Flexible Roofing Facility: 2004 Summer Test Results

Authors

Parker, Danny
Sonne, Jeffrey
Sherwin, John

Original Publication

Danny Parker, Jeffrey Sonne, John Sherwin, "Flexible Roofing Facility: 2004 Summer Test Results", Prepared for U.S. Department of Energy Building Technologies Program, July 2005.

Publication Number

FSEC-CR-1514-05

Copyright

Disclaimer

Flexible Roofing Facility:
2004 Summer Test Results

FSEC-CR-1514-05
July 2005

Prepared for:

U.S. Department of Energy
Building Technologies Program

George James, Program Manager
Building America, Washington, DC

Bill Haslebacher, Project Officer
DOE NETL, WV

Prepared by:

Danny S. Parker
Jeffrey K. Sonne
John R. Sherwin

Building AMERICA
U.S. Department of Energy
Industrialized
Housing Partnership

Florida Solar Energy Center
1679 Clearlake Rd.
Cocoa, FL 32922-5703

Table of Contents

Appendices

NOTICE

REPORT AUTHORS

Danny S. Parker
Jeffrey K. Sonne
John R. Sherwin

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). Since 1989 the testing has evaluated how roofing systems impact summer residential cooling energy use and peak demand. In the summer of 2004, the following roofing systems were tested. Cell numbering is from left to right.[1]

Cell #	Description
1	Galvalume®[2] unfinished (unpainted) 5-vee metal with vented attic (3rd year of exposure)
2	Proprietary test cell
3	Proprietary test cell
4	Galvanized unfinished 5-vee metal with vented attic (3rd year of exposure)
5	Black shingles with standard attic ventilation (Control Test Cell)
6	White standing seam metal with vented attic (3rd 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. The measured thermal impacts include ceiling heat flux, unintended attic air leakage and duct heat gain.

The white metal roof results in the coolest attic over the summer, with an average day peak air temperature of only 95.7ºF – 22.2º cooler than the peak in the control attic with dark shingles.

Test Cells #2 and #3 had proprietary test configurations that are not further described in this report.

A major objective for 2004 was comparative testing of metal roofing under long term conditions. Given the popularity of unfinished metal roofs, we tested both galvanized and Galvalume® roofs in their third 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 (10.9ºF and 2.1ºF cooler than the control dark shingle respectively). However, both unfinished metal roofs showed significant degradation in their performance over the three year period compared to the white metal roof.

We also estimated the combined impact of ceiling heat flux, duct heat gain and unintended attic air leakage from the various roof constructions. The alternative constructions produced lower estimated cooling energy loads than the standard vented attic with dark shingles. The Galvalume® roof clearly provided greater reductions to cooling energy use than the galvanized roof after three summers of exposure, although both suffered significant degradation relative to the first year's performance. More specifically, the Galvalume® and Galvanized roof system provided a 32% and 22% savings in the first year of exposure, but only 12% and 1% respectively after three years of exposure.

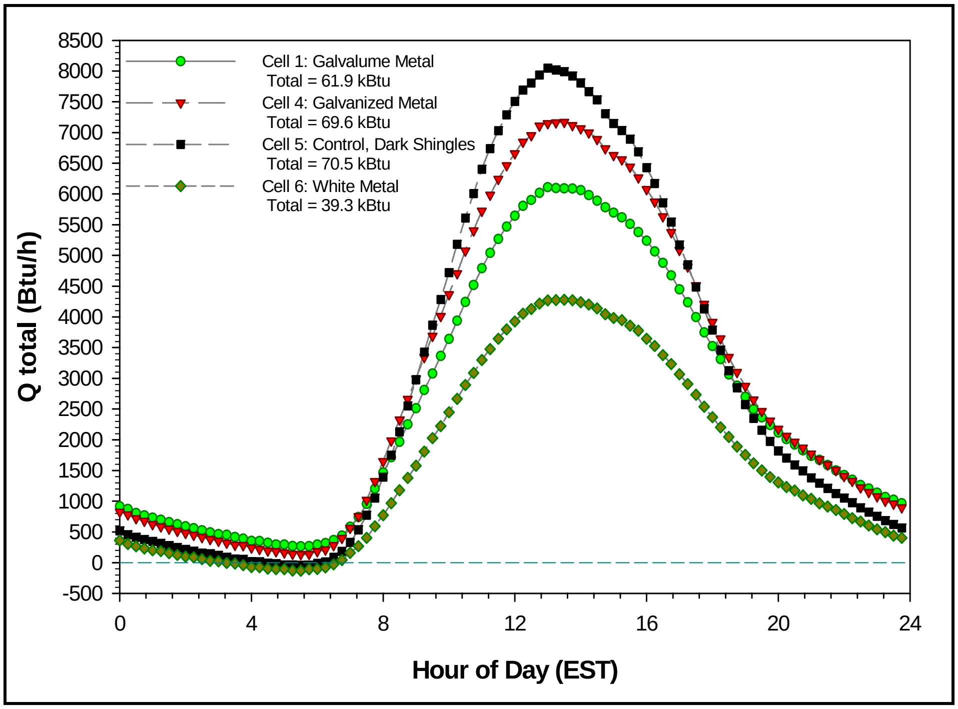

Figure E-2. Estimated combined impact of duct heat gain, air leakage from the attic to conditioned space and ceiling heat flux on space cooling needs on an average summer day in a 2,000 ft^2 home.

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)	44%	15%
2	Galvalume® unfinished metal with vented attic (Cell #1)	12%	4%
3	Galvanized unfinished metal roof with vented attic (Cell #4)	1%	0%

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. After long-term exposure, test results indicate that galvanized metal roofing is no better than a standard asphalt shingle roof after three years of exposure. On the other hand, the Galvalume roof does maintain some advantage although not nearly so great as the white metal type.

Flexible Roofing Facility: 2004 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.

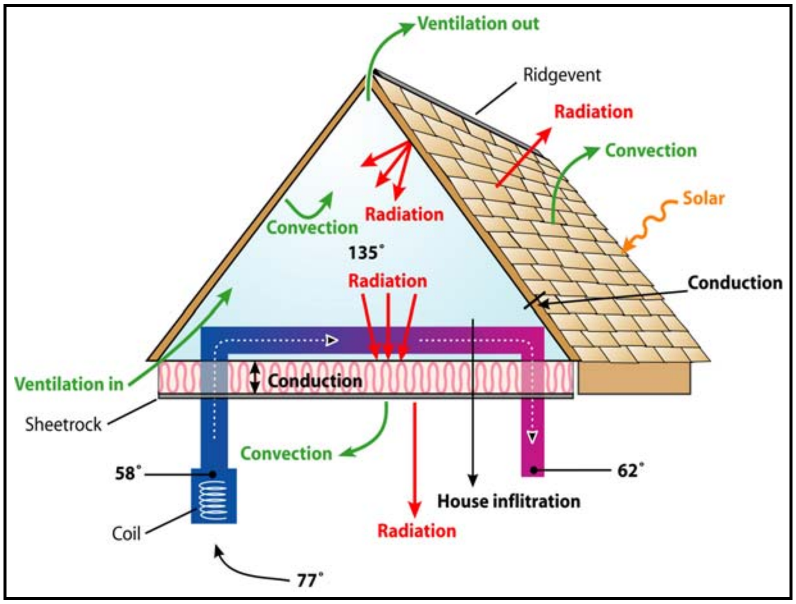

Figure 1. Vented attic thermal processes.

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 space cooling energy than those with air handlers located in garages or elsewhere.

---

[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 130ºF, and 78ºF 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 57ºF 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.

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 leakage plane from the exterior is through the ceiling.

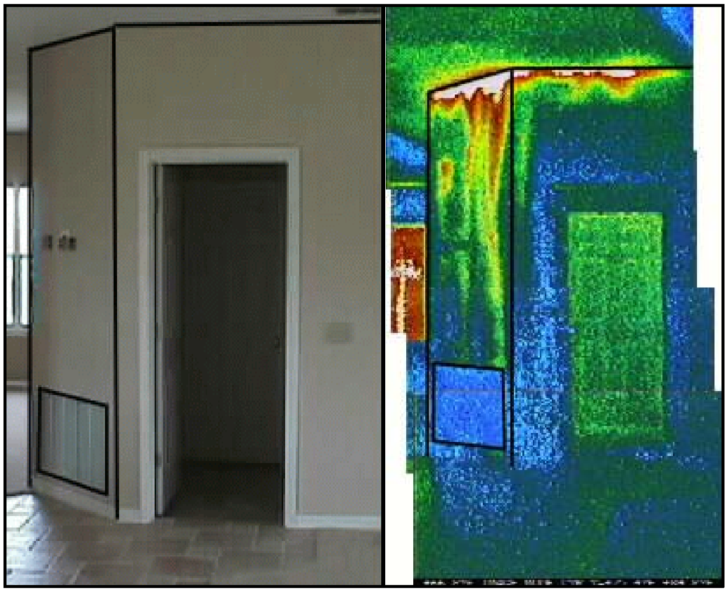

Figure 2. Thermograph of air being drawn from the attic to the air handler in a Florida house.

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 2004, 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-°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°) 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.

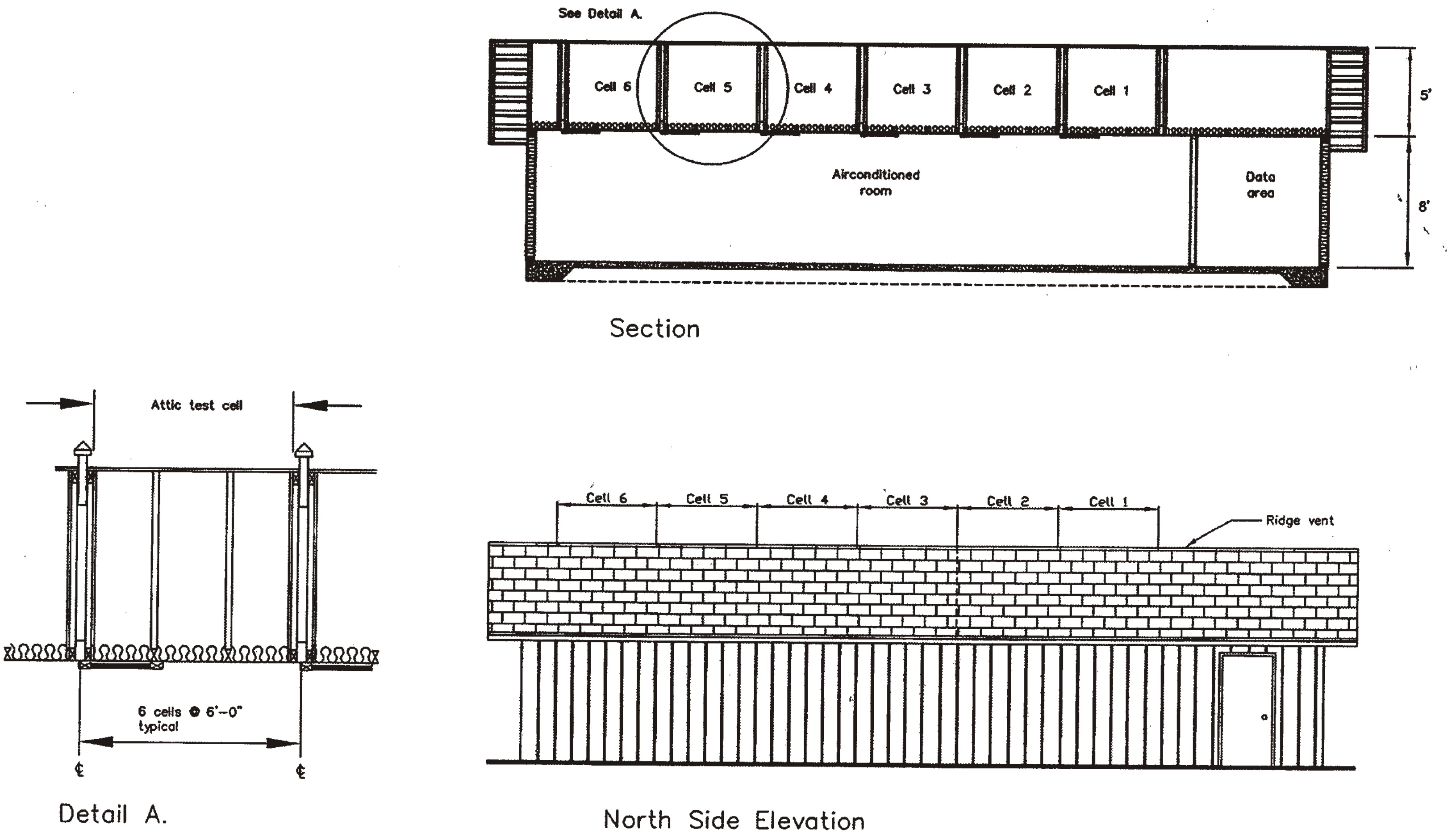

Figure 3. Flexible roofing facility layout and schematic.

Our public domain tests in 2004 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 in its third year of exposure?

3) How does a galvanized metal roof with vented attic perform relative to Galvalume® and other roof types in its third year of exposure?

4) How does a white standing seam metal roof with vented attic perform relative to the other unfinished metal roof types (8th year of exposure; 3rd year since cleaning)?

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 (3rd year)

Cell #2: Proprietary test cell

Cell #3: Proprietary test cell

Cell #4: Galvanized 5-vee unfinished metal roof; 1:300 ventilation (3rd 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 2004 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. The aged values for the materials will also be obtained and incorporated into the available data.

Note the large difference in the infrared emissivity of the unfinished metal roofs. Galvalume® (0.28) is much lower than the other painted metals (0.85), 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: Proprietary test cell	NA	NA
Cell #3: Proprietary test cell	NA	NA
Cell #4: Galvanized unfinished 5-vee metal	70.9%	0.04
Cell #5: Black shingle over vented attic	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; these are initial (not aged) values.

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, 2004, at which point data collection began. However, in early July in an effort began to attempt to make the ventilation of each test cell consistent with FHA 1:300 ventilation ratio for venting. Unfortunately, those doing the testing were under the common, but mistaken impression that the 1:300 ventilation ratio refers to the free inlet area in both soffit and ridge. 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.

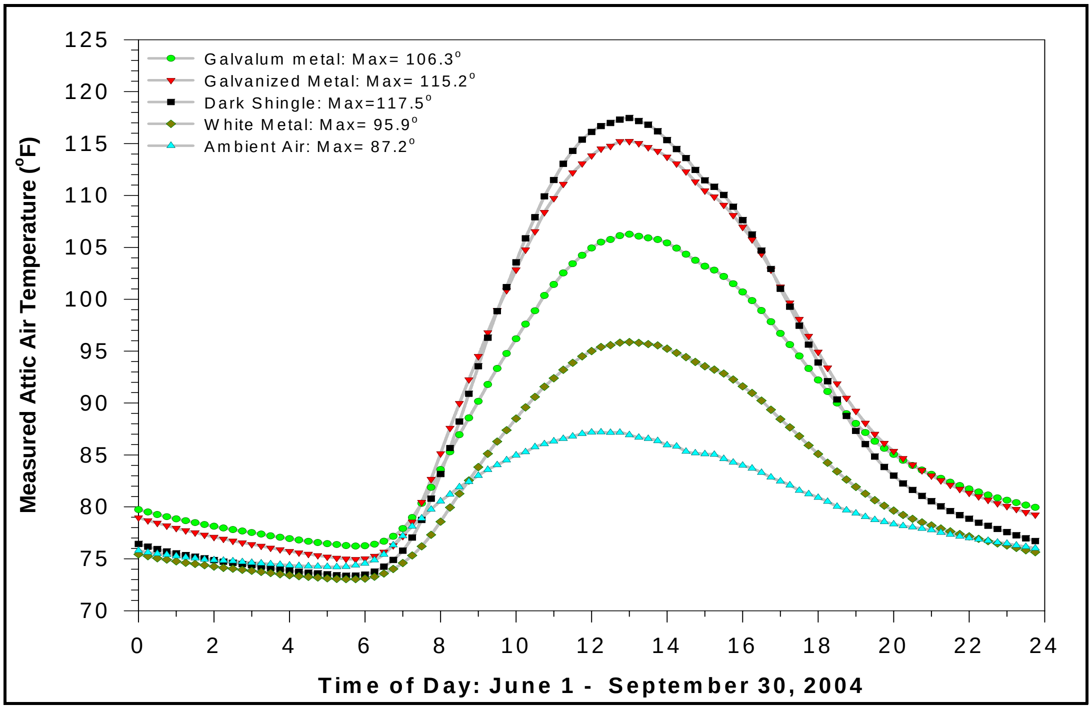

Figure 5. Measured average mid-attic air temperatures over the 2004 summer period

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 (82.3°F). Second best performance is Cell #3 with the gree metal roof on battens with an air space and radiant barrier (85.7°F). Next best in performance is Cell #1 with the Galvalume® metal roof and vented attic at 88.8°F. The lower emissivity galvanized metal roof (Cell #4) averaging 90.9°F, is actually worse than the standard attic which is at 90.0°F. It is noteworthy, that both the unfinished metal roofs showed substantially worse performance during their third year of exposure with the galvanized roof no longer provide any benefits at all and the *Galvalume* roof only providing marginally better performance. Meanwhile, after eight years of exposure (and one cleaning three years ago), the white standing seam metal roof shows clearly superior performance to the other types.

Table 2
FRF: Measured Mid-Attic Air Temperatures (°F)
June 1 - September 30, 2004

	Description	**Mean**	**Minimum**	**Maximum**
Outdoor Air	Ambient Air	79.9	66.8	95.9
Cell #1	Galvalume® metal roof over vented attic	88.4	67.3	129.7
Cell #2	Proprietary test cell	NA	NA	NA
Cell #3	Proprietary test cell	NA	NA	NA
Cell #4	Galvanized metal roof over vented attic	90.9	67.0	146.8
Cell #5	Black shingle over vented attic (control)	90.0	68.7	152.6
Cell #6	White metal roof over vented attic	82.3	66.0	109.3

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. Galvalume® metal roof with vented attic
3 Black asphalt shingles with vented attic (control)
4 Galvanized metal roof with vented attic

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, 2004. 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	106.0ºF	87.2ºF	+ 18.8ºF
Cell #2	Proprietary test cell	NA	NA	NA
Cell #3	Proprietary test cell	NA	NA	NA
Cell #4	Galvanized metal roof	114.8ºF	87.2ºF	+ 27.6ºF
Cell #5	Black shingle (control cell)	116.9ºF	87.2ºF	+ 29.7ºF
Cell #6	White metal roof	95.7ºF	87.2ºF	+ 8.5ºF

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

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

The white metal roof (Cell #6) with attic ventilation provided the coolest attic of the cells. The average maximum mid-attic temperature in this case was 95.7ºF, or 8.5ºF higher than ambient. It was in its 3rd year of exposure since cleaning in 2001. Comparison with the previous year shows no evidence of further soiling of the white roof on performance. In 2003 the average daily maximum attic air temperature above ambient was +8.8ºF against +8.5ºF in the summer of 2004.

Ceiling Heat Flux

Table 4 shows the statistics for ceiling heat fluxes over the 2004 summer period, and Figure 6 shows the data for the same period graphically. This represents heat conduction through the ceiling. Test Cell #6 with the white metal roof had the lowest average heat flux over the daily cycle. The vented white metal roof shows the lowest overall average heat flux. It also has a relatively low average flux of 0.42 Btu/ft^2/hr, although substantially higher than the white metal roof at 0.34 Btu/ft^2/hr. The Galvalume® roof (mean heat flux of 0.65 Btu/ft^2/hr) performs better than the galvanized metal roof (mean 0.72 /Btu/ft^2/hr). Both Galvalume and Galvanized roofs showed substantial degradation of thermal performance in their third year of exposure. Mean heat fluxes were 0.47 and 0.55 Btu/ft^2/hr, respectively in 2003 and 0.43 and 0.53 in the first year of exposure in 2002.

Table 4
FRF Measured Ceiling Heat Fluxes (Btu/ft^2/hr)
June 1 - September 30, 2004

Cell #	Description	Mean	Min	Max	Avg. Flux Change Relative to Cell #5
1	Galvalume® metal roof	0.65	-0.39	2.68	-12.2%
2	Proprietary test cell	NA	NA	NA	NA
3	Proprietary test cell	NA	NA	NA	NA
4	Galvanized metal roof	0.72	-0.39	3.42	-2.7%
5	Black shingle (control cell)	0.74	-0.45	3.76	Ref
6	White metal roof	0.34	-0.45	1.60	-54.1%

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

1. White metal with vented attic
2. Galvalume® metal roof with vented attic
3. Galvanized metal roof with vented attic
4. Black asphalt shingles with RBS and sealed attic

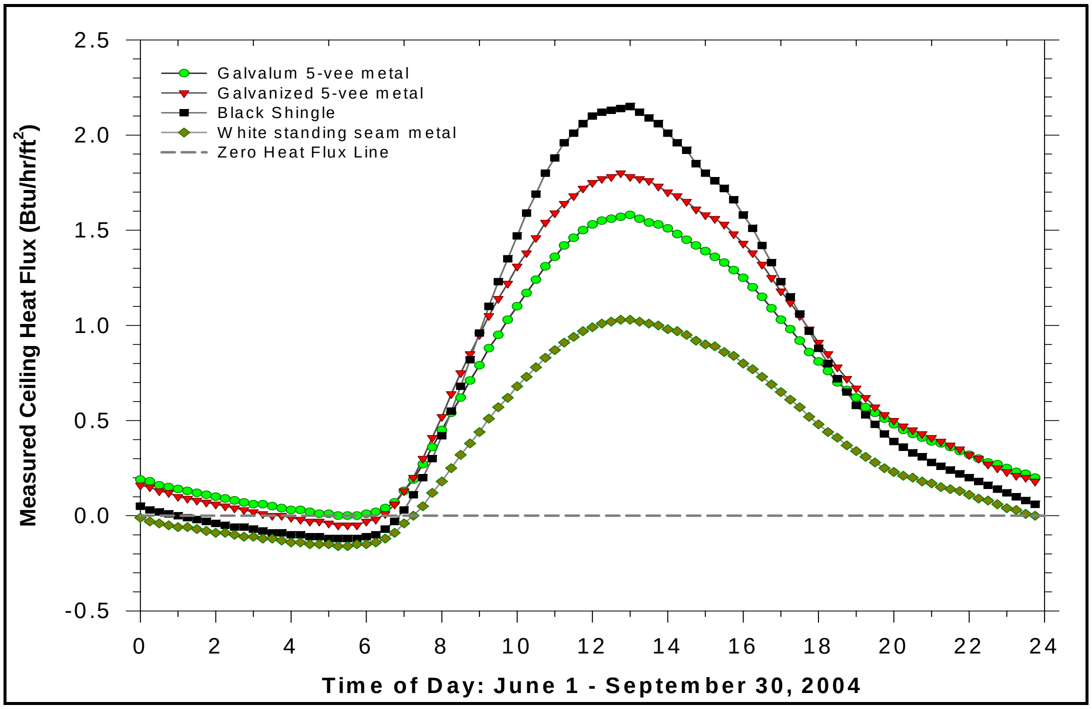

Figure 6. Measured average ceiling heat flux over the summer of 2004.

Note from the graph that while the double roof with radiant barrier does well at reducing the peak afternoon heat flux, its performance is adversely affected by its positive heat fluxes at night which were higher than any other system.

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.

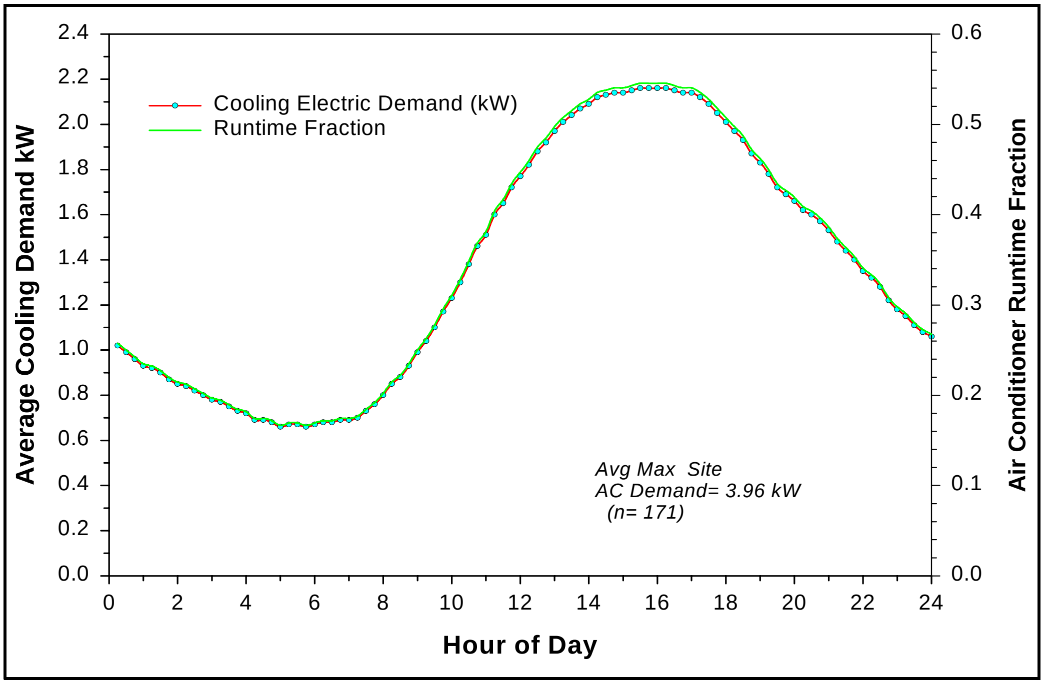

Figure 7. Average air conditioner power and average runtime fraction over an average summer day in a large sample of Central Florida homes.

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)

$\text{Area}_{\text{duct}}$ = 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
$T_{\text{duct, air}}$ = typical air temperature leaving evaporator (58°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:

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

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 °F)
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°F)
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:

$$Q_{\text{ceiling}} = \text{Area}_{\text{ceiling}} * Q_{\text{flux}}$$

Where:
$\text{Area}_{\text{ceiling}}$ = 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:

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

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.

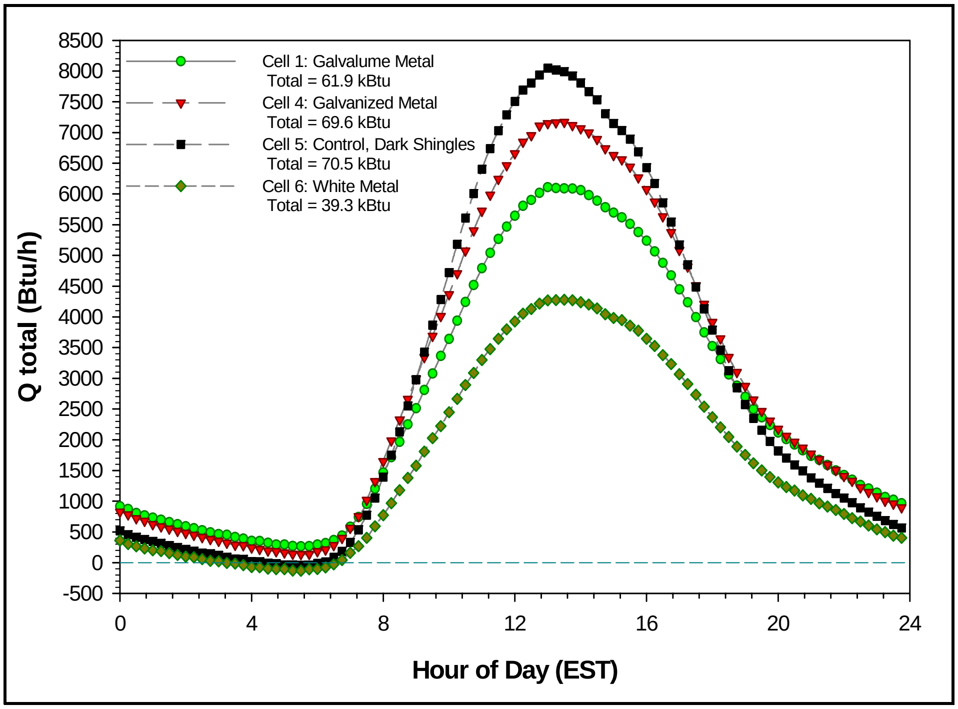

Figure 8. Estimated combined impact of duct heat gain, air leakage from the attic to conditioned space and ceiling heat flux on space cooling needs on an average summer day in a 2,000 ft^2 home.

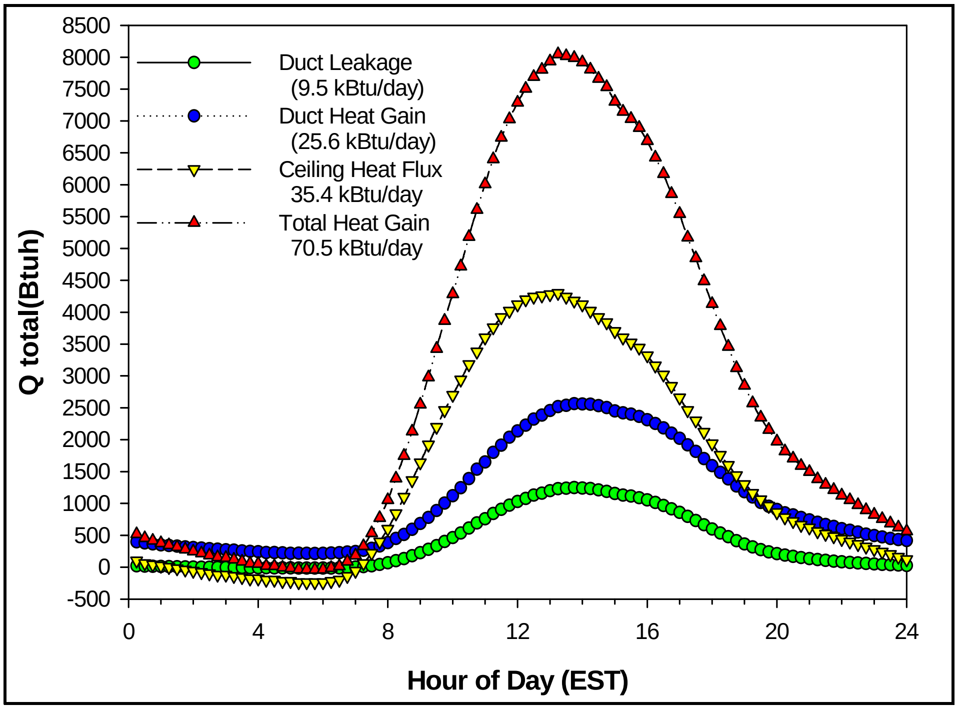

Figure 9. Components of estimated daily heat gain due to the duct heat gain, air leakage from the attic to the conditioned space and ceiling heat flux for Cell #5.

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	61.9	-12.2%
Cell #2	Proprietary test cell	NA	NA
Cell #3	Proprietary test cell	NA	NA
Cell #4	Galvanized metal roof	69.6	-1.3%
Cell #5	Black shingle (control cell)	70.5	0.0%
Cell #6	White metal roof	39.3	-44.3%

The estimation shows that the white metal roof (Cell #6) does best (44% reduction). The Galvalume® metal roof with a ventilated attic provides about a 12% reduction in heat gain– down substantially from the previous year. The galvanized roof with its lower emissivity and aged reflectivity provided only a 1% heat reduction– within the bound of experimental error. Both the *Galvalume* and galvanized roofs provide less reduction in heat gain compared to the previous year (*Galvalume* = 24% → 12%; Galvanized = 16% →1 %) showing aging and decreased reflectance of the unfinished metal products. The numbers from the first year of aging were year (*Galvalume* = 30% → 24%; Galvanized = 20% → 16%). Conversely, the white metal test cell showed only slight reduction in its performance three years after cleaning.

Conclusions

The 2004 FRF test results were evaluated to yield of the relative thermal performance of various roofing systems under typical Florida summer conditions. Within 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. Its attic temperatures were also much lower than the conventional dark shingled attic test cell. The average daily maximum attic temperature was only about 96°F. The overall cooling related savings from this roof construction was on the order of 44% of roof-related heat gain.

Testing was done with two proprietary test configurations in Test Cell #2 and #3 which is not further described.

An important objective for testing for 2004 was to continue evaluation of popular unfinished metal roofing systems in a third 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 initial 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 12% reduction in roof and attic related heat gain over the summer as compared with a 1% reduction for the galvanized roof– essentially equivalent performance to the control cell. Comparatively, the savings were 32% and 22% respectively, in the first year. Galvanized roofs are known to lose their solar reflectance over time as the zinc surface oxidizes, so we had expected to see a drop in performance. Although white metal performs best, the *Galvalume®* metal roofing surface is a good second choice for mixed climates, although we did see a substantial drop in performance in the third year of exposure.

Within the analysis, 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 aged white metal and Galvalume® 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. However, the savings level of the aged galvanized roof was not significant – indicating the long term advantage of Galvalum®.

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 final 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).[2]

	Roof-related Savings	Approximate Overall Savings
• White metal with vented attic:	44.3%	15%
• Galvalume® unfinished metal roof with vented attic:	12.2%	4%
• Galvanized unfinished metal roof, vented attic	1.1%	0%

---

[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.

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.

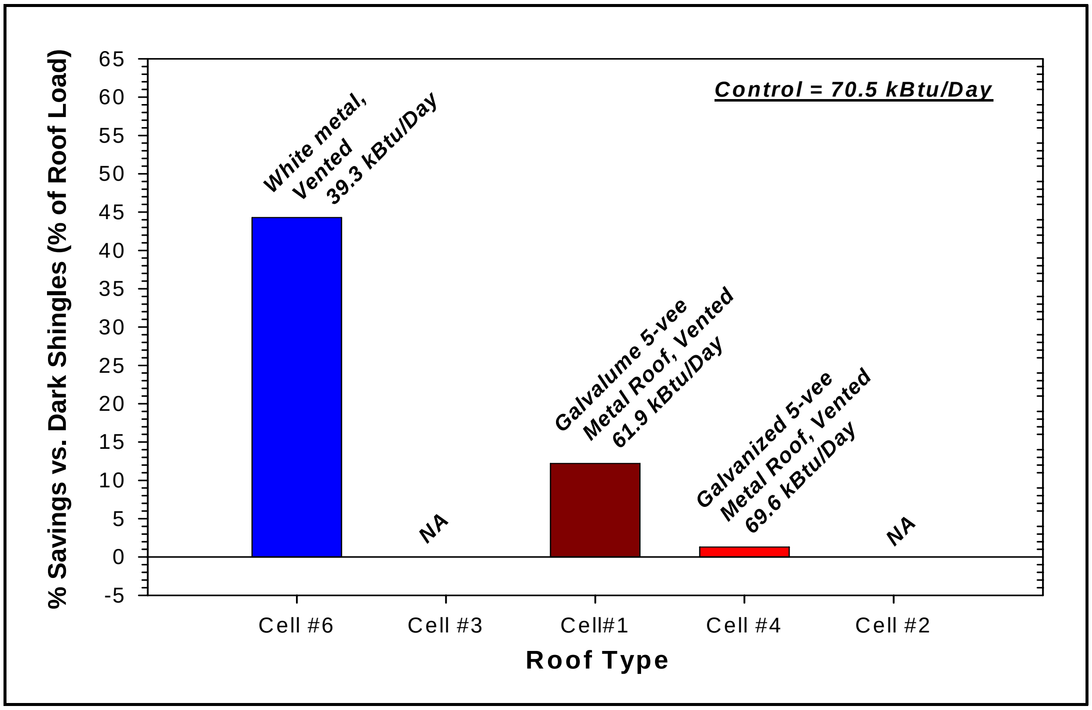

Figure 10. Percentage savings in daily total roof/attic related heat gain.

References

D. Beal 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, U.S. DOE/ORNL/BTEC, December 4-8, 1995, Clearwater, FL.

F.A. Joy, 1958. “Improving Attic Space Insulation Values,” *ASHRAE Transactions*, Vol. 64, Atlanta: American Society of Heating Refrigerating, and Air Conditioning Engineers.

D.A. Jump, 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 Buildings, Vol. 1, p. 147, American Council for an Energy Efficient Economy, Washington, DC.

D.S. Parker and J.R. Sherwin, 1998. “Comparative Summer Attic Thermal Performance of Six Roof Constructions,” ASHRAE Transactions, American Society of Heating, Refrigerating and Air Conditioning Engineers, June 20-24, 1998, Toronto, CA.

D.S. Parker, J.K. Sonne, J.R. Sherwin and N. Moyer, 2000. “Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida,” FSEC-CR-1220-00, Florida Solar Energy Center, Cocoa, FL.

D.S. Parker, 2002. “Research Highlights from a Large Scale Monitoring Study in a Hot Climate,” International Symposium on Highly Efficient Use of Energy and Reduction of its Environmental Impact, Japan Society for the Promotion of Science, January 22-23, 2002

L. Gu et. al. Comparison of Duct System Computer Models That Could Provide Input to the Thermal Distribution Standard Method of Test (SPC 152P, FSEC-CR-929-96, Appendix G; Table G-2, Florida Solar Energy Center, Cocoa, FL.

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 - 2004. 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 - 2004

		------------ Cell #5 -------------			
Year	Avg. Ambient Temp (°F)	Avg. Attic Temp (°F)	Max Attic Temp (°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
2004	79.9	90.0	152.6	0.74	3.76

The year 1998 stands out as an outlier, but that is expected (record breaking hot summer). The year 2003 was unusually cool, whereas 2004 was average. The mean idea of this tracking is 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. Note that the attic ventilation rates were altered in the summer of 2004 to attempt to create correspondence with a 1:300 ventilation rate.

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

2004

1 Galvalume® 5-vee Roof, vented (3rd year of exposure)
2 Proprietary Test Cell
3 Proprietary Test Cell
4 Galvanized 5-vee roof, vented (3rd year of exposure)
5 Dark shingles with standard ventilation (Control)
6 White standing seam roof, vented (8th year of exposure; 3rd since cleaning)