI}-1.6), of which the above-sheathing ventilation is estimated to contribute about R_{US}-2.7 (R_{SI}-0.48) or roughly 30% of the total resistance of the R_{US}-8.9 (R_{SI}-1.6) deck. In contrast, the asphalt shingle roof deck (i.e., the control roof) is about R_{US}-1.8 (R_{SI}-0.32).

Metal Roofing Field Data

Miller, Wilson, and Karagiozis (2006) field tested stone-coated metal roofs on adjacent attic test assemblies on ORNL's Envelope Systems Research Apparatus similar to the assemblies used for testing tile. A conventional dark-gray stone-coated metal shake (SR08E90) and a light-gray metal shake (SR26E90) were tested on identical double-batten constructions (air space of ¾ in. [0.019 m]). The dark-gray metal shake and the control shingle have almost identical solar reflectance and thermal emittance characteristics, yet the heat flow crossing the roof deck of the dark-gray shake was just 70% of the heat flow crossing the roof deck of the control shingle (Fig. A4). The 30% reduction in heat flow was caused by the thermal resistance of the air space due to convection occurring in the air space, and in part by the low emittance (0.35) of the underside of the stone-coated roof shake.

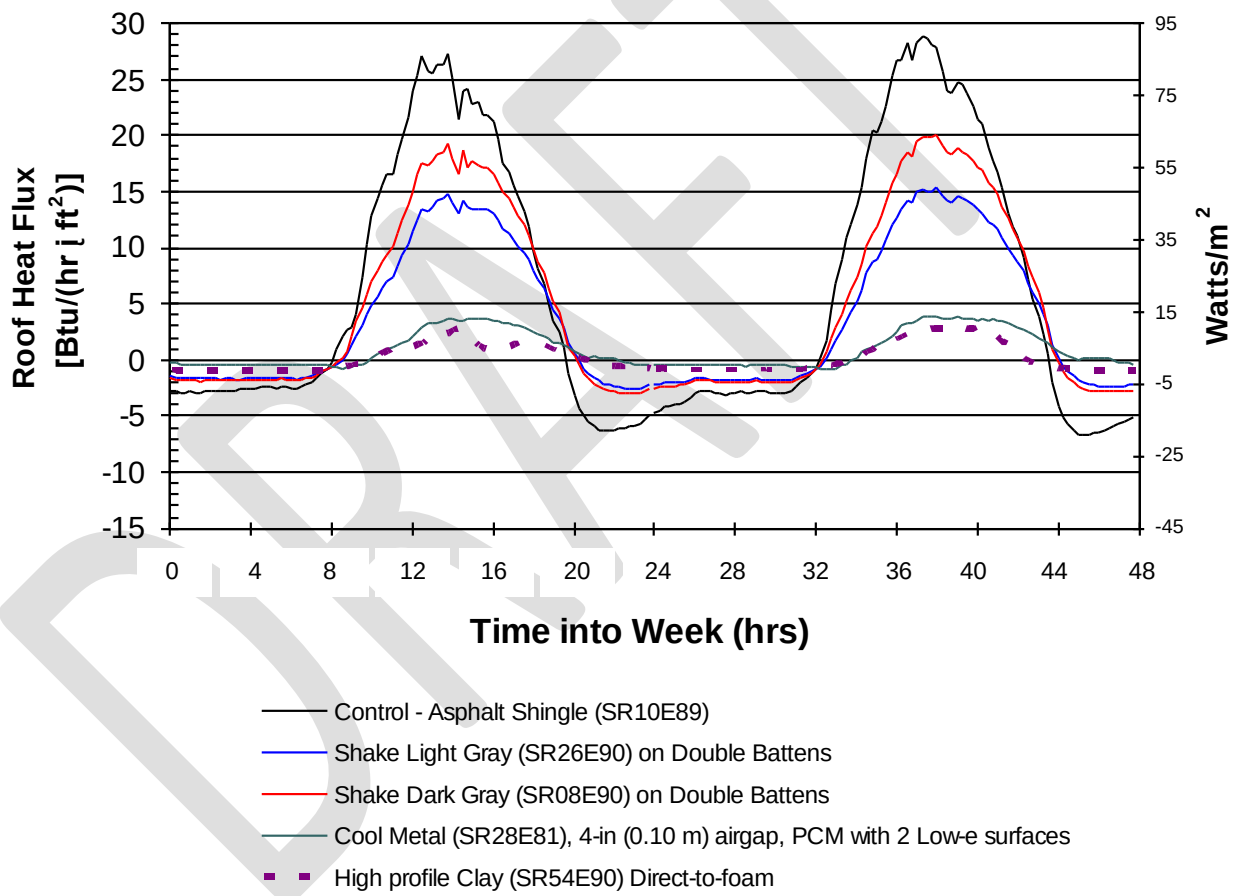


Figure A4. Heat flow measured crossing the roof deck of a direct-nailed shingle roof and stone-coated metal roofs with and without cool color pigments. Metal roofs installed on 1½ × 1½-in. (0.038 × 0.038-m) double-battens. The July 2005 field data are benchmarked against AtticSim.

Increasing solar reflectance from 0.08 to 0.26 caused the heat flow crossing the roof deck of the light-gray shake to be less than the heat flow crossing the deck of the dark-gray stone-coated shake (Fig. A4). Miller, Wilson, and Karagiozis (2006) also determined that the heat flow removed by above-sheathing ventilation of the hotter dark-gray stone-coated shake is more than double that removed by the light-gray shake. The hotter dark-gray stone-coated shake causes greater buoyancy-induced airflows;

therefore, the ventilation scheme is somewhat self-regulating. The darker the roof, the hotter the roof and the greater is the buoyant flow that carries heat away from the attic space. The stone-coated metal lacks the mass of a concrete tile, implying that above-sheathing ventilation and/or the effective thermal resistance of the air space significantly affect the amount of heat penetrating into the attic.

Miller and Kosny (2008) showed that a standing-seam painted metal roof (SR28E81) having a 4-in. (0.102-m) air space with two low-e surfaces facing each other across the space yielded almost identical heat transfer through the roof deck as observed for the best performing clay tile assembly shown in Fig. A3 and compared to the standing seam metal assembly in Fig. A4. The painted metal roof had two different fabric sheathings that contained PCMs in the amount of about 0.125 lb/sq ft (0.61-kg/m^2) of roof deck. The PCMs and the inclined air space with low-e surfaces acted as a buffer against heat loss during the winter. For three consecutive winter evenings, the surface and sheathing temperatures of the control shingle roof dropped below the outdoor air temperature as a result of night-sky radiation. Measures of the surface temperature for the painted metal roof indicated that it had the coldest nighttime temperature (Fig. A5); however, its sheathing temperature never dropped below the outdoor air temperature for the three consecutive winter nights in January 2007.

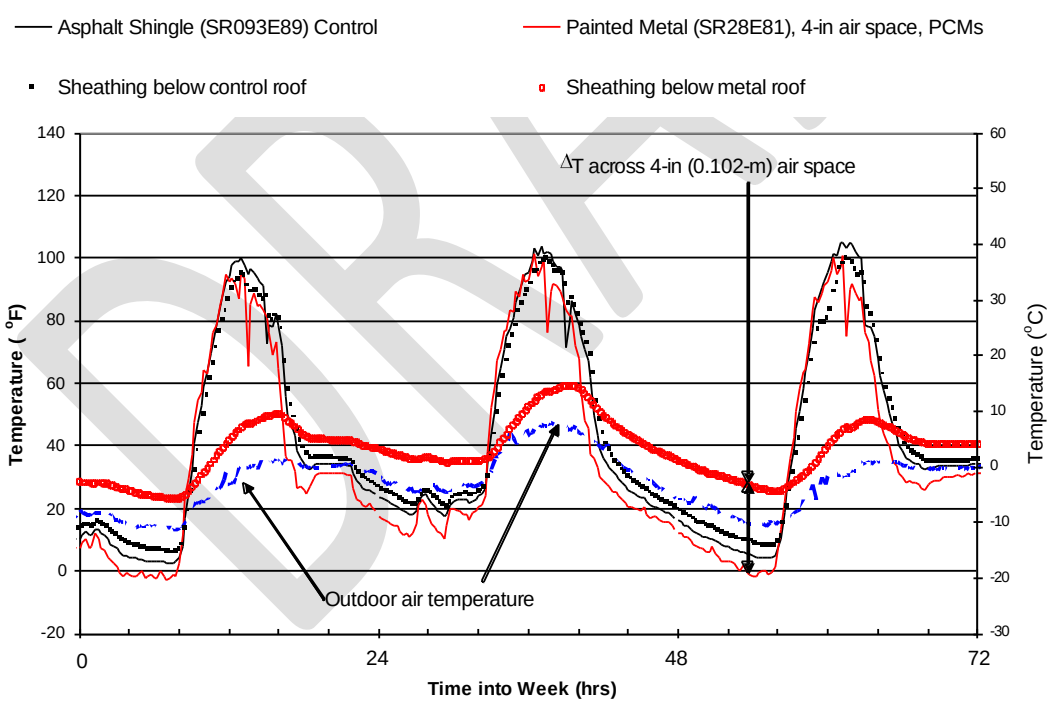


Figure A5. Temperatures of the roof sheathing and the underside of the roof cover for three consecutive winter days. Data for January 2007.

Hence, the design is retarding the loss of heat from the roof deck of the metal roof and attic assembly because of the air space, the low-e surfaces, and the PCM that releases heat stored during the daytime.

Subsequently, the prototype roof assembly significantly decreased variations in the attic air temperature, resulting in warmer nighttime temperatures during the winter and cooler daytime temperatures during the summer.

Asphalt Shingle Assemblies

Shingle roofs are by far the least expensive roofing option as evidenced by the predominance of these roofs across the country (Dodge 2002). Three roofs that have the same style of architectural shingle and the same solar reflectance and thermal emittance were field tested with and without a radiant barrier. The radiant barrier used in one assembly was a perforated, foil-faced, oriented strand board (OSB) with the foil facing into the attic. The other attic assembly used EPS insulation that is profiled to fit between roof rafters (Fig. A6). It is foil-faced on both sides to serve as a radiant barrier facing into the attic and as a low-e surface facing into the inclined air space. It has application for both new and retrofit construction. The EPS insulation is profiled to provide a 1-in. (0.0254-m) air space. An OSB with a foil facing is placed on top of the insulation to provide an additional low-e surface. A slot is cut near the eave just above the soffit vent to provide make up air from the soffit vent and attic plenum (Fig. A6). Buoyant air moves up the inclined air space and creates a negative pressure at the eave, which pulls cool makeup air from the soffit and attic to enhance thermal performance in the inclined air space. The design puts the opening to the air space within the soffit enclosure, which helps block any burning embers from entering the space and thereby improves the fire protection design of the roof.

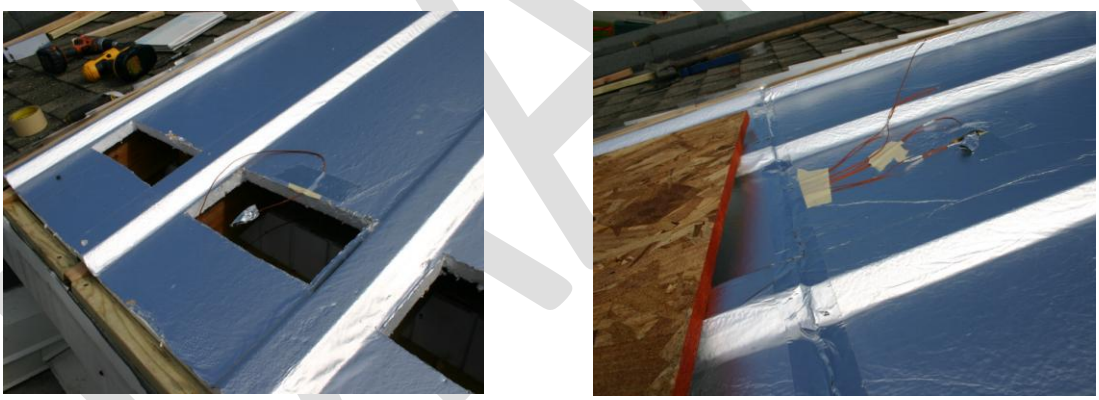
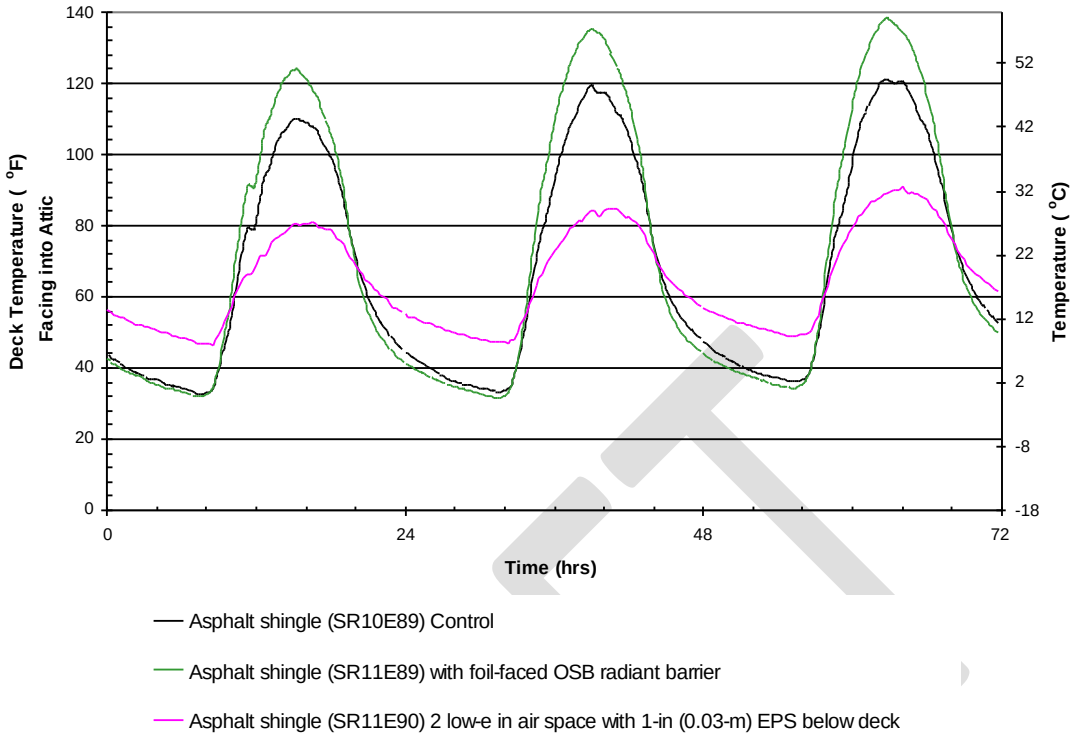


Figure A6. Setup of a prototype roof for new construction shows the EPS with vent slots and a perforated foil-faced OSB deck laid on top of the EPS to create an air gap. The slots in the EPS provide a passageway for air from the soffit vents and also from the attic space.

The conventionally pigmented asphalt shingle (SR11E89) with a foil-faced OSB radiant barrier dropped the peak day heat transfer by 20% of that measured for the control shingle roof (SR10E89) (Fig. A7b). The only difference between the two shingle roofs and their attic assemblies was the addition of the foil-faced, OSB radiant barrier. The surface temperatures of shingles were very similar; the control shingle roof reached a high of 160°F (71°C) at solar noon, and the other shingle roofs with radiant barrier were slightly higher but within two or three degrees. However, the underside temperature of the foil-faced OSB was 15°F (8.3°C) hotter than the underside deck temperature for the control (Fig. A7a), because the foil prevented the transfer of thermal radiation into the attic space.

(a)



(b)

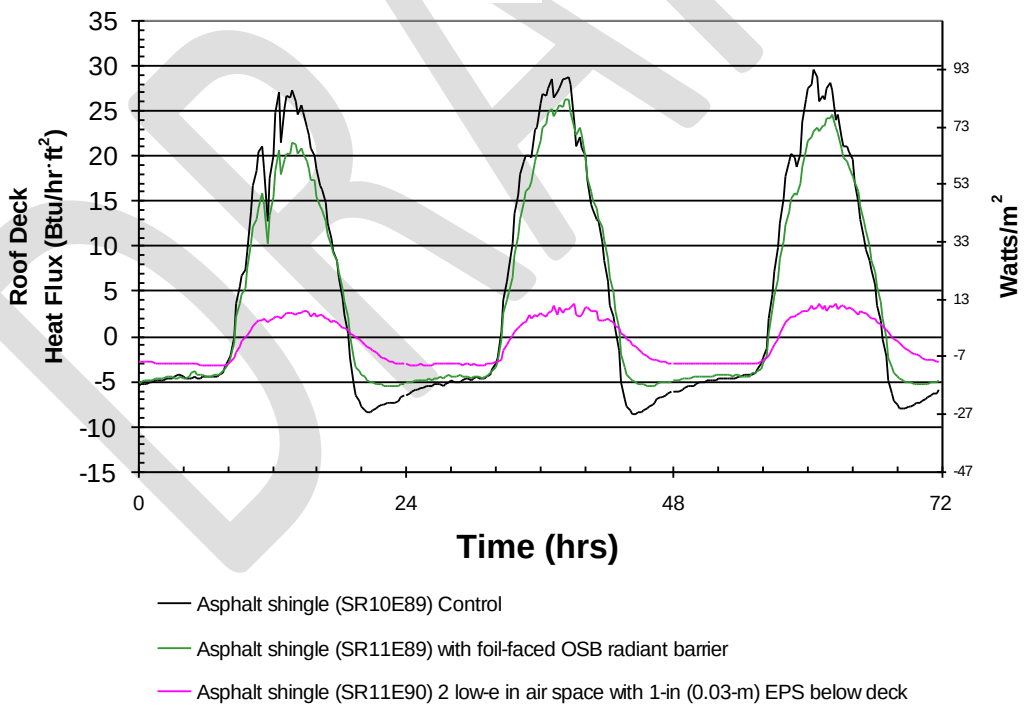


Figure A7. Temperature measured on the underside of the roof deck (a) and the measured heat flux crossing the roof deck (b).

By comparison, the attic assembly with the profiled and foil-faced EPS radiant barrier was 32°F (17.8°C) cooler than the control shingle roof around solar noon; it was 50°F (27.8°C) cooler than the foil- faced OSB (Fig. A7a). The lower temperature (which is measured at the underside of the foil-faced EPS insulation) is the result of the above-sheathing ventilation that carries heat away from the deck by natural convection to the ridge vent, the low-e surfaces in the air space, and the EPS insulation. Therefore, because heat transfers to the attic floor primarily by convection and radiation, the cooler temperatures for the EPS radiant barrier reduces the heat transfer crossing the attic floor (Fig. A7b). Performance of the prototype shingle roof is very similar to that observed for the best prototype painted metal roof and the high-profile clay tile with EPS foam. Their attic air temperatures did not exceed the outdoor air temperatures throughout the summer.

Thermal Simulations

The ASTM standard (ASTM 2004) used for estimating heat transfer through ceilings under attics was benchmarked against field data for the insulated and ventilated shingle roof. Simulations were made for Miami (Fig. A8) to judge the effectiveness of the new roof design against Building America's benchmark (BA benchmark), which calls for no ducts in the attic, the attic floor sealed, and R_{US}-50 (R_{SI}-8.8) insulation placed on the attic floor. An attic of 1539 sq ft (143 m^2) with a roof pitch of 18° was modeled that had a cool color shingle roof with solar reflectance of 0.25.

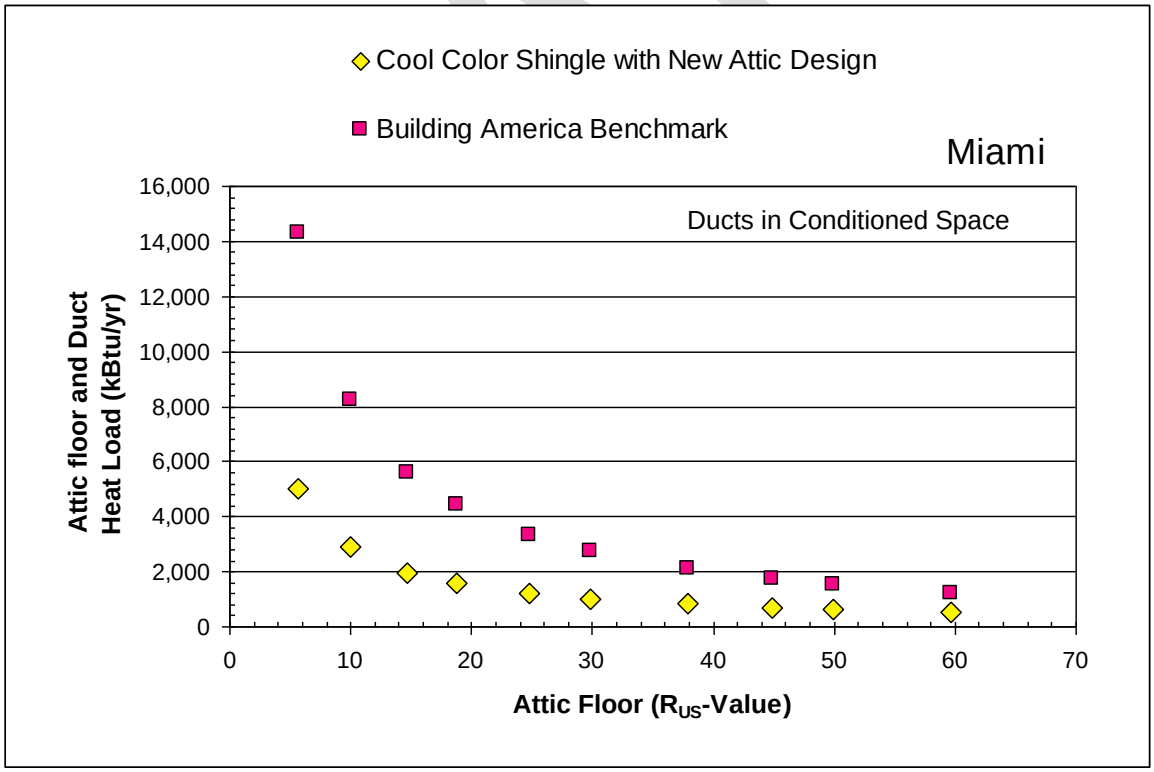


Figure A8. Building America Benchmark at R_{US}-50 (R_{SI}-8.8) is compared to the new roof design having an insulated and ventilated roof deck.

The cooling and heating season roof heat transfer were computed for the BA benchmark and for the new roof and attic design (Fig. A8). Increasing the level of insulation on the attic floor from IECC code level for Miami of R_{US}-30 (R_{SI}-5.3) to the BA benchmark of R_{US}-50 (R_{SI}-8.8) lowers the ceiling heat transfer by 45% of that computed for the code level of insulation. At R_{US}-50 (R_{SI}-8.8) there is only 1,500 kBtu/yr crossing the attic floor; however, the new attic design with R_{US}-30 (R_{SI}-5.3) shows heat flow of about 1,000 kBtu per year. Therefore, the integrated roof designs described here are able to halve the roof and attic energy losses.

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