Cool Roofs FOR Hot Climates

Steven Spencer, FSEC

Lighten the loads on home air conditioners with reflective roofing, radiant barriers, or better insulation and ventilation

by Danny Parker

Even in hot, sunny climates, it's common to see dark shingle roofs. That heat-absorbing choice carries a significant energy penalty: In sunny climates, heat gain through the roof makes up a major share of a house's cooling load.

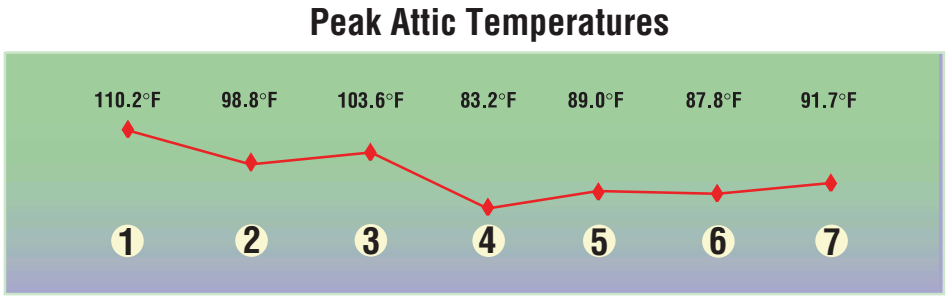
People try different strategies to limit heat gain through the roof. Extra ceiling insulation, extra ventilation, under-roof radiant barriers, and sealed attics with insulated roof decks can all help in certain circumstances. But research shows that the single most effective way to cut the cooling loads from a hot-climate roof is to make the roof reflective. There's a reason all those quaint little cottages in Bermuda have white roofs — they work.

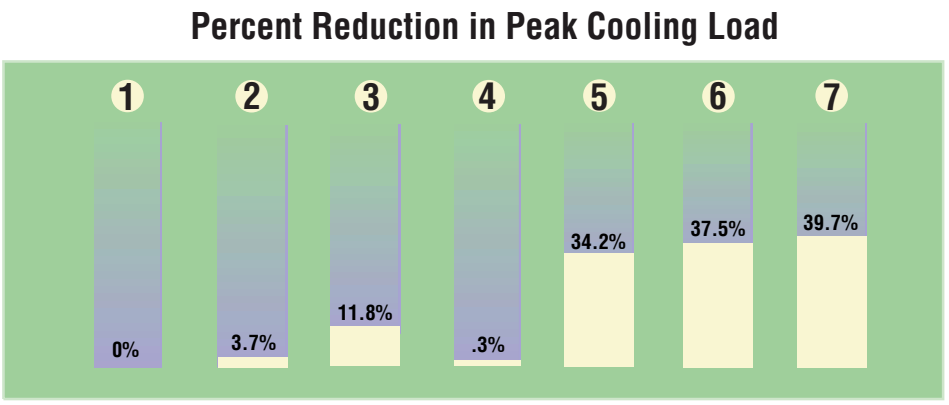
Reflective roofs work because they stop the rooftop heat before it ever gets going. The sun's rays hit the roof at the speed of light, and at the speed of light they bounce back into space. White or light-colored materials work best, but some new dark pigments reflect enough invisible infrared radiation to reject a lot of solar energy. And whether you're applying tile, metal, membranes, or even asphalt shingles, choosing a more reflective version seldom adds cost.

Let's look first at reflective roofs, then consider some of the other options for cutting heat gain through the roof.

Reflective Roof Savings

1. Standard dark shingles (base case)
2. Terra Cotta S-tile roof
3. Light-colored shingles
4. Standard dark shingles with sealed attic and R-19 roof deck insulation
5. White "barrel" S-tile roof
6. White flat tile roof
7. White metal roof





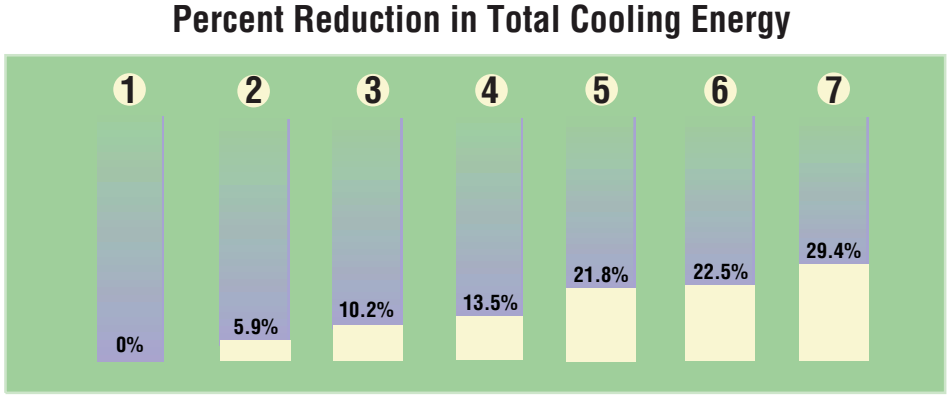


Figure 1. Florida Solar Energy Center researchers compared the air-conditioning power use of seven identically built houses with different roof coverings. Reflective roofing dramatically reduced total power use (bottom chart) and had an even greater effect on peak A/C power demand (middle chart). Insulating the roof deck and sealing the attic, without using a reflective roof, cut total energy use somewhat but did not reduce peak cooling loads noticeably.

Figure 2. Kynar roof coatings using spectrally selective pigments from Ferro Corporation allow Classic Roofs to produce aluminum and steel shingles in several dark colors that meet Energy Star minimums with solar reflectances better than white asphalt shingles. Tests indicate that the colors will sharply reduce solar heat gain through the roof.

Reflective Roofing

It's well established that reflective roofing materials can lighten the load on home air conditioners. When researchers at the Florida Solar Energy Center (FSEC), where I am a principal scientist, whitened the roofs of nine occupied homes in the summer of 1994, air-conditioning savings averaged 19%. We got even better information by comparing seven otherwise identical new homes with various roof types in a study sponsored by Florida Power & Light (FPL) during the summer of 2000 (see Figure 1, previous page). All these homes had R-19 ceiling insulation, but each had a different roof covering. Clearly, reflective roofing made a huge difference.

One house of the seven had an insulated roof deck, to keep the ductwork within the sealed, conditioned attic. That modification did save energy on average, but not as much as the reflective roofs — and it had little effect on peak loads.

Cool colors. Until recently, a roof had to be white to have high solar reflectance — something not every customer wants. But we now have tile and metal roofing systems made with "spectrally selective" paints, which absorb some colors of light in the visible range but reflect rays in the infrared and ultraviolet spectra that account for much of the sun's heat. These colors give designers more choices, while still saving considerable energy (Figure 2).

BASF Corporation's ULTRA-Cool metal-roof coatings (800/669-2273, www.basf.com), which use spectrally selective pigments from Ferro Corporation (216/641-8580, www.ferro.com), have a 38% reflectivity in colors that achieve only 25% reflectivity when made with standard pigments. And at least two companies, Classic Products (800/543-8938, www.classicroof.com) and MCA Tile (800/736-6221, www.mca-tile.com) now supply metal or clay tile in a range of colors with solar reflectance around 30%. Classic's "Musket Brown," for instance, reflects 31% — quite a bit better than a white shingle — while the same color in traditional paint would reflect only 8%.

Bare metal roofs. Unfinished galvanized or "tin" roofs are still fairly common in the hot Southeast. Galvanized steel is highly reflective when new, but its reflectivity soon drops as the zinc oxidizes; and the material also has low infrared emittance. The high absorptance and low emittance can combine to keep the roof blazing hot.

When FSEC researchers put a white coating on the ten-year-old galvanized steel roof of a retail strip mall, the roof's reflectance went from 30% to 77%. The average air-conditioning reduction in seven monitored shops was more than 24% (Figure 3, next page).

If you want unfinished metal roofing, Galvalume (an alloy of aluminum and zinc) is a much better cool-roof choice than galvanized steel, especially in mixed heating and cooling climates. Galvalume maintains its reflectance as it ages, and its low emissivity means it holds heat well in winter even though it reflects well in summer.

Tile Roofing

It's conventional wisdom that tile roofs are cooler than shingle roofs. To a small extent, that's true: S-tiles permit cooling airflow between the tile and the roof deck, and their thermal mass stores energy during the day and re-radiates it at night, instead of passing it all through to the attic.

But the color of the tile matters. For instance, we painted some dark gray tiles bright white at midsummer in central Florida in 1996, and we measured an 18% drop in space-cooling energy.

Shape appears to be far less important than color. In the seven-home

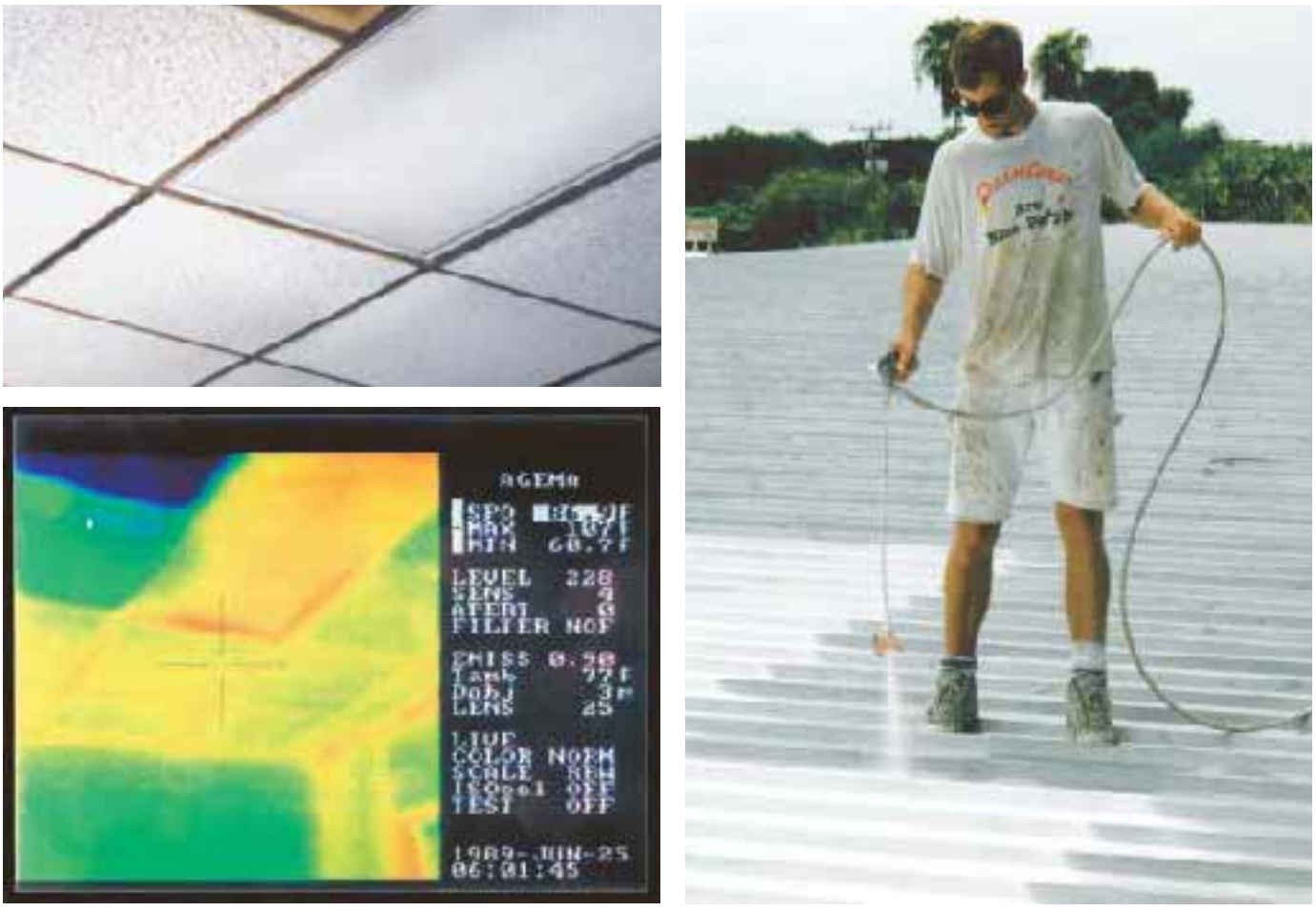


Figure 3. Unfinished galvanized steel roofs may look shiny when new, but they age quickly to become very nonreflective. The infrared thermal scan (above left) shows the drop ceiling (top) at a radiant temperature of almost 90°F under the metal roof of a strip mall building, despite insulation below the roofing. When FSEC researchers applied a reflective coating (right), the building's air-conditioning power use dropped 16%, and tenants reported improved comfort. One tenant even called to thank the landlord for fixing the air conditioner. (He hadn't.)

side-by-side study for Florida Power & Light, one of the homes had flat white tile, and another had white S-tile. We didn't see much difference — both roofs did about 20% better than the asphalt shingle roof. An S-shaped red tile roof in the same study was only 3% better than dark asphalt shingles.

In general, light-colored metal roofs will outperform tile in a hot climate like Florida's. At night, they actually radiate attic heat upward into the night sky, cooling the attic to below the ambient air temperature. The thermal mass of tile will not let attic heat escape so readily.

Radiant Barrier Systems

When a house has a dark, sun-absorbing roof, radiant barriers in the attic can cut heat gain and save energy. But they don't necessarily work in every case, and they're not always the best solution.

The basic radiant barrier is a layer of aluminum foil placed with its shiny side facing a clear air space. Placed under the rafters, aluminum's low emissivity prevents heat from radiating off the shiny surface onto the insulation below (Figure 4, next page). If the surface gets dirty, it won't work as well; that's why radiant barriers placed shiny side down, so dust can't collect, work better than radiant reflective material placed facing up.

There's now a range of material choices for attic radiant barriers, including radiant-barrier sheathing,

spray-applied low-emissivity coatings, and a wide variety of foil products. Homes with complex attic geometry and poor access to the space are not great candidates for a foil application, but a radiant barrier sheathing is easy to apply to any new house, and a spray-applied low-e coating such as Lo/Mit from Solec, Inc. (www.solec.org) makes a practical retrofit.

Energy savings. Radiant barriers are effective. Our research indicates that under-roof foil barriers reduce heat flow through the ceiling by 30% to 50% and can bring annual cooling electricity savings of 7% to 10% in the Southeast climate.

Radiant barriers also have a strong effect on peak loads for the air conditioner. A nine-home retrofit study we conducted for Florida Power Corporation found that radiant barriers reduced air-conditioning power use by 9% and cut afternoon air-conditioning peak loads by 16%. In a six-ton system, that's a ton of cooling. Attic temperature peaks dropped by about 8°F. Perhaps most important, indoor temperatures fell by an average 2°F — a boost for homeowner comfort.

But that was in the South. In colder climates, radiant barriers may create a risk of wintertime condensation, because some foil products also act as vapor barriers. For cool-climate homes, it's wise to search out a product that has high permeability as well as low emissivity (manufacturers can supply data sheets with perm ratings, emissivity ratings, and other useful information).

And be aware that if you have a reflective roof to begin with, a radiant barrier is overkill — and may even be counterproductive. Since the underside of a reflective roof does not get hot, a radiant barrier under the roof adds little benefit. On the other hand, by reflecting heat inward, the radiant barrier will impede the ability of the attic to radiate excess heat to the night sky.

Another word of caution: We installed our test radiant barriers in midsummer, so we could immediately measure the benefit. But the attics we worked in were dangerously hot — one of our people actually had to stop and get medical attention. It's much safer to install attic radiant barriers in the cool season, or at least during the early morning before the attic is baking hot.

Boosting Attic Ventilation

If the attic is too hot, is more ventilation a good idea? Maybe, but maybe not. Increasing the roof's passive air vents can reduce the cooling load, but it is usually one of the least effective options. The incoming ventilation air is hottest just when you need the cooling.

In retrofit work, we have seen increased ventilation bring a 5% reduction in building cooling loads. But in humid or coastal locations, it can also create problems: At night, the vents bring in moist outside air that may condense on duct systems.

Since passive vents work inconsistently, some people recommend powered ventilation fans. But the electric power used to operate the fan usually outweighs the air-conditioning savings.

FI-foil Corp.

Solec, Inc.

Figure 4. Radiant barrier foil under the rafters stops heat from radiating into the attic, because the foil will not emit heat radiation even when it's hot (top left and right, before and after). Lo/Mit low-emissivity silicone coating spray-applied to the roof underside (right) is a cost-effective alternative method.

And there's another drawback: Power attic ventilation can depressurize the house and cause gas water heaters to backdraft. It may also draw conditioned air out of the house into the attic, creating a further energy penalty.

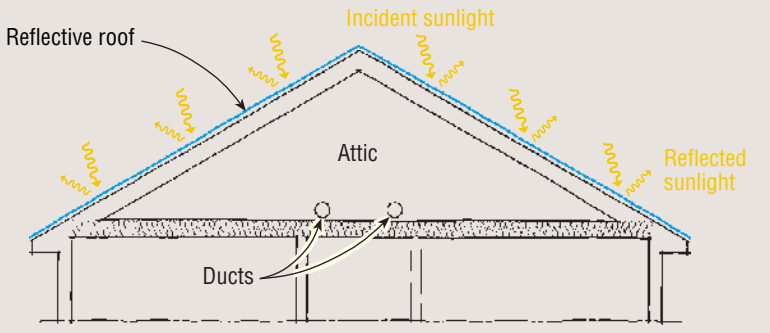
We've conducted tests of photovoltaic solar-powered attic fans in Florida. They run whenever the sun is shining, and we found savings of about 6% on electric bills. But at around $600 for the solar panels plus the fan, the savings don't really justify the cost in simple financial terms.

Added Insulation

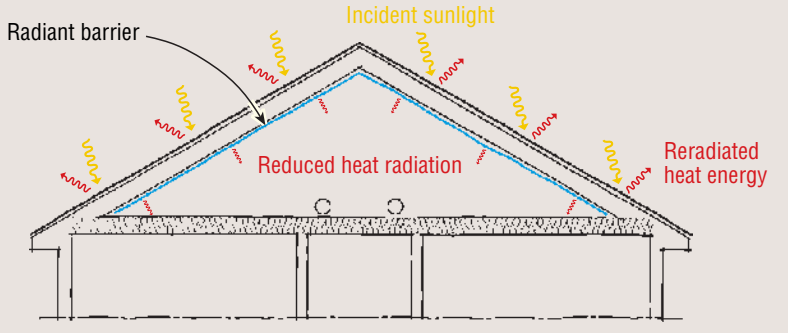
Added insulation is another option for cutting heat gain through the roof. It certainly works: One of our studies for a Florida utility showed that boosting ceiling insulation from R-19 to R-30 cut space cooling by about 9% in summer.

But your mileage may vary. Duct systems in many homes run through the hot attic and may be insulated to only R-4 or R-6. So the air conditioner is sending 55°F air into the duct in a space that can reach 130°F on a hot day. That's a temperature difference of 75°F, across just an R-6 insulated duct wall — much greater than the 20°F difference you might see from indoors to outdoors across an R-11 or R-19 build-

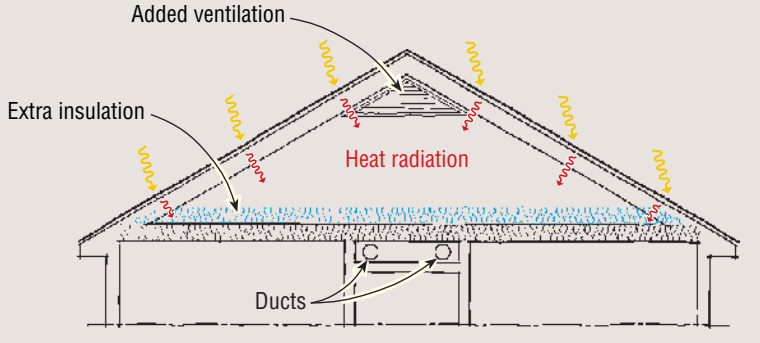
Options for Stopping Rooftop Heat Gain



Reflective Roof



Radiant Barrier



Extra Insulation, Ducts Under Ceiling

Field research at the Florida Solar Energy Center (FSEC) has found several effective ways to limit rooftop heat gain in sunny conditions. Using a highly reflective roofing material (top) is the simplest and most effective: It stops the sun's energy before any heat is absorbed, so that even the roof sheathing and framing stay cool. If the existing roof is dark colored or the customer prefers a darker roof, heat can still be blocked by adding a radiant barrier foil just below the roof deck (middle). Savings from this method are roughly comparable to the saving achieved with reflective roofing; however, some conductive heating of the attic space will still take place, and the roof deck and shingles will experience some increased heat stress. A third option is to increase the insulation between the attic and the living space below, and to run the hvac ductwork within the conditioned space rather than in the unconditioned attic. This method has a smaller effect on cooling loads than the reflective or radiant barrier roof systems but is effective at reducing heating loads as well as cooling loads, making it the most cost-effective option in mixed heating and cooling climates.

ing wall. And duct surface area is much greater than you might think — often as much as 25% of the house floor area. During the hottest hours, as much as 30% of the cooling system's capacity can be lost to heat gains in the duct system. Besides the wasted energy, this means it takes longer to cool down the house when the air conditioner kicks in.

Unlike a reflective roof or attic radiant barrier, ceiling insulation does little to address duct system losses. So if your design relies on ceiling insulation to limit roof-related cooling loads, try to locate the duct system within the thermal envelope, below the insulated ceiling. Even running the ducts through the crawlspace, though they might be exposed to outdoor air temperatures, will add less to the load than running them through the solar-heated attic.

Insulated Roof Deck With Sealed Attic

Sealing the attic and insulating the roof deck is another way to get the duct system into a more friendly environment. Some code officials may not like this roof design, and researchers don't recommend it in colder climates, but it does save energy. It also creates semi-conditioned storage space in the attic, reduces interior moisture loads in hot climates, and avoids the risk of condensation on air handlers and ducts.

In our seven-home side-by-side comparison, the house with a sealed and insulated attic used 9% less energy than the base case house, even though both had dark shingles. Some of us were expecting a greater savings, but several factors limit the benefit of this method.

The big advantage is that the ductwork is inside the thermal envelope. However, while a ventilated attic can flush some heat out through the vents, an insulated roof deck fights its whole battle at the roof surface. Also, the air conditioner has to treat the additional air volume of the attic space.

Beyond that, an insulated roof deck contributes more heat to the house than an insulated attic floor does. Heat transfer is proportional to the temperature difference, and also to the area of the surface. In a ventilated attic on a hot day, the top surface of the ceiling insulation may hit 130°F — a 55°F difference with the 75°F interior. But the deck of an insulated roof in the direct sun may reach 170°F while the attic reaches 85°F, for a difference of 85°F across the insulation. That wider temperature gap drives faster heat gain. And that faster gain is multiplied by a greater area, since the roof area is anywhere from 5% to 40% greater than the ceiling area, depending on the pitch of the roof (not to mention the gable ends).

So with an insulated roof deck and a sealed attic, it is very worthwhile to block that solar gain right off the bat: Use a lighter tile, white shingles, or a more reflective metal. In our study, the sealed system with dark shingles did about 9% better than a ventilated attic with dark shingles. With a reflective roof, the sealed attic would likely post savings of 25% or 30%. Even matched with white shingles (with a reflectance of 25%), we estimate that the insulated roof would have scored about a 13% savings compared to the dark shingles and vented attic. Also, it's worth noting that we carefully sealed the ductwork in all the test houses, to avoid confusing the results. If the ducts are leaky, the benefit of a sealed attic is much greater, because those leaks can't communicate with the outdoors.

Smart Choices

Good roof details can save energy anywhere in the country. But climate and other building details do affect the choices. Here's how to approach the decision:

Northern climate options. If you build in the North, reflective roofing materials or radiant barriers bring only modest savings. Adding insulation in the attic is a much more cost-effective upgrade. Insulation cuts both heating and cooling costs; and the heating savings in northern winters add up to much more money. (For the full benefit, it's important to run ductwork within the insulated envelope — winter or summer, ducts in the attic will bypass the ceiling insulation and reduce its effectiveness.)

Not that cooling doesn't matter up north, however. In summer, attics get hot everywhere. So even in the North, reflective roofing or radiant barriers may be worth installing simply to improve summer comfort and to reduce peak loads on the air conditioner. But if you want a reflective roof in the North, look for a material like Galvalume that is both reflective and low-e: This conserves attic heat during the winter as well as providing a summer cooling benefit.

Southern choices. Down south, reflective roofs are a no-brainer — they're money in your pocket. Air conditioning is the big energy cost, and reflective roofs can cut it by a third in the hottest months. Increasing the attic insulation can't hurt, but reflective roofs are more cost effective, particularly if the ductwork runs through the attic.

If you're stuck with a dark roof, attic radiant barriers can achieve savings comparable to a reflective roof's performance. But if you use radiant barriers under an asphalt shingle roof, you're wise to also choose white shingles, just so the shingles themselves won't get quite so hot.

Good ductwork location and reflective or radiant-barrier roof construction bring independent benefits, but they also complement each other. If you have a dark roof and a hot attic, bringing the ductwork below the insulated ceiling will help quite a lot. If the ducts are in the attic, switching from a dark roof to a reflective roof can help. But combining the two tactics — applying reflective roofing and bringing the ducts inside — provides the greatest total benefit. In a hot climate like Florida's, your summer cooling loads could drop by as much as 40%.

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