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# Comparative Summer Attic Thermal Performance of Six Roof Constructions

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# Comparative Summer Attic Thermal Performance of Six Roof Constructions

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## ABSTRACT

*The summer attic thermal performance of six roofs has been measured at a heavily instrumented test site, the Flexible Roof Facility (FRF), which is a 1,152 ft² (107 m²) building with six roof adjacent test cells that are heavily insulated from each other. Some 233 channels of data were obtained; this includes 20 temperature measurements per cell, extensive meteorological conditions, surface and tower wind speeds, and attic humidity and roof surface moisture accumulation. The data were collected over the ASHRAE definition of summer (June - September) to compare the cooling season thermal performance of roofing systems. Six different roof types were evaluated, with variations in color, ventilation, roof mass, and the use of radiant barrier systems (RBS). The tests show that roof system reflectivity greatly influences attic summer temperatures. Two white roofing systems outperformed the other options. Another large improvement comes from greater roof mass; tiled roofs performed better than those with asphalt shingled roofs. An increased attic ventilation rate improved the effectiveness of an attic radiant barrier. Of the evaluated options, a white tile roof best controlled attic heat gain.*

## INTRODUCTION

Improving attic thermal performance is fundamental to controlling residential cooling loads in hot climates. Research shows that the influence of attics on space cooling is not only due to the change in ceiling heat flux but often due to conditions within the attic itself and their influence on heat gain to duct systems and on air infiltration into the building.

The importance of ceiling heat flux has long been recognized, with insulation a proven means of controlling excessive gains. However, when ducts are present in the attic, the magnitude of heat gain to the thermal distribution system under peak conditions can be much greater than the ceiling heat flux (Parker et al. 1993; Hageman and Modera 1996). A simple calculation illustrates this fact. Assume a 2,000 $\text{ft}^2$ ceiling with R-30 attic insulation. Supply ducts in most residences typically comprise a combined area of ~25% of the gross floor area (see Gu et al. [1996], Appendix G, and Jump et al. [1996]) but are only insulated to between R-4 to R-6. With the peak attic temperature at 130°F, and 78°F maintained inside, a UA $\Delta T$ calculation shows a ceiling heat gain of 3,500 Btu/h. With R-5 ducts in the attic and a 57°F air conditioner supply temperature, the heat gain to the duct system is 7,300 Btu/h if the cooling system ran the full hour under design conditions—more than twice the ceiling flux. This influence may be exacerbated by the location of the air handler within the attic space, a common practice in much of the southern U.S. The air handler is poorly insulated, with the greatest temperature difference at the evaporator of any location of the cooling system. It also has the greatest negative pressure just before the fan so that some leakage into the unit is inevitable. As evidence for this influence, a monitoring study of air-conditioning energy in 48 central Florida homes (Cummings et al. 1991) found that homes with the air handlers located in the attic used 30% more space cooling energy than those with the air handlers located in garages or elsewhere.

Buildings research also shows that duct system supply air leakage can lead to negative pressures within the house interior when the air handler is operating. This can result in hot air from the attic being drawn down to the conditioned space gaps around recessed light fixtures or other bypasses from the attic to the interior (Cummings et al. 1991, p. 41). This phenomenon is commonly encountered in slab-on-grade homes in Sunbelt states in the U.S., where the dominant infiltration leakage plane from the exterior is through the ceiling.

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The impact of these two factors results in placing much greater importance on controlling attic air temperatures than is apparent from focusing on ceiling heat flux alone.[1] Consequently, in our assessment of the impact of different roof constructions on cooling-related performance, we considered both ceiling flux and attic air temperature.

## TEST FACILITY DESCRIPTION AND OBJECTIVES

During the summer of 1997, tests were performed on six different residential plywood-decked roofing systems. The experiments were conducted at the flexible roof facility (FRF) located in Cocoa, Florida, ten miles (17 km) west of the Atlantic Ocean on mainland Florida. The FRF is a 24 ft by 48 ft (7.3 by 14.6 m) frame building with its long axis oriented east-west (Figure 1). The roof and attic are partitioned to allow simultaneous testing of multiple roof configurations. The orientation provides a northern and southern exposure for the building materials under evaluation. The attic is sectioned into six individual 6 ft (1.8 m) test cells (detail A in Figure 1) spanning three 2 ft (0.6 m) trusses thermally separated by partition walls insulated to R-20 $ft^2 \cdot h \cdot °F/Btu$ (RSI-3.5 $m^2 \cdot K/W$) using 3 in. (7.6 cm) of isocyanurate insulation. The partition between the individual cells was well sealed to prevent airflow cross-contamination. The gable roof has a 5/12 pitch (22.6°) and 3/4 in. (1.9 cm) plywood decking. On the attic floor, R-19 (RSI-3.3) unfaced batt insulation is installed between the trusses in all of the test bays in a consistent fashion. One-half-inch (1.3 cm) gypsum board separates the attic from the conditioned interior. The interior of the FRF is a single, open conditioned space.

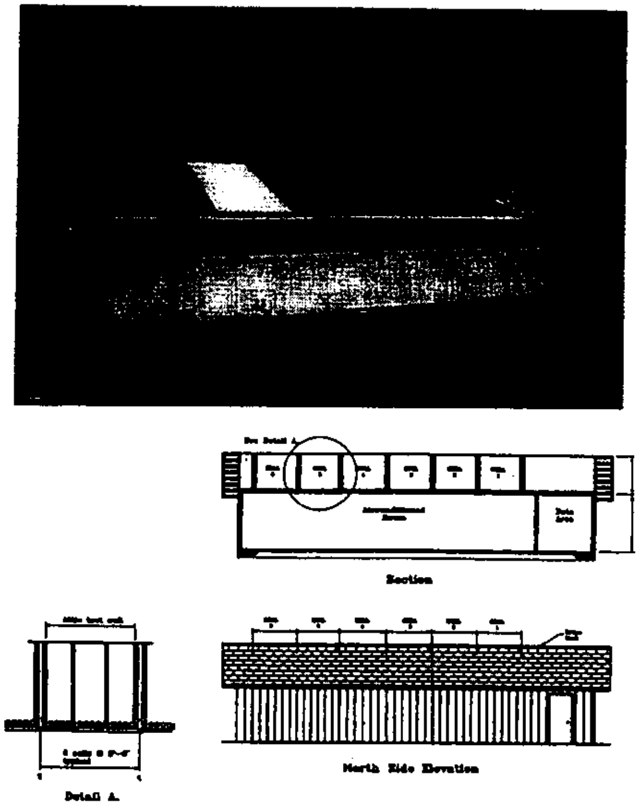

*Figure 1 The flexible roof facility.*

The roof lends itself to easy reconfiguration with different roof products and has been used in the past to examine different levels of ventilation and installation configurations for tile roofing (Beal and Chandra 1995). A black asphalt shingle roof on one of the test cells serves as a reference for other roofing types.

Our tests in 1997 addressed the following questions:

1. What is the performance (ceiling flux and attic air temperatures) of a standard black asphalt shingle roof with 1:300 ventilation?
2. How does addition of a truss mounted radiant barrier system (RBS) impact performance?
3. How does added ventilation (1:150) impact RBS performance?
4. How does a direct nailed red barrel tile roof perform relative to other types?
5. How doe a white barrel tile roof perform relative to red tile and to the others?
6. How does a white standing seam metal roof perform relative to white tile and the other types?
7. How do near roof wind velocities relate to those taken at a 10 meter height?
8. Can differences be seen in water evaporation rates on differing roofing systems?
9. How do roofing system differences impact attic relative humidities?
10. What impact on shingle surface temperatures is produced by an attic truss RBS?

### Test Configuration and Instrumentation

To answer the above questions, we configured the test cells in the following fashion:

Cell 1: Direct nailed white concrete barrel tile
Cell 2: Black asphalt shingles; deck mounted RBS; 1:150 soffit and ridge ventilation
Cell 3: Black asphalt shingles; deck mounted RBS; 1:300 soffit and ridge ventilation
Cell 4: Direct nailed red concrete barrel tile; 1:300 ventilation
Cell 5: Black asphalt shingles; 1:300 soffit and ridge ventilation (reference cell)
Cell 6: White standing seam metal; 1:300 soffit and ridge ventilation

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[1] Reducing heat gain to the duct system and air infiltration from the attic is so important that a specific roof construction where the insulation is moved from the plane of the ceiling to the sloped roof has been demonstrated to reduce cooling energy use in homes in both Florida and Nevada (Rudd et al. 1996).

The final appearance of the facility as configured for test is shown in the photographic insert in Figure 1. All roofing materials were installed in a conventional manner, according to manufacturer's specifications and current practice in the central Florida area. Although raised counterbatten-type tile installations, which promote ventilation, have been shown as thermally beneficial (Beal and Chandra 1994), current practice, with its focus on lower first costs, dictated a direct nailed application method for the tile roofs. Perforated vinyl soffit vents were used; ridge vents were the "shingle vent" type with foam mesh over the ridge outlet covered by shingles. Standard tile ridge vents were utilized for the two tile roof sections, and a manufacturer-supplied ridge vent was used with the standing seam metal roof. In each test cell, the free ventilation area was first estimated based on dimensional measurements and then verified by a fan pressurization test of the attic to estimate the equivalent leakage area. Soffit or ridge vent area was then closed off to match the target free vent area to within 10%. The 1:300 attic vent to floor area was observed for all of the test cells, except for a single cell that had enhanced ventilation (1:150) to examine its relative influence on RBS performance.

Samples of the roofing materials were sent to a laboratory to establish their integrated solar reflectance using ASTM Test Method E-903 (1996); long-wave emittance was measured also using the ASTM E-408 test procedure. The values reported are listed in Table 1.

Instrumentation for the project was extensive (see Figure 2) so the data can eventually validate a detailed attic simulation model. A number of temperature measurements using type-T thermocouples, with air temperatures shielded from the influence of radiation, included:

- Exterior surface of the roof and underlayment temperatures
- Decking interior surfaces
- Air temperatures at different heights within the attic
- Soffit inlet air temperature/ridge vent exit air temperature
- Insulation top surface temperatures
- Conditioned interior ceiling temperature

The following meteorological data were taken:

- Solar insolation
- Aspirated ambient air temperature
- Ambient relative humidity

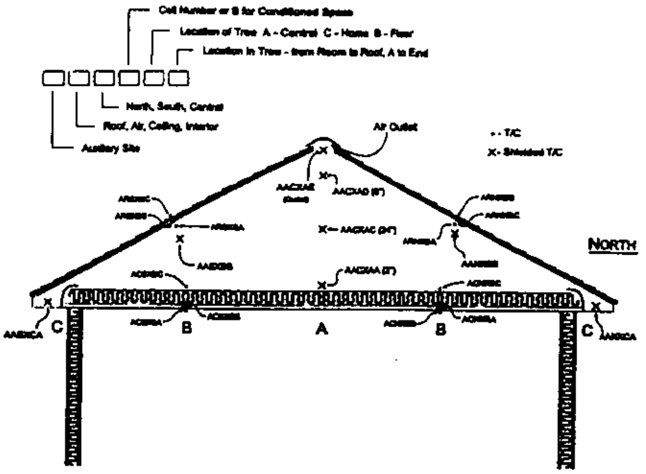

*Figure 2 FRF instrumentation schematic.*

- Wind speed at a 32 ft (10 m) height
- Rainfall (tipping bucket)

Three additional unique measurements were taken. Previous attic simulation analysis has shown that knowledge of the airspeed just above the roofing system is critical to estimation of the roof surface convective heat transfer coefficient as well as attic ventilation rates, although empirical data are often lacking (Parker et al. 1991; Wilkes 1991). Thus, A cupped anemometer was mounted both on the north and south of Cell 3 at mid-roof at a ten in. (0.25 m) height so that wind speed near the roof surface could be compared with the 32 ft (10 m) value on the weather tower 25 ft (8 m) southeast of the facility. Earlier data also revealed that moisture accumulation on roofs resulted in measurable differences in attic thermal performance during morning hours due to evaporative cooling. To examine this phenomenon, we mounted small surface wetness sensors to the south roof exposure of each roof section to measure when dew formed on the roof surfaces and when it was finally evaporated. The sensors, adapted from electrical impedance grids for measuring leaf wetness (Gillespie and Kidd 1978), were painted to match the roofing samples and calibrated so that it was possible to determine when the roof was wet or dry. Their sensitivity was verified by physical inspection. Finally, we installed calibrated hygrometers at mid-attic in each of the test cells to measure relative humidity levels.

## TABLE 1

## Tested Roofing Material Solar Reflectances and Emittances[a]

| Sample | Solar Reflectance | Long-Wave Emittance |
|---|---|---|
| Black asphalt shingle[b] | 2.7% | 0.90 |
| White tile | 75.4% | 0.88 |
| Red tile | 19.5% | 0.91 |
| White metal | 67.6% | 0.83 |

[a] Test results for new, unexposed products.
[b] Used in three test cells.

All of the test cells were operational by June 5, 1997, at which point data collection began. The test cells were maintained in an unaltered state through the end of September with continuous data collection.

## RESULTS

### Attic Air Temperatures

Data collected for June 16, 1997, show typical thermal behavior prevailing throughout the cooling season (Figure 3). The plotted data are for attic air temperature at a six-inch height above the insulation at mid attic, where the duct system often would be located. The standard test cell (#5) is the hottest, reaching 134.9°F (57.2°C) on a hot summer day (peak ambient temperature was 92.2°F or 33.4°C). The attic with RBS with 1:300 ventilation is next hottest (128.1°F or 53.4°C), followed by the attic with RBS with 1:150 ventilation (116.1°F or 46.7°C). The red tile roof exhibits similar performance to the well-ventilated radiant barrier case during the daytime hours (maximum = 115.7°F or 46.5°C) but is warmer at night. Both white roofs show the lowest temperatures. The white metal roof does not rise more than 10 degrees above ambient, 102.2°F (39°C). One of the most interesting findings with regard to the performance of the white tile roof is that the attic in this configuration does not typically rise above ambient air temperature until after 2 p.m. EST in the afternoon. Its maximum daily temperature is only 91.5°F (33.1°C) and the average daily attic air temperature, 80.8°F (27.1°C), is only one degree warmer than the average ambient air temperature.

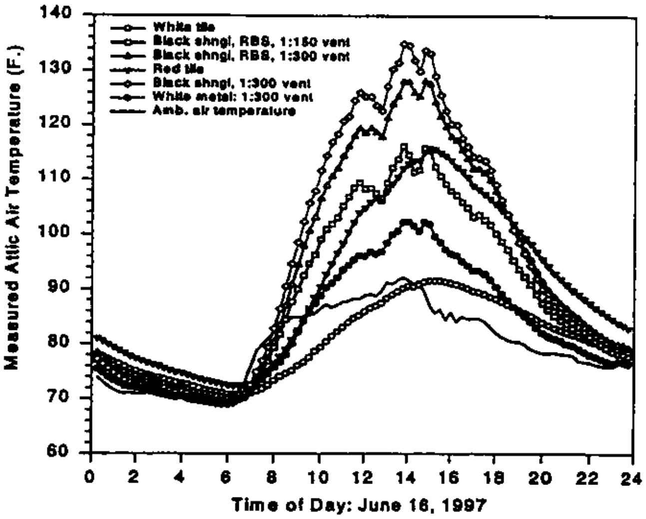

***Figure 3*** *Measured mid-attic and ambient air temperatures in the six test cells on June 16, 1997.*

Data from the site for the entire summer (June 1 - September 30) are summarized in Table 2 and Figure 4. The attic and ambient air temperatures were used for the data analysis. The attic air temperature was taken at mid-height, halfway between the decking and insulation surface (a 24 in. [0.6 m] height). The summer 15-minute data comprised 11,262 observations with averages, minimums, and maximums given in the table. These were further sorted by the average ambient air temperature into the top 2.5% of the observations (~282) of the highest temperature coinciding with the ASHRAE definition of the summer design condition. Within the top 2.5% of observations, the average outside air temperature, attic air temperature, and coincident difference are reported.

Within each of the test cells, thermocouples recorded the insulation surface temperature on both the north and south sides of the attic, as well as the temperature of the gypsum board ceiling's interior surface immediately below. The insulation in each cell was R-19 (RSI-3.3) so that the both the temperature difference and heat flux could be calculated. These data are presented in Table 3 with averages for the entire summer shown in Figure 5 over the daily cycle.

The approximate fluxes in Btu/h·ft$^2$·°F (W/m$^2$·K) can be obtained by dividing the temperature difference data by 19. This would indicate that the maximum heat flux for the reference cell on a daily basis (Figure 5) is on the order of 2.2 Btu/ft$^2$·h. Figures 6- 8 show a comparison of all the calculated flux data for each test cell plotted against the temperature differ-

### TABLE 2
### FRF Mid-Attic Temperatures for Summer 1997

| Designation | Description | Temperature (°F) | | | 2.5% Design | |
|---|---|---|---|---|---|---|
| | | Mean | Min | Max | T(°F) | ΔT |
| Ambient | Aspirated air temperature | 79.8 | 67.6 | 96.8 | 92.6 | Ref |
| Cell #1 | White tile roof, 1:300 vent | 80.0 | 63.7 | 96.0 | 91.4 | −1.2 |
| Cell #2 | Black shingle, RBS, 1:150 vent | 86.1 | 62.8 | 121.6 | 113.3 | 20.7 |
| Cell #3 | Black shingle, RBS, 1:300 vent | 90.0 | 63.6 | 136.3 | 125.4 | 32.8 |
| Cell #4 | Red tile roof, 1:300 vent | 88.1 | 64.6 | 122.2 | 113.0 | 20.4 |
| Cell #5 | Black shingle, 1:300 vent, ref. | 91.0 | 62.5 | 141.9 | 131.5 | 38.9 |
| Cell #6 | White metal, 1:300 vent | 81.9 | 62.4 | 106.8 | 101.5 | 8.9 |

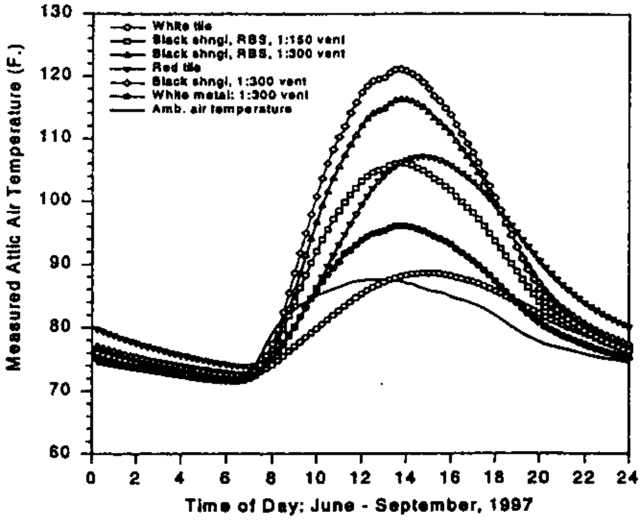

*Figure 4* *Measured mid-attic and ambient air temperatures in the six test cells over course of entire summer.*

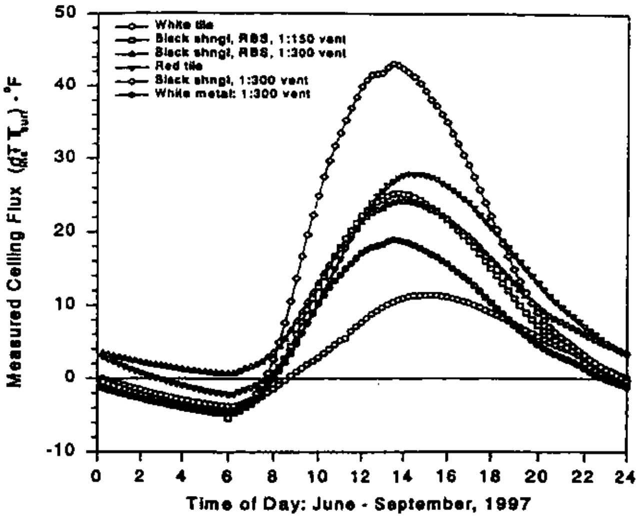

*Figure 5* *Calculated average ceiling temperature flux* ($T_{insulation}-T_{ceiling,interior}$) *for the six test cells over the course of the summer.*

ences across the ceiling in the reference cell (No. 5).

## Ventilation and Radiant Barrier Systems

Figure 6 shows that much of the improvement in heat transfer brought about by added ventilation in the two RBS cells compared occurs during evening hours when fluxes in the standard roof become negative and the added ventilation helps to remove accumulated heat from the RBS attic, which is more inhibited in its surface radiant heat transfer to the sky. The added ventilation aids the RBS flux abatement considerably, from a 26% to a 36% reduction over the entire summer.

## Tile Roofs

Figure 7 shows a similar comparison for the red and white tile roofs. There is a much wider spread in the comparison of the fluxes for the red tile roof to the reference cell due to thermal storage within the roof tiles. This is clearly evident from the oval shape of the plots for individual days. During the morning hours, the fluxes are relatively lower than are the late afternoon values with the same flux in the reference cell. It is also noteworthy that the fluxes from the red tile roof are often positive during evening hours when the reference roof has a negative heat flux. This impact is important to consider; constraint of the analysis only to periods when the reference cell heat flux is positive shows better performance for the red tile roof (35% flux reduction) than when considering the overall period (23% lower). The white tile roof shows the largest measured average reductions in ceiling heat flux of those measured—76%.[2]

## White Roofs

Figure 8 shows a comparison of the relative ceiling flux of the two white roof systems. The lower thermal capacitance

### TABLE 3
### FRF Ceiling Flux Impact for Summer 1997

| | | $\Delta T$ ($T_{ins}-T_{ceiling}$)(°F) | | | 1– ($\Delta TCell/\Delta TCell5$) |
|---|---|---|---|---|---|
| **Designation** | **Description** | **Mean** | **Min** | **Max** | **% Reduction** |
| Cell #1 | White tile roof, 1:300 vent | 3.37 | –35.5 | 18.9 | 75.9% |
| Cell #2 | Black shingle, RBS, 1:150 vent | 8.88 | –11.7 | 39.5 | 36.4% |
| Cell #3 | Black shingle, RBS, 1:300 vent | 10.29 | –11.8 | 35.3 | 26.4% |
| Cell #4 | Red tile roof, 1:300 vent | 10.73 | –13.0 | 43.1 | 23.3% |
| Cell #5 | Black shingle, 1:300 vent, ref. | 13.98 | –12.6 | 61.7 | Reference |
| Cell #6 | White metal, 1:300 vent | 5.40 | –13.1 | 30.0 | 61.3% |

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[2] The average flux reduction was obtained by comparing the average ceiling flux of each test cell over the entire summer against that for the reference (#5).

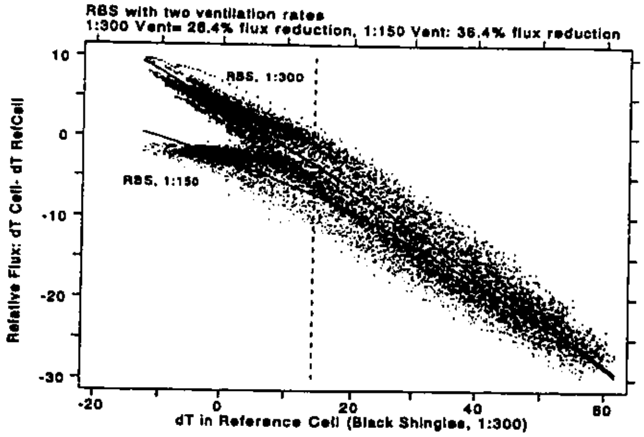

*Figure 6* *Measured temperature difference between two radiant barrier system test cells with different ventilation rates relative to reference test cell (black asphalt shingle).*

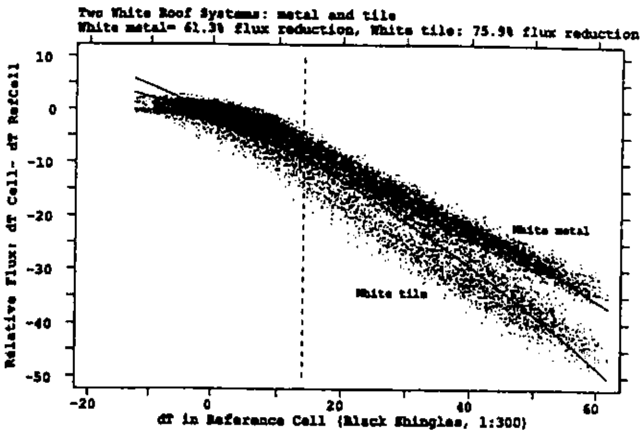

*Figure 8* *Measured temperature difference between white metal and white tile test cells and reference test cell (black asphalt shingle).*

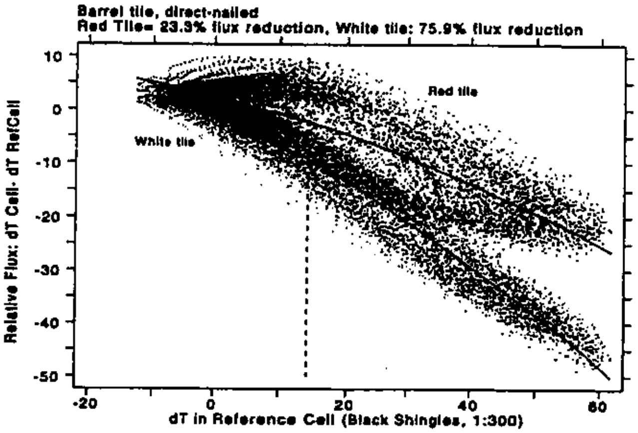

*Figure 7* *Measured temperature difference between white and red tile test cells and reference test cell (black asphalt shingle).*

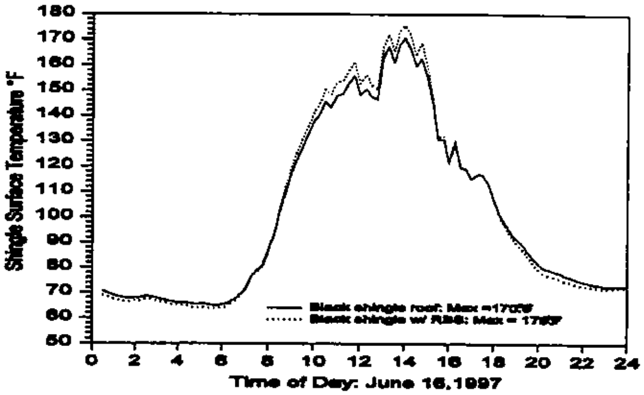

*Figure 9* *Measured shingle surface temperature elevation of cell with radiant barrier system vs. reference test cell on June 16, 1997. At peak, the temperature of the shingle surface on the roof of the attic with the RBS was 5°F greater than that on the reference cell.*

of the white metal roof is clearly visible in the data. The white tile roof produces an average 76% flux reduction against 61% for the white metal, with better relative performance. It should be pointed out, however, that the measured solar reflectance of the white tile sample (75%) was greater than that for the metal system (68%), which likely has some impact on the relative comparison. Regardless, it seems likely that the thermal capacitance of the tile roof, and its ability to store coolness from the night sky would result in superior performance to the metal roof even with similar reflectances. One major caveat on this conclusion, however, has to do with degradation. The superior performance of white roofs is due to a surface property (high solar reflectance). Observation of existing roofing systems of both types in Florida suggests that metal roofs with their smooth surface may maintain their reflectance for a longer period of time. On the other hand, the surprisingly good performance of red tile roofs, previously observed by Beal and Chandra (1995), suggests that even a soiled white tile roof will exhibit significantly better performance than asphalt roofs. Aesthetic concerns, however, may be a greater issue.

## OTHER FINDINGS

As part of the evaluation, we examined how much black asphalt shingle surface temperatures were elevated by the presence of a radiant barrier. This is an oft expressed issue with shingle manufacturers, concerned that elevated temperatures will reduce product life. Figure 9 shows the measured surface temperature of the shingles on June 16, 1997, on the reference cell (#5) and those on cell #3 with an RBS and 1:300 ventilation. The plot shows a maximum increase in the shingle surface temperature of 6.2°F (3.4°C). The maximum shingle temperatures measured over the course of the summer were 179.3 °F (81.8°C) with the standard roof and 183.8° (84.3 °C) with the RBS.

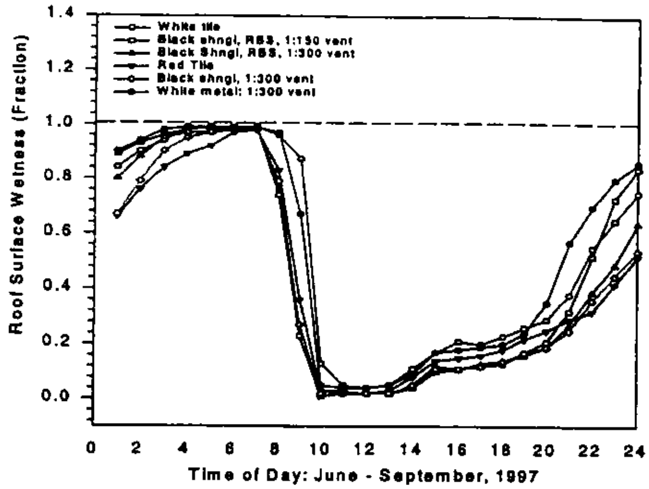

***Figure 10*** *Average roof surface wetness over entire summer. Sensors were calibrated so that at unity water droplets could be observed on the roof surface; none could be seen at zero.*

Figure 10 depicts the measured surface wetness for the different roofs over the summer. In the early monitoring we speculated that a portion of the better performance of the white tile and metal roofs in the morning hours was due to the longer period required for evaporation of dew accumulation from the previous evening. The data from the surface wetness sensors supported this hypothesis. During the early evening, the white metal roof was the first to have dew form, with the surface near saturation each night by about 2 a.m. The white tile roof reached a similar condition approximately an hour later. Both white roofs were also the last to dry during the morning, typically the white tile surface not being completely dry until approximately 11 a.m. On the other hand, the red tile roof, having accumulated heat during the day, was the last to have dew form on its surface, not reaching saturation until around 5 a.m. Both roofs with the radiant barriers tended to form surface moisture more rapidly than did the reference cell (#5), due to the shingle surface temperature depression caused by the low-emissivity surface under the decking. All of the shingle roofs dried by 10 a.m. The influence of central Florida's summer afternoon rain showers is obvious in the data beginning at 3 p.m. Not surprisingly, once rains ceased, the white tile or white metal roofs tended to stay wet for a longer time.

Figure 11 shows how mid-attic relative humidity varied in each cell over the daily cycle throughout the summer. As expected, the white roofing systems (white tile mean = 75%, white metal = 72%) showed the greatest average relative humidity due primarily to the lower attic's interior dry-bulb temperature. This was not unexpected since simulation analysis had indicated this influence (Burch et al. 1996). The reference test cell (#5) had the lowest average humidity (53%) closely followed by the RBS cell at 1:300 ventilation (54%) and the RBS cells with 1:150 ventilation (62%). The red tile roof's attic averaged 61%. It is not clear how much the added ventilation in Cell#2 increased attic moisture levels. Recently, attic ventilation has become a contentious issue, due in part to the lack of scientific basis for the 1:300 ventilation rate (Rose 1995), simulation influences (Burch et al. 1996), as well as shingle manufacturers' concerns regarding the life expectancy of roofing materials exposed to elevated shingle temperatures from lower ventilation.

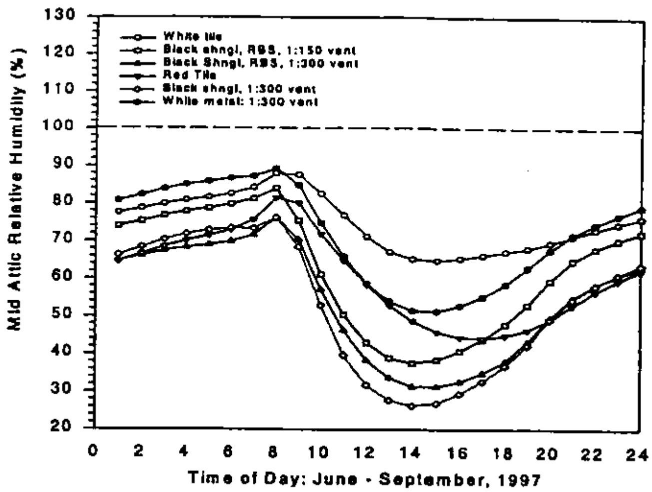

***Figure 11*** *Measured average mid-attic relative humidity in test cells over the course of the summer.*

We learned that the wind speed at a 10 m height is much higher than that just above the roof surface.[3] The average wind velocity on the weather tower over the course of the summer was 5.30 mph (2.37 m/s) against 0.83 mph (0.37 m/s) measured10 in. (0.25 m) above the south side of the roof and 0.33 mph (0.15 m/s) above the north (leeward side of prevailing wind direction). The low velocities seen in Figure 12 have implications for the calculation of the roof surface convective heat transfer coefficient within simulation models. In particular, the very low values seen during evening hours suggest that radiant heat transfer to the night sky from the roof will be enhanced while daytime roof surface temperatures will be elevated from lack of convective heat transfer.

## CONCLUSIONS

The finding that white roofing systems exhibited superior thermal performance was not unexpected. Field research in ten existing homes has shown that white roofing systems can reduce space cooling energy use by an average of 19% (Parker and Barkaszi 1997). Similarly, other prior data have shown that tile roofs provide superior thermal performance to dark asphalt shingles.[4] However, one of our most interesting findings is the superior thermal performance of the white tile roof;

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[3] Obviously, the impact of local shielding and building geometry will vary for other sites. However, since the FRF test area is fairly open, the decrement in the rooftop windspeed in more built-up suburban areas may be even greater.

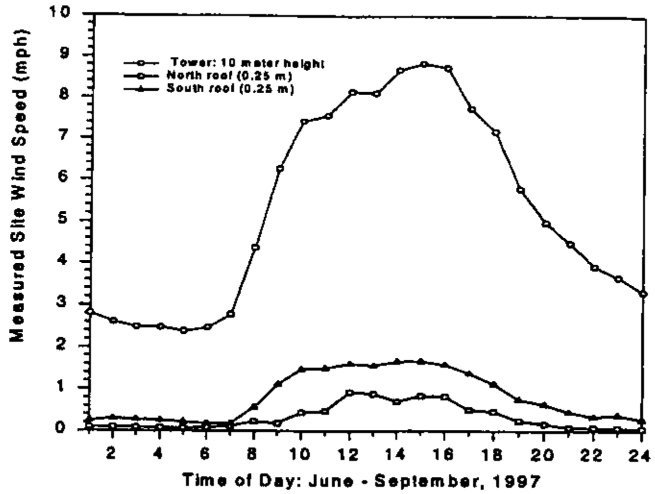

*Figure 12* *Measured average wind speed at 10 m weather tower and 0.25 m over the FRF mid-roof over the course of the summer. The north side of the roof is on the leeward side to the predominant wind direction.*

the attic in this configuration does not typically rise above ambient air temperature until after 2 p.m. in the afternoon. Moreover, the calculated ceiling flux data also revealed that the white tile roof provided best performance (76% flux reduction relative to a black shingle roof). The white metal roof was second best (61% flux reduction). All of the alternative roofing systems evaluated did show measurable improvements in both flux and attic temperature performance. Tile roofs showed both a reduction in peak attic air temperature as well as a 23% average reduction in the ceiling heat flux.

The FRF data indicate that white tile roofing system offers the best thermal performance in hot climates of those tested. An interesting aside is that this conclusion echoes one of 50 years earlier describing the overwhelming architectural preference after World War II for white tile roofs in south Florida prior to the advent of air conditioning (Langewiesche 1950).[5] One important caveat to this conclusion from our study, however, is that the white standing seam metal roof provided nearly as good performance (better during evening hours) and, based on observation of both roofing systems in application in Florida, will likely maintain its reflectivity for a longer period of time.

A remaining issue associated with white roofing systems, identified from our measurements, is their tendency to maintain greater moisture levels, both on the roof surface as well as the attic interior than with asphalt shingle roofing types. Detailed data have been collected that should allow improved modeling of key physical processes involved in the measured performance.

## ACKNOWLEDGMENTS

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## REFERENCES

Beal, D., and S. Chandra. 1995. The measured summer performance of tile roof systems and attic ventilation strategies in hot, humid climates. *Thermal Performance of the Exterior Envelopes of Buildings VI.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Burch, D.M., G.A. Tsongas, and G.N. Walton. 1996. Mathematical analysis of practices to control moisture in the roof cavities of manufactured homes, NISTIR 5880. Gaithersburg, Md.: National Institute of Standards and Technology.

Cummings, J.B., J.J. Tooley, and N. Moyer. 1991. Investigation of air distribution system leakage and its impact in ventral Florida homes. FSEC-CR-397-91, Florida Solar Energy Center, Cocoa, Fla.

Gillespie, T.J., and G.E. Kidd,. 1978. Sensing duration of leaf moisture retention using electrical impedance grids. *Canadian Journal of Plant Science* 58:179-187.

Gu, L., J.E. Cummings, M. V. Swami, P. Fairey, and S. Awwad. 1996. Comparison of duct system computer models that could provide input to the thermal distribution standard method (SPC-152P). FSEC-CR-929-96, Florida Solar Energy Center, Cocoa, Fla.

Hageman, R., and M.P. Modera. 1996. Energy savings and HVAC capacity implications of a low-emissivity interior surface for roof sheathing. *Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings*, Vol. 1, p. 117. Washington, D.C.: American Council for an Energy Efficient Economy.

Jump, D.A., I.S. Walker, and M.P. Modera. 1996. Measurements of efficiency and duct retrofit effectiveness in residential forced air distribution systems. *Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in*

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[4] A companion paper (Parker and Sherwin 1998) with collected attic temperature data from a number of houses with different colored asphalt shingle roofs shows that although the performance of white asphalt shingles is better than dark, it is only marginally better due to a high solar absorptance (about 75%) because of the dark substrate on nominally white asphalt shingles.

[5] This bit of common wisdom was later supported by measurements made by Weatherington (1979) for Florida Power Corporation in the late 1970s. He found that all tile roofs exhibited lower attic temperatures than asphalt shingle roofs, but temperatures in white tile attics were often lower than ambient air temperatures (likely due to duct heat transfer and/or leakage).

*Buildings*, Vol. 1, p. 147. Washington, D.C.: American Council for an Energy Efficient Economy.

Langewiesche, W. 1950. Your house in Florida. *House Beautiful*, Jan.

Parker, D.S., and S.F. Barkaszi, Jr. 1997. Roof solar reflectance and cooling energy use: Field research results from Florida. *Energy and Buildings* 14. Netherlands: Elsevier Sequoia.

Parker, D., and J. Sherwin. 1998. Monitored summer peak attic air temperatures in Florida residences. *ASHRAE Transactions* 104 (2).

Parker, D.S., P.W. Fairey, and L. Gu. 1991. A stratified air model for simulation of attic thermal performance. *ASTM STP-1116, Insulation Materials: Testing and Applications*, p. 44. Philadelphia: American Society of Testing and Materials.

Parker, D., P. Fairey, and L. Gu. 1993. Simulation of the effects of duct leakage and heat transfer on residential space cooling energy use. *Energy and Buildings* 20: 97-113. Netherlands: Elsevier Sequoia.

Rose, W.B. 1995. The history of attic ventilation regulation and research. *Thermal Performance of the Exterior Envelopes of Buildings VI*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Rudd, A.F., J. W. Lstiburek, and N.A. Moyer. 1996. Measurement of attic temperatures and cooling energy use in vented and sealed attics in Las Vegas, Nevada. Proceedings: '96 Excellence in Building Conference. Minneapolis: Energy Efficient Building Association.

Wetherington, T.I., Jr. 1979. Measure of attic temperatures in Florida. *Proceedings, Workshop on Summer Attic and Whole House Ventilation, July 19, 1978*. NBS SP 548. Washington D.C.: National Bureau of Standards (now National Institute of Standards and Technology).

Wilkes, K.E. 1991. Thermal model of attic systems with radiant barriers. ORNL/CON-262, Oak Ridge National Laboratory, Oak Ridge, Tenn.