FLORIDA SOLAR ENERGY CENTER®

Flexible Roofing Facility: 2003 Summer Test Results

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Original Publication

Danny Parker, Jeffrey Sonne, John Sherwin, "Flexible Roofing Facility: 2003 Summer Test Results", prepared for U.S. Department of Energy Building Technologies Program, July 2004.

Publication Number

FSEC-CR-1475-04

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ACKNOWLEDGMENT

This work is sponsored, in large part, by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy Building Technologies Program, under cooperative agreement no. DE-FC26-99GO10478. This support does not constitute an endorsement by DOE of the views expressed in this report.

The authors appreciate the encouragement and support from George James and Ed Pollock of the US DOE Building America program in Washington DC and William Haslebacher at US DOE/NETL. We are also grateful to our colleagues Subrato Chandra and Robin Vieira for technical advice. Thanks to Wanda Dutton for report preparation.

Executive Summary

The Flexible Roof Facility (FRF) is a test facility in Cocoa, Florida designed to evaluate five roofing systems at a time against a control roof with black shingles and vented attic (Figure E-1). The testing evaluates how roofing systems impact summer residential cooling energy use and peak demand. In the summer of 2003, the following roofing systems were tested. Cell numbering is from left to right.[1]

Cell #	Description
1	Galvalume®[2] unfinished 5-vee metal with vented attic (2nd year of exposure)
2	Sealed attic with proprietary configuration
3	High reflectance brown metal shingle with vented attic
4	Galvanized unfinished 5-vee metal with vented attic (2nd year of exposure)
5	Black shingles with standard attic ventilation (Control Test Cell)
6	White standing seam metal with vented attic (2nd year of exposure after cleaning)

Figure E-1. Flexible Roof Facility in summer of 2003 configuration.

[1] The left-hand-most section of the roof is not a test cell; test cell #1 is the Galvalume section.

[2] Galvalume is a quality cold-rolled sheet to which is applied a highly corrosion-resistant hot-dip metallic coating consisting of 55% aluminum 43.4% zinc, and 1.6% silicon, nominal percentages by weight. This results in a sheet that offers the best protective features characteristic of aluminum and zinc: the barrier protection and long life of aluminum and the sacrificial or galvanic protection of zinc at cut or sheared edges. According to Bethlehem Steel, twenty-four years of actual outdoor exposure tests in a variety of atmospheric environments demonstrate that bare Galvalume sheet exhibits superior corrosion-resistance properties.

All had R-19 insulation installed on the attic floor except in the configuration with the sealed attic (Cell #2) which had R-19 of open cell foam sprayed onto the bottom of the roof decking. The measured thermal impacts include ceiling heat flux, unintended attic air leakage and duct heat gain.

Cell #2 had a proprietary configuration which is not reported upon in this report.

A major thrust of the testing for 2003 was comparative testing of metal roofing under long term exposure. Given the popularity of unfinished metal roofs, we tested both galvanized and Galvalume® roofs in their second year of exposure. Galvalume® roofs are reported to better maintain their higher solar reflectance than galvanized types. Average daily mid-attic maximum temperatures for the Galvalume® and galvanized metal roof systems showed significantly better performance for Galvalume® product (17.5^{o}F and 13.1^{o}F cooler than the control dark shingle respectively).

Other than the sealed attic case, the white metal roof results in the coolest attic over the summer, with an average peak of only 94.6^{o}F – 22.1^{o} cooler than the peak in the control attic with dark shingles. The highly reflective brown metal shingle roof (Cell #3) provided the next coolest peak attic temperature. Its average maximum daily mid-attic temperature was 101.5^{o}F (15.2^{o}F lower than the control dark shingle cell). While the brown metal shingle roof's reflectance was lower than the two metal roofs and white metal roof we observed evidence that the air space under the metal shingles provides additional effective thermal insulation.

We also estimated the combined impact of ceiling heat flux, duct heat gain and unintended attic air leakage from the various roof constructions. All of the alternative constructions produced lower estimated cooling energy loads than the standard vented attic with dark shingles (Figure E-2). The Galvalume® roof clearly provided greater reductions to cooling energy use than the galvanized roof after two summers of exposure.

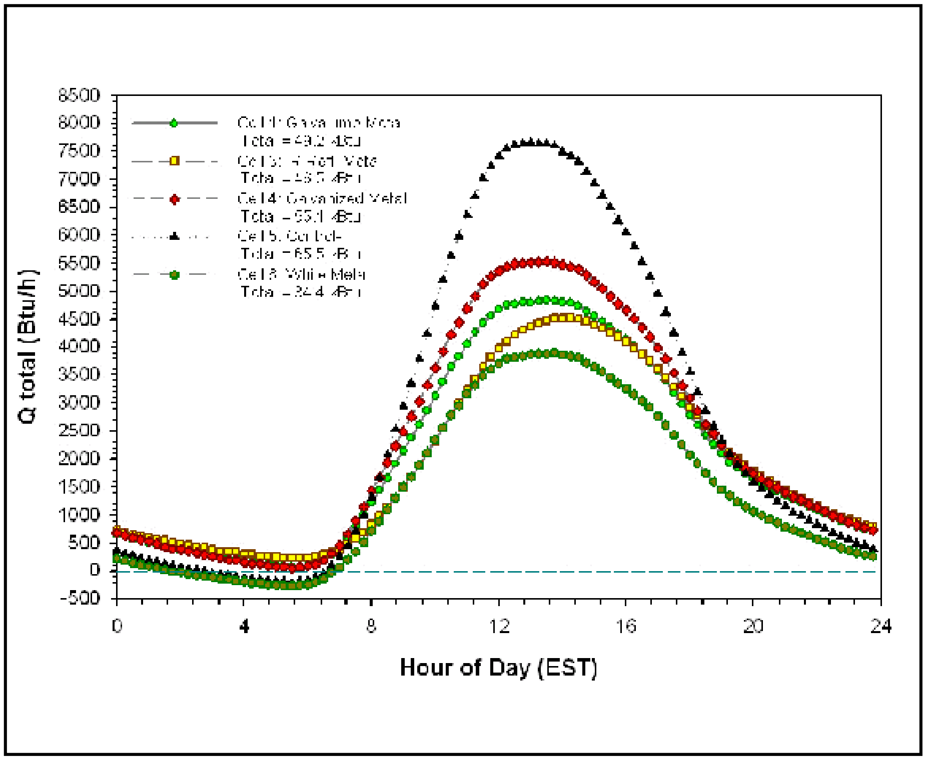


Figure E-2. Estimated combined impact of duct heat gain, air leakage from the attic to conditioned space and ceiling heat flux on space cooling needs on an average summer day in a 2,000 ft^2 home.

One important fact from our testing is that nighttime attic temperature and reverse ceiling heat flux have a significant impact on the total daily heat gain, particularly for the metal roofs. The rank order below shows the percentage reduction of roof/attic related heat gain and approximate overall building cooling energy savings (which reflect the overall contribution of the roof/attic to total cooling needs):

Rank	Description	Roof Cooling Load Reduction	Overall Cooling Savings
1	White metal with vented attic (Cell #6)	47%	15%
2	High reflectance brown metal shingle with vented attic (Cell #3)	29%	10%
3	Galvalume® unfinished metal with vented attic (Cell #1)	25%	8%
4	Galvanized unfinished metal roof with vented attic (Cell #4)	16%	5%

The relative reductions are consistent with the whole-house testing recently completed for FPL in Ft. Myers (Parker et al., 2001). This testing showed white metal roofing having the largest reductions, followed by darker constructions.

Flexible Roofing Facility: 2003 Summer Test Results

Background

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 the conditions within the attic itself and their influence on heat gain to duct systems and on air infiltration into the building. Figure 1 illustrates the fundamental thermal processes with a conventional vented attic.

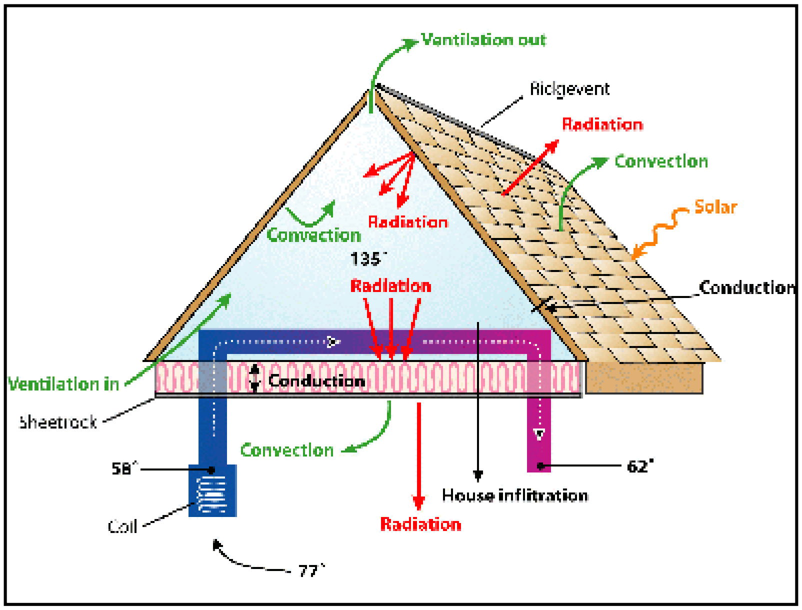


Figure 1. Vented attic thermal processes

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).[3] This influence may be exacerbated by the location of the air handler within the attic space – a common practice in much of the southern US. The air handler is poorly insulated but has the greatest temperature difference at the evaporator of any location in 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 use in 48 central Florida homes (Cummings, 1991) found that homes with the air handlers located in the attic used 30% more

[3]1 A simple calculation illustrates this fact. Assume a 2,000 square foot 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 and Jump and Modera, 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 the house, a UA ΔT calculation shows a ceiling heat gain of 3,500 Btu/hr. 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/hr if the cooling system ran the full hour under design conditions – more than twice the ceiling flux.

space cooling energy than those with 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. The negative pressures can then result in hot air from the attic being drawn down into the conditioned space through gaps around recessed light fixtures or other bypasses from the attic to the interior. Attic air is often also directly drawn into the return air stream through leakage pathways (see Figure 2). These phenomena are commonly encountered in slab on grade homes in Sunbelt states in the U.S. where the dominant infiltration l;eakage plane from the exterior is through the ceiling.

Figure 2. Thermograph of air being drawn from the attic to the air handler in a Florida house.

The impact of duct heat transfer and air leakage from the attic space shows that controlling attic air temperatures can be equally important as controlling ceiling heat flux alone. 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 2003, 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 x 14.6 m) frame building constructed in 1987 with its long axis oriented east_west (Figure 3). The roof and attic are partitioned to allow simultaneous testing of multiple roof configurations. The orientation provides a northern and southern exposure for the roofing materials under evaluation. The attic is sectioned into six individual 6 foot (1.8 m) wide test cells (detail A in Figure 3) spanning three 2 ft (0.6 m) trusses thermally separated by partition walls insulated to R_20 ft2_hr_^{o}F/Btu (RSI_3.5 m2_K/W) using 3 inches (7.6 cm) of isocyanurate insulation. The partitions between the individual cells are also well sealed to prevent air flow cross_contamination. The gable roof has a 5/12 pitch (22.6^{o}) and 3/4 inch (1.9 cm) plywood decking. On the attic floor, R_19 (RSI_3.3) unsurfaced batt insulation is installed between the trusses in all of the test bays (with the exception of Cell #2) in a consistent fashion. The attic is separated from the conditioned interior by 0.5 inch (1.3 cm) gypsum board. The interior of the FRF is a single open air conditioned space.

The roof lends itself to easy reconfiguration with different roofing products and has been used in the past to examine different levels of ventilation and installation configurations for tile roofing

(Beal and Chandra, 1995). Testing has also compared reflective roofing, radiant barriers and sealed attic construction (Parker and Sherwin, 1998). Appendix B lists the test cell configurations over recent years. A black asphalt shingle roof on one of the test cells serves as a reference for other roofing types.

Our tests in 2003 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 (the control cell)?

2) How does a Galvalume® metal roof with vented attic compare to the control cell?

3) How does a galvanized metal roof with vented attic perform relative to Galvalume® and other roof types?

4) How does a higher IR reflectance brown metal shingle roof function relative to the higher reflectance one installed the previous summer?

5) How does a white standing seam metal roof with vented attic perform relative to the other unfinished metal roof types?

Test Configuration and Instrumentation

To answer the above questions, we configured the test cells in the following fashion. Ages of roof construction are in parenthesis.

Cell #1: Galvalume® 5-vee unfinished metal roof; 1:300 vented attic (2nd year)

Cell #2: Sealed attic with proprietary configuration.

Cell #3: IR reflective brown metal shingles; 1:300 soffit and ridge ventilation (1st year)

Cell #4: Galvanized 5-vee unfinished metal roof; 1:300 ventilation (2nd year)

Cell #5: Black asphalt shingles; 1:300 soffit and ridge ventilation (control cell; 16 years old)

Cell #6: White standing seam metal; 1:300 vented attic (8 years old, but cleaned two year before)

The final appearance of the facility as configured for testing is shown in Figure 4. All roofing materials were installed in a conventional manner, and according to manufacturer’s specifications and current practice in the Central Florida area. Although raised wooden-battens type are sometimes used for metal roofing installations, current practice, with its focus on lower first costs, dictated a direct screwed application method for the metal roofs. Perforated vinyl soffit vents were used, and ridge vents for the vented cells were the "shingle vent" type with foam mesh or rigid plastic over the ridge outlet covered by shingles. The metal roofs had cap-type ridge vents.

Figure 4. Flexible Roof Facility in summer of 2003 configuration.

In applicable test cells the free ventilation area was estimated to be similar to typically installed roof systems. Samples of the new, unexposed roofing materials were sent to a laboratory to establish their integrated solar reflectance using ASTM Test Method E_903 (1996) and long wave emittance using ASTM E_408. Table 1 shows the laboratory reported values.

Note the large difference in the infrared emissivity of the unfinished metal roofs. Galvalume® (0.28) is much lower than the other painted metals (0.83), but galvanized roofs are much lower still (0.04). Generally, low emissive surfaces reach much higher temperatures since they do not readily give up collected heat back to the sky and its surroundings.

Table 1
Tested Roofing Material Solar Reflectances and Emittances*

Sample and Cell #	Solar Reflectance (%)	Long-wave emmittance
Cell #1: Galvalume® unfinished 5-vee metal	64.6%	0.28
Cell #2: Black shingle	2.7%	0.90
Cell #3: IR reflective brown metal shingle	30.8%	0.83
Cell #4: Galvanized unfinished 5-vee metal	70.9%	0.04
Cell #5: Black shingle	2.7%	0.90
Cell #6: White metal standing seam	67.6%	0.83

* Laboratory tested values using ASTM E-903 and ASTM E-408.

Instrumentation for the project was extensive so the data can eventually validate a detailed attic simulation model. A number of temperature measurements using type_T thermocouples were made. Air temperature measurements were shielded from the influence of radiation. The temperature measurements included:

- Exterior surface of the roof and underlayment
- Decking underside
- Attic air at several heights within the attic
- Soffit inlet air and ridge vent exit air
- Insulation top surface
- Conditioned interior ceiling

The following meteorological data were taken:

- Solar insolation
- Aspirated ambient air temperature
- Ambient relative humidity
- Wind speed at a 33 ft (10 m) height
- Rainfall (tipping bucket)

All of the test cells were operational by June 1, 2003, at which point data collection began. The test cells were maintained in an unaltered state through the middle of September with continuous data collection.

Results

Attic Air Temperatures

The average summer day mid-attic air temperature profiles are shown in Figure 5. The profiles show the impact of the various roofing options in reducing summer cooling energy use associated with attic duct heat gains and loads from unintended air leakage coming from the attic zone.

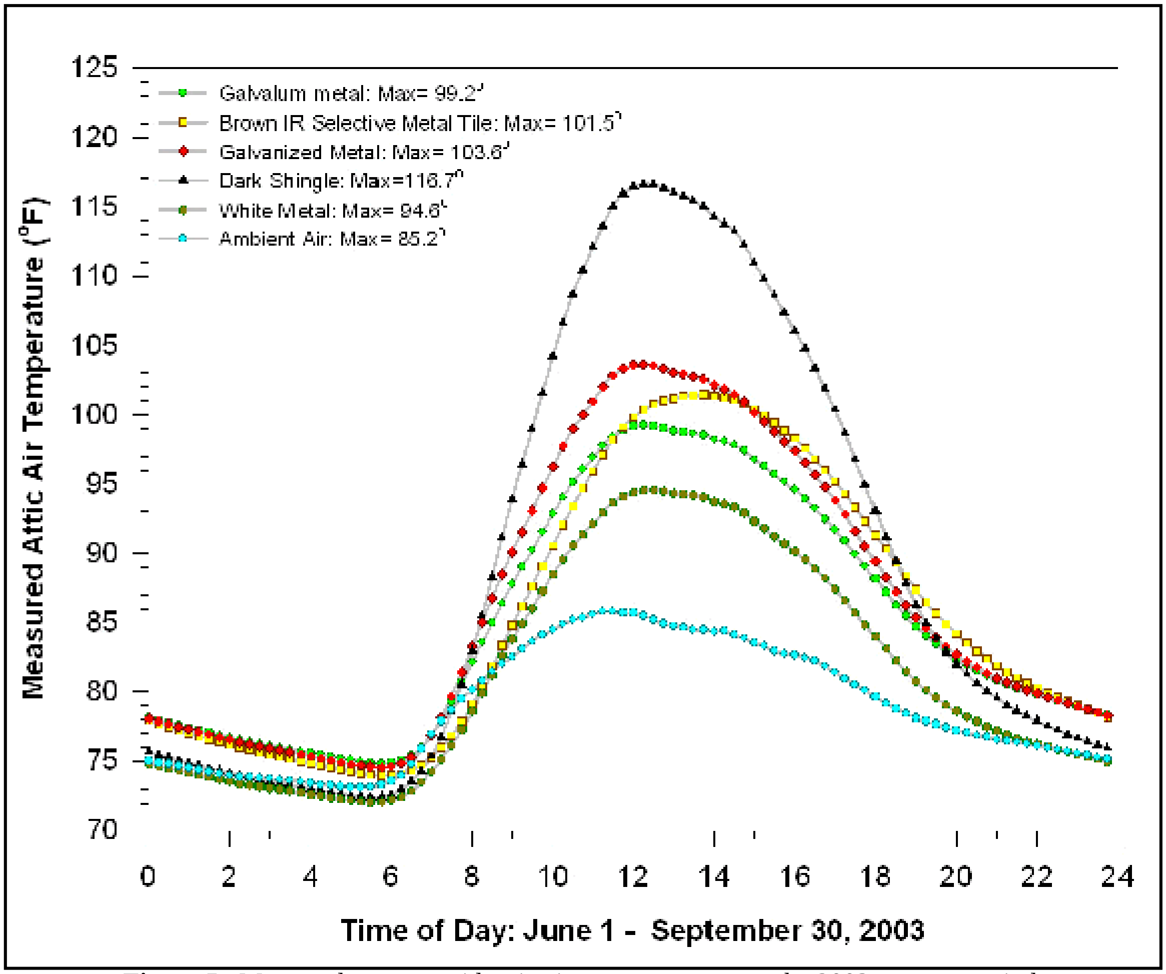


Figure 5. Measured average mid-attic air temperatures over the 2003 summer period.

The statistics for the average, minimum and maximum mid-attic air temperatures over the entire summer (hot average day) are summarized in Table 2. The most effective roof combination in this regard is Cell #6 with the vented white metal roof (81.0°F). Very similar to this performance is Cell #3 with the IR reflective metal shingle roof (82.3°F). Next best in performance is Cell #1 with the Galvalume® metal roof and vented attic at 83.6°F. The lower emissivity galvanized metal roof (Cell #4) averaging 85.2°F, is least beneficial relative to the standard attic which is at 89.1°F.

Table 2
FRF: Measured Mid-Attic Air Temperatures (^oF)
June 1 - September 30, 2003

	Description	**Mean**	**Minimum**	**Maximum**
Outdoor Air	Ambient Air	78.9	65.6	93.3
Cell #1	Galvalume® metal roof	85.2	68.5	112.7
Cell #3	High reflectance brown metal shingle	85.7	66.2	115.9
Cell #4	Galvanized metal roof	86.6	67.1	118.7
Cell #5	Black shingle (control cell)	89.4	63.8	138.1
Cell #6	White metal roof	81.4	63.3	105.8

A rank order impact listing from best to worst summarizes these findings. Note that this ranking doesn't account for ceiling fluxes.

Rank Order on Reducing Cooling Season Impact Due to Duct System Heat Gains and Air Leakage (best to worst)

1. White metal roof with vented attic
2. IR reflective brown metal shingles with vented attic
3. Galvalume® metal roof with vented attic
4. Galvanized metal roof with vented attic
5. Black asphalt shingles with vented attic (control)

Maximum Attic Air Temperatures

A comparison of the average daily maximum mid-attic air temperature for each cell against the average daily maximum ambient air temperature along with the corresponding temperature difference is shown in Table 3 below for the period between June 1 and September 30, 2003. These results show the performance of the various roofing options in controlling duct heat gains and loads from unintended air leakage under averaged peak conditions for the period.

Table 3
FRF Average Maximum Attic and Ambient Air Temperatures

Cell No.	**Description**	**Average Max. Attic**	**Average Max. Ambient**	**Difference**
Cell #1	Galvalume® metal roof	99.2^oF	85.8^oF	+ 13.4^oF
Cell #3	High reflectance brown metal shingle	101.5^oF	85.8^oF	+ 15.7^oF
Cell #4	Galvanized metal roof	103.6^oF	85.8^oF	+ 17.8^oF
Cell #5	Black shingle (control cell)	116.7^oF	85.8^oF	+ 30.9^oF
Cell #6	White metal roof	94.6^oF	85.8^oF	+ 8.8^oF

Rank Order on Reducing Peak Impact Due to Duct System Heat Gains and Air Leakage (best to worst)

1. High reflectance brown metal shingles with vented attic
2. White metal with vented attic
3. Galvalume® metal with vented attic
4. Galvanized metal with vented attic
5. Black asphalt shingles with vented attic

The highly reflective brown metal shingle (Cell #3) provided the coolest attic of the cells without roof deck insulation. The average maximum mid-attic temperature in this case was 101.5^{o}F, or 8.2^{o}F higher than ambient. In 2002 the ivory, IR reflective shingle on the test cell had a maximum attic air temperature that was 7.4^{o}F higher than ambient. In 2000, a non-IR reflective brown metal shingle that was on the same cell had an average maximum attic temperature 13.5^{o}F higher than ambient, while in 1999, a white highly reflective metal shingle on the same cell had an average maximum attic temperature 3.8^{o}F higher than ambient. Thus, the new brown colored IR reflective shingle is only slightly worse than the lighter colored ivory product tested the previous year.

The white standing seam metal (Cell #6) roof was vented during the 2003 summer test period. It was in its second year of exposure to allow comparison with the pristine Galvalume® and galvanized metal roofs. Comparison with the previous year shows that soiling of the white roof only slightly impacted performance. In 2002 the average daily maximum attic air temperature above ambient was +7.8^{o}F against +8.8^{o}F in the summer of 2003.

Ceiling Heat Flux

Table 4 shows the statistics for ceiling heat fluxes over the 2003 summer period, and Figure 6 shows the ceiling flux data for the same period graphically. The highly reflective brown metal shingle roof (Cell #3) has the lowest peak ceiling heat flux at 1.42 Btu/ft^2/hr, and also has a relatively low mean flux of 0.39 Btu/ft^2/hr, although higher than the white metal roof at 0.26 Btu/ft^2/hr. The vented white metal roof shows the lowest overall average heat flux and thus the lowest indicated ceiling influence on cooling for the overall period. The Galvalume® roof (mean heat flux of 0.47 Btu/ft^2/hr) performs better than the galvanized metal roof (mean 0.55 /Btu/ft^2/hr).

Table 4
FRF Measured Ceiling Heat Fluxes (Btu/ft^2/hr)
June 1 - September 30, 2003

Cell #	Description	Mean	Min	Max	Flux Change Relative to Cell #5
1	Galvalume® metal roof	0.47	-0.53	1.90	-28.8%
3	High reflectance brown metal shingle	0.39	-0.28	1.42	-40.9%
4	Galvanized metal roof	0.55	-0.55	2.21	-16.7%
5	Black shingle (control cell)	0.66	-0.61	3.13	Ref
6	White metal roof	0.26	-0.63	1.45	-60.6%

Rank Order on Reducing Cooling Season Ceiling Heat Flux (best to worst)

1. White metal with vented attic
2. Brown high reflectance metal shingles with vented attic
3. Galvalume® metal roof with vented attic
4. Galvanized metal roof with vented attic
5. Black asphalt shingles with ventiled attic

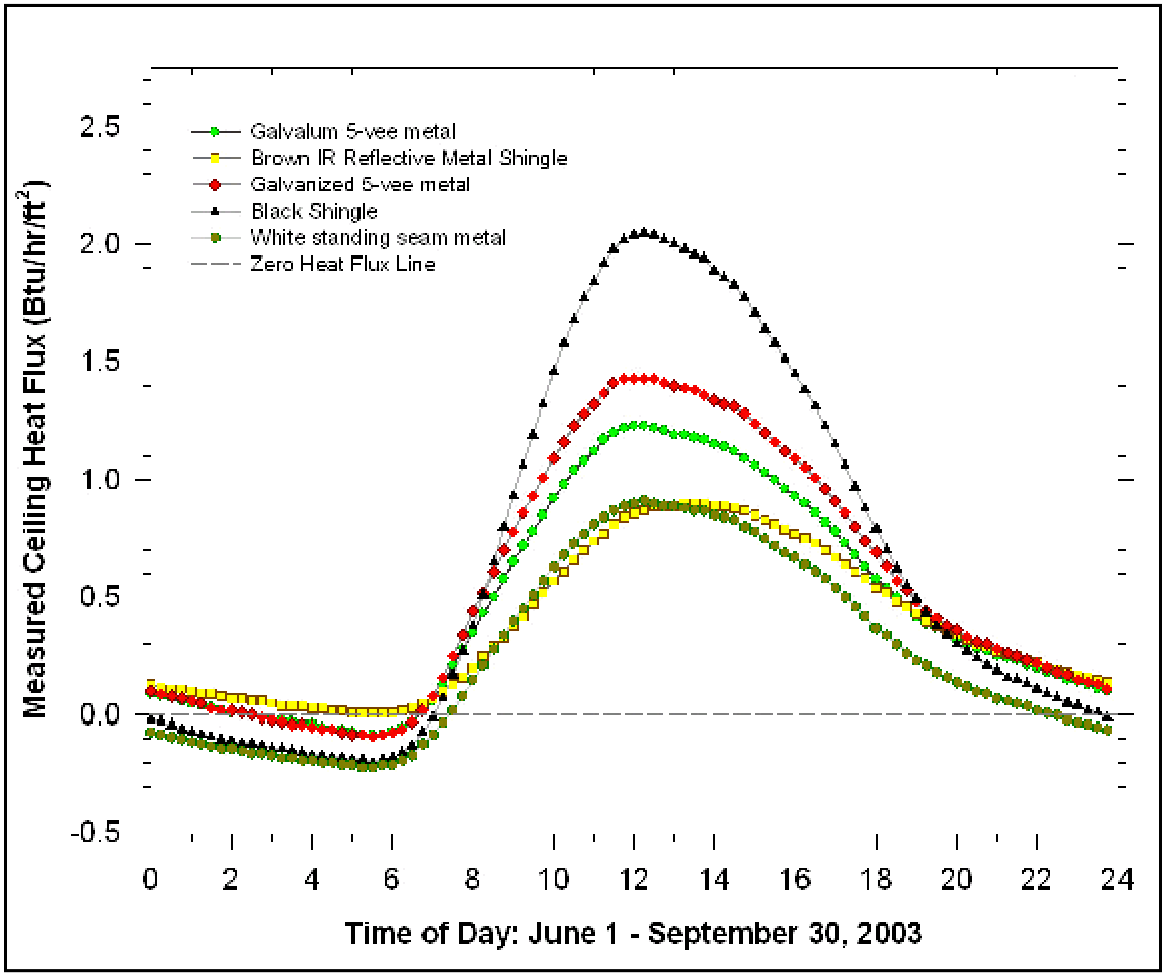


Figure 6. Measured average ceiling heat flux over the summer of 2003.

Estimation of Overall Impact of Roofing System

As described earlier in the report, the impact of a roofing system on cooling energy use in southern climates is often made up of three elements:

- Ceiling heat flux to the interior

- Heat gain to the duct system located in the attic space
- Air unintentionally drawn from the attic into conditioned space

The heat flux through the ceiling impacts the interior temperature and hence the thermostat which then calls for mechanical cooling. Thus, the heat flux impacts cooling energy use at all hours and affects the demand for air conditioning.

The other two influences, air leakage drawn from the attic into the conditioned space and heat gain to the duct system primarily occur only when the cooling system operates. Thus, the impact depends on the air conditioner runtime in a particular time interval. To obtain the average cooling system runtime, we used a large set of residential cooling energy use data which has only recently been made public domain. This data comes form 171 homes monitored in the Central Florida area where the 15-minute air conditioner power was measured for over a year (Parker, 2002).

For each site, the maximum demand during summer was also recorded to determine the maximum cooling system power. Thus, it is possible to determine the diversified runtime fraction by dividing the average air conditioner system power by its maximum demand. This calculation was made by averaging the air conditioner and air handler power for all sites and dividing by the average maximum summer demand, which was 3.96 kW.

Figure 7 shows the maximum average cooling system runtime is approximately 55% at 4 PM and is at its minimum of 15% at 6 AM. It is important to note that this is an average summer day as determined by evaluating all data from June - September inclusive. It does not represent an extreme summer day condition.

With the runtime fraction determined for an average home in Central Florida for the summer, it is then possible to estimate the impact of duct heat gain and attic return air leakage with some working assumptions.

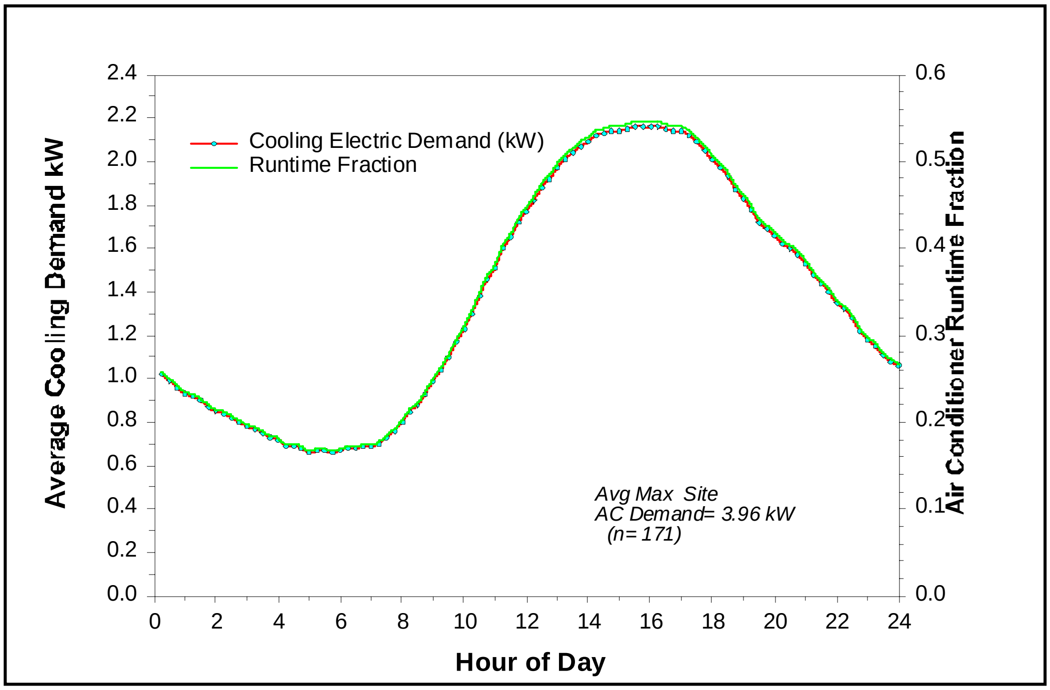


Figure 7. Average air conditioner power and average runtime fraction over an average summer day in a large sample of Central Florida homes.

To estimate the overall impact of each roofing system, we first assume a typical single-story home with 2,000 square feet of conditioned floor area. Then three equations are defined to estimate the individual impacts of duct heat gain (Q_{duct}), attic air leakage to conditioned space (Q_{leak}) and ceiling heat flux ($Q_{ceiling}$).

For duct gains, heat transfer is estimated to be:

$$Q_{duct} = (Area_{duct}/R_{duct}) * (T_{attic} - T_{duct,air}) * RTF$$

Where:

Q_{duct}	= cooling load related to duct gains (Btu/hr)
$Area_{duct}$	= 25% of conditioned floor area or 500 ft^2 (Gu et al., 1996, see Appendix G)
R_{duct}	= R-6 flex duct
T_{attic}	= attic air temperature measured in FRF test cells
$T_{duct, air}$	= typical air temperature leaving evaporator (58^{o}F)
RTF	= typical air conditioner runtime fraction as determined from data in Figure 7

Generally, the duct heat gains will favor attic construction which result in lower surrounding attic temperatures. For attic air leakage to conditioned space, the estimated heat transfer is:

$$Q_{leak} = Flow * PctLeak * PctAttic * 1.08 * (T_{attic} - T_{interior}) * RTF$$

Where:

Q_{leak}	= cooling load related to unintentional air leakage to conditioned space from attic (Btu/hr)
Flow	= air handler flow; 4-ton system for 2000 ft^2 home, 400 cfm/ton = 1600 cfm
PctLeak	= duct leakage assumed as 10% of air handler flow
1.08	= air specific heat density product per CFM (Btu/hr CFM ^oF)
PctAttic	= 33% of duct leakage is assumed to be leakage from the attic (see Figure 1)
T_{attic}	= attic air temperature measured in FRF test cells
$T_{interior}$	= interior cooling temperature (75^oF)
RTF	= typical air conditioner runtime fraction as determined from data in Figure 7

Heat flux is proportional to the house ceiling area and is estimated as:

$$Q_{ceiling} = Area_{ceiling} * Q_{flux}$$

Where:

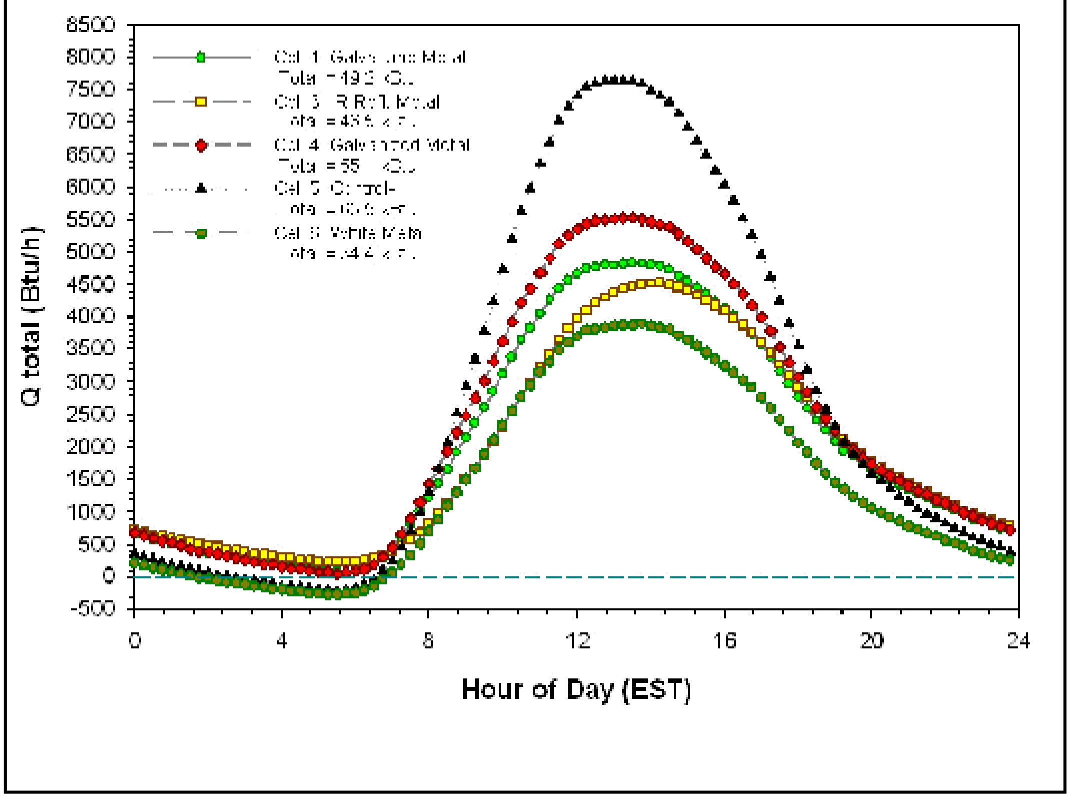
$Area_{ceiling}$	= 2,000 ft^2
Q_{flux}	= measured ceiling heat flux from FRF data

So the total heat gain impact of a roofing systems is estimated to be:

$$Q_{tot} = Q_{duct} + Q_{leak} + Q_{ceiling}$$

Figure 8 shows the combined roofing system heat gain estimated for 2,000 square foot houses with each of the six roofing systems tested this summer. Figure 9 breaks down the Q_{duct}, Q_{leak} and $Q_{ceiling}$ components of Figure 8 for the Cell #5 control roof to show the relative contribution of each component. Note that the combined estimated duct leak gain and duct conduction gain is approximately equal to the ceiling flux gain.

Figure 8. Estimated combined impact of duct heat gain, air leakage from the attic to conditioned space and ceiling heat flux



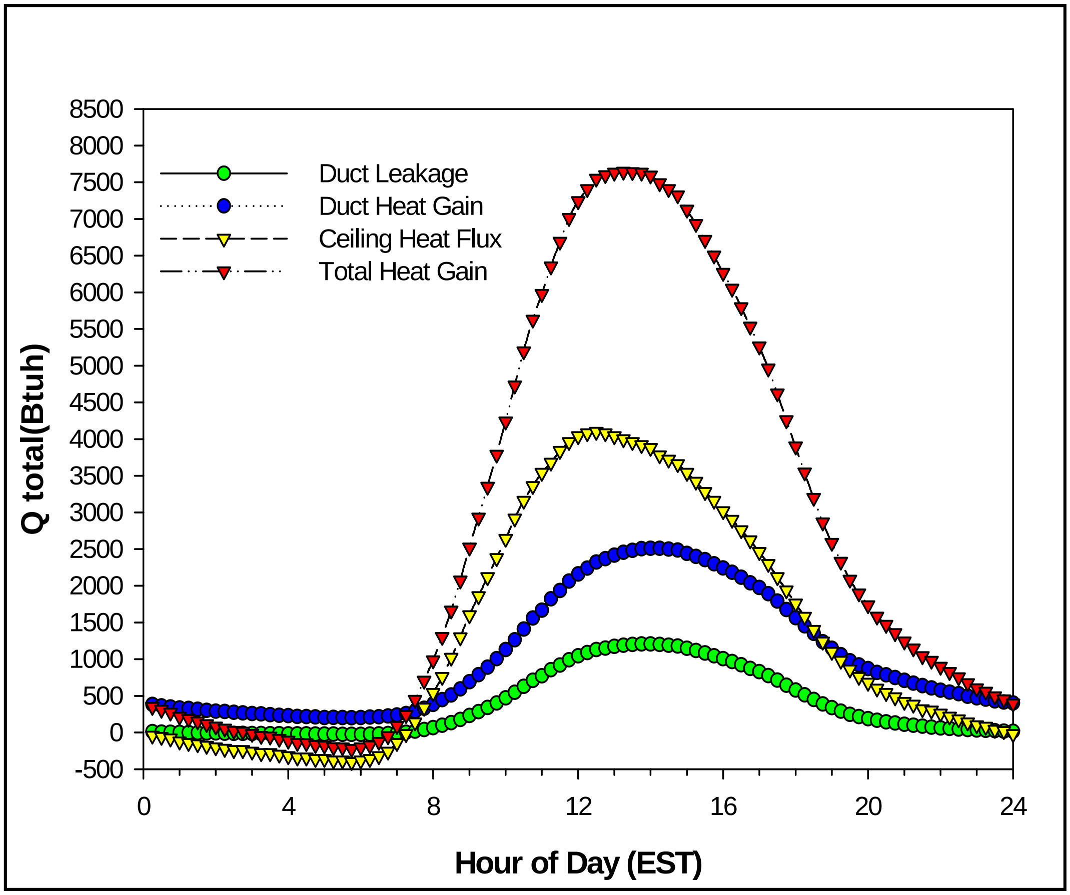


Figure 9. Components of estimated daily heat gain due to the duct heat gain, air leakage from the attic to the conditioned space and ceiling heat flux for Cell #5.

Table 5 shows the relative impact on space cooling and performance relative to the control (Cell #5).

Table 5
Combined Ceiling Heat Flux, Duct Heat Gain and Attic Duct Leakage Impact in a 2000 sqft Home

Case		Average Daily kBtu from Roof/Attic	Percent Heat Gain Difference Relative to Control
Cell #1	Galvalume® metal roof	49.2	-24.9%
Cell #3	High reflectance brown metal shingle	46.5	-29.0%
Cell #4	Galvanized metal roof	55.1	-15.9%
Cell #5	Black shingle (control cell)	65.5	0.0%
Cell #6	White metal roof	34.4	-47.5%

The alternative test cells do better than the standard reference cell. The estimation shows that the white metal roof (Cell #6) does best, followed by the high reflectance brown metal shingle roof (Cell #3). The Galvalume® metal roof with a ventilated attic provides about a 24% reduction in heat gain. The galvanized roof with its lower emissivity and aged reflectivity provides only about a 16% heat reduction. Both the *Galvalume* and galvanized roofs provide less reduction in heat gain compared to the previous year (*Galvalume* = 30% → 24%; Galvanized = 20% → 16%) showing aging and decreased reflectance of the products. Conversely, the white metal test cell showed no measurable change in its performance two years after cleaning.

Conclusions

The 2003 FRF test results suggest indicators of the relative thermal performance of various roofing systems under typical Florida summer conditions. Within the body of the report, we describe the various relative impacts to ceiling heat flux, unintended attic air leakage and duct heat gain. Here we provide a summary extrapolated heat gain analyses as a useful means of estimating total cooling energy benefits of different roofing systems.

The vented standing seam white metal roof had the lowest total system heat gain of all the tested roofs since its ceiling heat flux was much lower than that with the sealed attic construction. Its attic temperatures were also much lower than the conventional dark shingled attic test cell. The average daily maximum attic temperature was only about 95^{o}F. The overall cooling related savings from this roof construction was on the order of 47% of roof-related heat gain.

Testing was done on a proprietary sealed attic system within Cell #2 which is not reported on in the public domain report.

An important objective for testing for 2003 was to continue evaluation of popular unfinished metal roofing systems in a second of year of exposure to compare with other types. We tested an unfinished *Galvalume*® 5-vee metal roof with attic ventilation as well as a galvanized 5-vee metal roof in an identical configuration. The galvanized roof has a high solar reflectance, but a much lower infrared emittance (0.04) which we expected to hurt its performance. The monitoring bore out this fact. The *Galvalume*® metal roof both ran cooler and produced much less roof related heat gain. The *Galvalume*® roof provided a 24% reduction in roof and attic related heat gain over the summer as compared with a 16% reduction for the galvanized roof. Moreover, as galvanized roofs are known to lose their solar reflectance over time as the zinc surface oxidizes, we expect to see a further decrease in performance in a third season of testing. Although white metal performs best, the *Galvalume*® metal roofing surface is a good second choice for mixed climates, and does nearly as well as the IR selective brown metal shingles.

At an average maximum mid-attic temperature of 101.5^{o}F (15.2^{o}F lower than the control dark shingle cell), the highly reflective brown metal shingle roof (Cell #3) provided the coolest peak attic temperature of all cells without a sealed attic. While the brown metal shingle roof's reflectance was somewhat lower than that of the white metal roof, it is likely that the air space under the metal shingles provides additional effective insulation. Both of these characteristics probably come into play to help it achieve lower peak attic temperatures, while the additional insulating effect explains its slightly higher nighttime attic temperatures.

We also estimated the combined impact of ceiling heat flux, duct heat gain and air being unintentionally drawn from the attic into conditioned space for the various roof constructions. These estimates indicate that the tested roof configurations yield lower heat gains during the summer cooling season than the control roof which has dark shingles with R-19 ceiling insulation and 1:300 ventilation.

One finding from our testing over the last several years is that nighttime attic temperature and reverse ceiling heat flux have a significant impact on the total daily heat gain, and therefore constructions that produce lower evening attic temperatures benefit from these effects. The rank order is shown below and in Figure 10 with the percentage reduction of roof/attic related heat gain (and the approximate overall building cooling energy savings).[4]

	Roof-related Savings	Approximate Overall Savings
• White metal with vented attic:	47.5%	16%
• High reflectance brown metal shingle with vented attic:	29.0%	10%
• Galvalume® unfinished metal roof with vented attic:	24.4%	8%
• Galvanized unfinished metal roof, vented attic	15.9%	5%

The rank order of the reductions are consistent with the whole-house roof testing which was recently completed for FPL in Ft. Myers (Parker et al., 2001) which showed white metal roofing as having the largest reductions.

[4] [2] Since the roof/attic ceiling heat flux, duct heat transfer and duct leakage likely comprise about a third of the total home cooling loads, the above values are modified to approximate the overall impact.

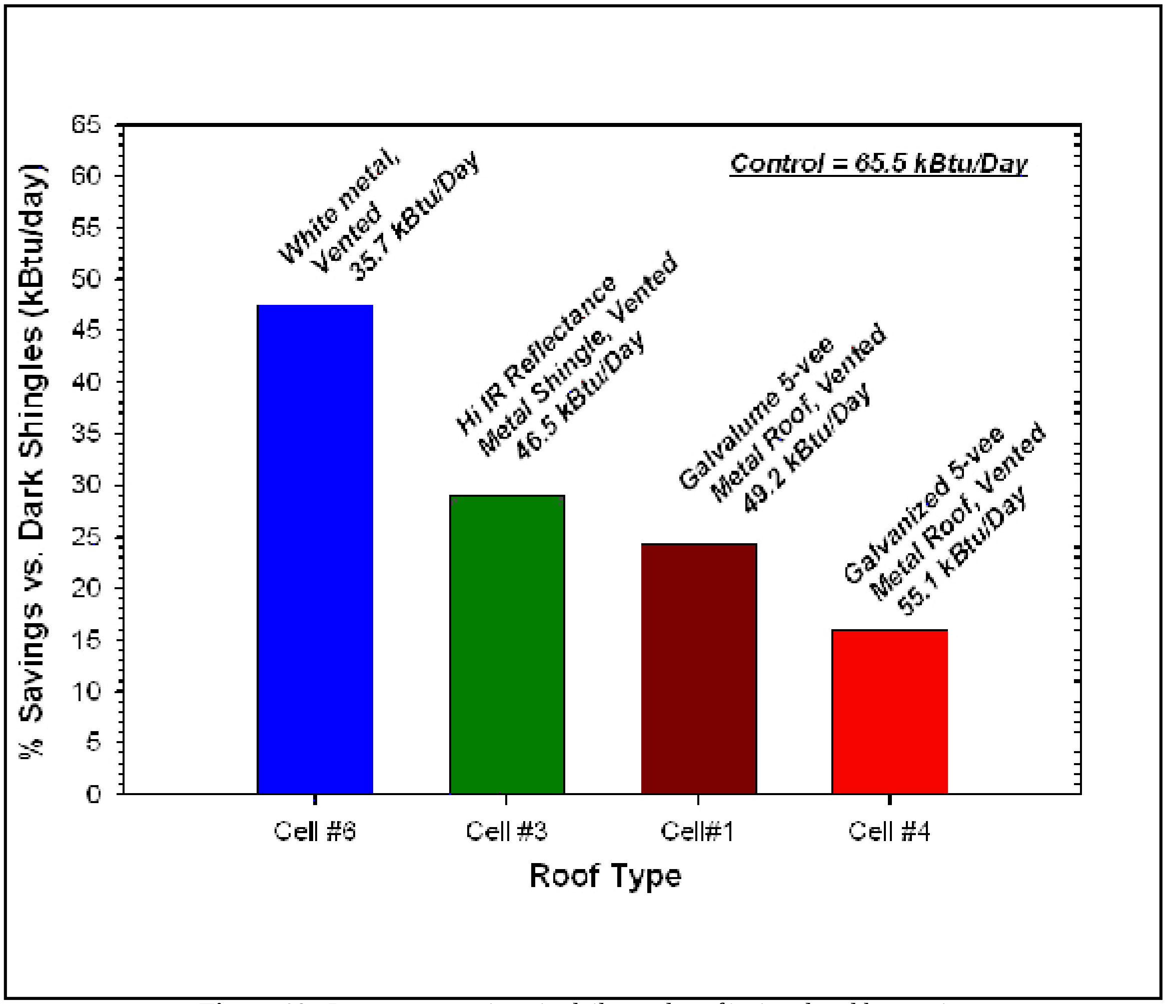


Figure 10. Percentage savings in daily total roof/attic related heat gain.

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Appendix A

Long Term Weather Data at the Flexible Roof Facility

Long Term Weather Data at the Flexible Roof Facility

For the analysis, we examined how the long term summer weather has varied at the Flexible Roof Facility (FRF) from 1997 - 2003. The purpose was to create a method that can be used to normalize data on attic temperatures and ceiling heat fluxes that will allow comparison over various roofing systems from one year to the next.

This was done by examining how temperatures and heat fluxes varied from one year to the next when evaluated from June - September. The results, which are shown below, evidence little variation from one year to the next, both for ambient air temperature and in Cell #5, the reference cell, over the last five years. Ceiling heat fluxes vary a little more, but not that much.

Table A-1
Variation of Weather and Reference Cell Conditions from 1997 - 2003

		Cell #5			
Year	Avg. Ambient Temp (^{o}F)	Avg. Attic Temp (^{o}F)	Max Attic Temp (^{o}F)	Avg. Flux (Btu/ft^{2}/hr)	Max Flux (Btu/ft^{2}/hr)
1997	79.1	90.8	141.9	0.73	3.34
1998	81.7	92.6	142.3	0.84	3.39
1999	79.9	90.9	142.3	0.77	3.41
2000	80.1	91.2	141.2	0.78	3.36
2001	79.3	90.4	143.4	0.74	3.48
2002	79.1	89.1	139.6	0.70	3.32
2003	78.9	89.4	138.1	0.66	3.13

The year 1998 stands out as an outliar, but that is expected (record breaking hot summer). Our working idea would be to ratio temperature and flux data to 1997 for each quantity to normalize for summer weather in future analysis of data from the FRF when evaluated over successive summer seasons.

Appendix B

FRF Test Cell Summer Configuration History

FRF Test Cell Summer Configuration History
(**Bold** = changed cell in that year)

1997

1 White barrel tile, standard ventilation
2 Dark shingles with RBS, 1:150 ventilation
3 Dark shingles with RBS, 1:300 ventilation
4 Red terra cotta tile, standard ventilation
5 Dark shingles with standard ventilation (Control)
6 **White standing seam metal with standard ventilation**

1998

1 White tile, standard ventilation
2 Dark shingles, sealed attic with R-19 Icynene deck insulation
3 Dark shingles with RBS, 1:300 ventilation
4 Red terra cotta tile, standard ventilation
5 Dark shingles with standard ventilation (Control)
6 White standing seam metal with standard ventilation

1999

1 White tile, standard ventilation
2 Dark shingles, sealed attic with R-19 Icynene deck insulation
3 White metal shingles with standard ventilation
4 Red terra cotta tile, standard ventilation
5 Dark shingles with standard ventilation (Control)
6 White standing seam metal with standard ventilation

2000

1 White tile, standard ventilation
2 Dark shingles, sealed attic with R-19 Icynene deck insulation
3 Dark brown metal shingles with standard ventilation
4 Red terra cotta tile, standard ventilation
5 Dark shingles with standard ventilation (Control)
6 White metal standing seam roof with standard ventilation

2001

1 White barrel tile, unvented
2 Dark shingles, double roof, sealed attic with R-19 Icynene deck insulation
3 IR reflective brown metal shingles with standard ventilation
4 Red terra cotta tile, standard ventilation
5 Dark shingles with standard ventilation (Control)
6 White metal standing seam roof, unvented

2002

1 Galvalume® 5-vee Roof, vented
2 Dark shingle, double roof, sealed attic with R-19 Icynene deck insulation
3 IR reflective ivory metal shingles, vented
4 Galvanized 5-vee roof, vented
5 Dark shingles with standard ventilation (Control)
6 White standing seam roof, vented

2003

1 Galvalume® 5-vee Roof, vented
2 Proprietary Test Cell
3 IR reflective brown metal shingles, vented
4 Galvanized 5-vee roof, vented
5 Dark shingles with standard ventilation (Control)
6 White standing seam roof, vented