Comparative Summer Thermal Performance of Finished and Unfinished Metal Roofing Products with Composition Shingles

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ABSTRACT

This paper presents an overview of results from experimental research conducted at FSEC's Flexible Roofing Facility in the summer of 2002. The Flexible Roof Facility (FRF) is a test facility in Cocoa, Florida designed to evaluate a combination of five roofing systems against a control roof using dark shingles. The intent of the testing is to evaluate how roofing systems impact residential cooling energy use. Recent testing emphasizes evaluation of how increasingly popular metal roofing systems, both finished and unfinished, might compare with other more traditional roofing types.

All of the test cells had R-19 insulation installed on the attic floor except in the double roof configuration which had R-19 of open cell foam blown onto the underside of the roof decking. The test results were used to determine relative thermal performance of various roofing systems under typical Florida summer conditions. Measured impacts included changes to ceiling heat flux and attic air temperature which influences loads from unintended attic air leakage and duct heat gain. We also develop an analysis method to estimate total cooling energy benefits of different roofing systems considering the various impacts.

The results show that all the options perform better than dark composition shingles. White metal performs best with an estimated cooling energy reduction of about 15%, but the spectrally selective metal shingles (12%) and unfinished *Galvalume* roofs (11%) do surprisingly well. Galvanized roofing did less well than Galvalume (7% reduction) and worse performance in the second year of exposure was observed due to corrosion of the zinc surface. The sealed attic with a double roof produced an estimated cooling energy reduction of only 2% -- largely due to increases in ceiling flux.

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 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.

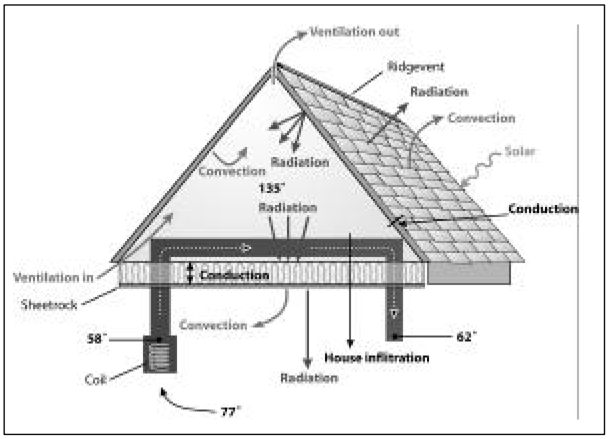

Figure 1. Vented attic thermal processes and interaction with duct system.

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).[1] This is aggravated 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

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[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^{o}F, and 78^{o}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^{o}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.

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.
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.

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.

FLEXIBLE ROOF FACILITY

During the summer of 2002, 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 ft2hr_^{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). Our tests in 2002 addressed the following questions:

- What is the performance (ceiling flux and attic air temperatures) of a standard black asphalt shingle roof with 1:300 ventilation (the control cell)?
- How Galvalume® and galvanized metal roof?
- How does a higher IR reflectance ivory metal shingle roof function relative to the lower reflectance one installed the previous summer?
- How does an innovative double roof construction with an insulated roof deck, radiant barrier and no attic ventilation perform compared with other types?
- 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 (1st year)
Cell #2: Black asphalt shingles with vented double roof deck with radiant barrier and 6" foam insulation on underside of bottom roof deck; unvented attic (2nd year)
Cell #3: IR reflective ivory metal shingles; 1:300 soffit and ridge ventilation (1st year)
Cell #4: Galvanized 5-vee unfinished metal roof; 1:300 ventilation (1st year)
Cell #5: Black asphalt shingles; 1:300 soffit and ridge ventilation (control cell; 15 years old)
Cell #6: White standing seam metal; 1:300 vented attic (7 years old)

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. 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.

Figure 2. Flexible Roof Facility in summer 2002 configuration.

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 ivory metal shingle	42.8%	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 5, 2002, 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 3. 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.

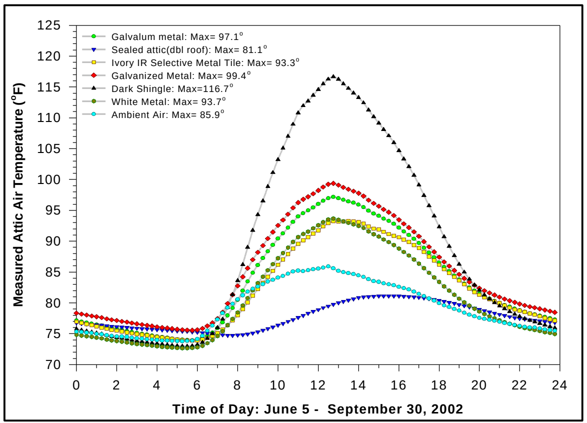

Figure 3. Measured average mid-attic temperatures over the 2002 summer period.

The statistics for the average, minimum and maximum mid-attic air temperatures over the entire summer (hot average day) are summarized in Table 2. These results show that the sealed attic with the double roof provides the lowest overall mean attic temperatures (77.7^{o}F) and hence lowest attic duct system heat gains and impact from return air leakage from the attic zone. The next most productive roof combination in this regard is Cell #6 with the vented white metal roof (81.0^{o}F). Very similar to this performance is Cell #3 with the IR reflective metal shingle roof (82.3^{o}F). Next best in performance is Cell #1 with the Galvalume® metal roof and vented attic at 83.6^{o}F. The lower emissivity galvanized metal roof (Cell #4) averaging 85.2^{o}F, is least beneficial relative to the standard attic which is at 89.1^{o}F.

Table 2
FRF: Measured Mid-Attic Air Temperatures (^{o}F)
June 5 - September 30, 2002

	Description	**Mean**	**Standard**	**Minimum**	**Maximum**
Outdoor Air	Ambient Air	89.1	4.13	67.8	95.3
Cell #1	Galvalume® metal roof	83.6	7.95	67.7	110.9
Cell #2	Double roof deck (sealed attic)	77.7	2.16	72.9	84.8
Cell #3	High reflectance ivory metal shingle	82.2	6.76	68.5	105.9
Cell #4	Galvanized metal roof	85.1	8.16	68.3	113.7
Cell #5	Black shingle (control cell)	89.1	15.39	67.0	139.6
Cell #6	White metal roof	81.0	7.29	67.0	104.4

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 for the period between June 5 and September 30, 2002. These results show the success 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	97.1^{o}F	85.9^{o}F	+ 11.2^{o}F
Cell #2	Double roof deck (sealed attic)	81.1^{o}F	85.9^{o}F	- 4.8^{o}F
Cell #3	High reflectance ivory metal shingle	93.3^{o}F	85.9^{o}F	+ 7.4^{o}F
Cell #4	Galvanized metal roof	99.4^{o}F	85.9^{o}F	+ 13.5^{o}F
Cell #5	Black shingle (control cell)	116.7^{o}F	85.9^{o}F	+ 30.8^{o}F
Cell #6	White metal roof	93.7^{o}F	85.9^{o}F	+ 7.8^{o}F

Note that Cell #2 with the sealed attic and insulation on the underside of the roof decking cannot be directly compared with the other cells as the others do not have roof deck insulation, but instead have insulation on top of the ceiling. Comparing the 2002 summer results with 1999 and 2000 Cell #2 results (sealed attic without double roof and RB) however, shows that the double roof/RB combination average maximum mid-attic temperature difference from ambient was 4.7^{o}F lower than the same sealed attic without the double roof. Its maximum mid-attic temperature of 81.1^{o}F was also 7.1^{o}F lower than the averaged 1999 and 2000 results.

The highly reflective ivory 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 93.3^{o}F, or 7.4^{o}F higher than ambient. In 2001 the brown, IR reflective shingle on the test cell had a maximum attic air temperature that was 10.6^{o}F higher than ambient. In 2000, the brown (non-highly reflective) 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 ivory colored IR reflective shingle is better than all the tested metal tile products except the white shingle.

The white standing seam metal (Cell #6) roof was vented during the 2002 summer test period. It was also cleaned prior to the test period to allow comparison with the pristine Galvalume® and galvanized metal roofs. Comparison with the previous year clearly shows the benefits of the cleaning and venting. In 2001 the average daily maximum attic air temperature above ambient was +14.4^{o}F against +7.8^{o}F in the summer of 2002.

Ceiling Heat Flux

Table 4 shows the statistics for ceiling heat fluxes over the 2002 summer period, and Figure 4 shows the ceiling flux data for the same period graphically. The uninsulated ceiling of the double roof with sealed attic (Cell #2) has a peak heat flux similar to that of the control (Cell #5), although with a significant time lag of over 3 hours. The mean heat flux for the double roof is 0.98 Btu/ft^2/hr, or 40% higher than the control. Also note from Figure 6 that the double roof has the highest flux values of all the cells. The highly reflective ivory metal shingle roof (Cell #3) has the lowest peak ceiling heat flux at 1.19 Btu/ft^2/hr, and also has a relatively low mean flux of 0.39 Btu/ft^2/hr, which is slightly higher than the white metal roof at 0.30 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 0.43 Btu/ft^2/hr) performs similarly to the IR reflective roof with poorer performance for the galvanized metal roof (mean 0.53 /Btu/ft^2/hr).

Table 4
FRF Measured Ceiling Heat Fluxes (Btu/ft^2/hr)
June 5 - September 30, 2002

Cell #	Description	Mean	Stddev	Min	Max	Flux Change Relative to Cell #5
Flux 1	Galvalume® metal roof	0.43	0.43	-0.37	1.88	-38.6%
Flux 2	Double roof deck (sealed attic)	0.98	0.71	-1.11	3.33	+40.0%
Flux 3	High reflectance ivory metal shingle	0.39	0.23	-0.09	1.19	-44.3%
Flux 4	Galvanized metal roof	0.53	0.45	-0.32	2.09	-24.3%
Flux 5	Black shingle (control cell)	0.70	0.78	-0.38	3.32	Ref
Flux 6	White metal roof	0.30	0.38	-0.40	1.49	-57.1%

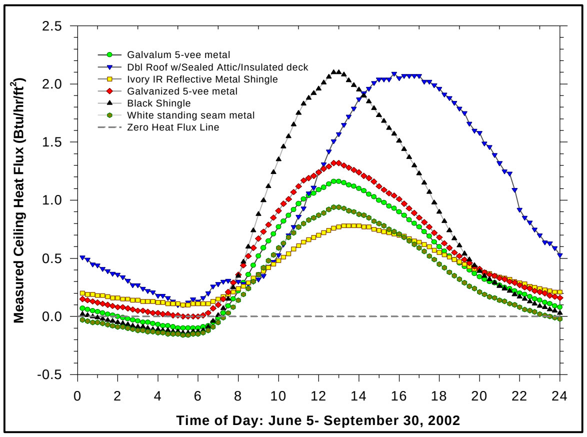

Figure 4. Measured average ceiling heat flux over the summer of 2002.

Estimation of Overall Impact of Roofing System

As described earlier, 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 5 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.

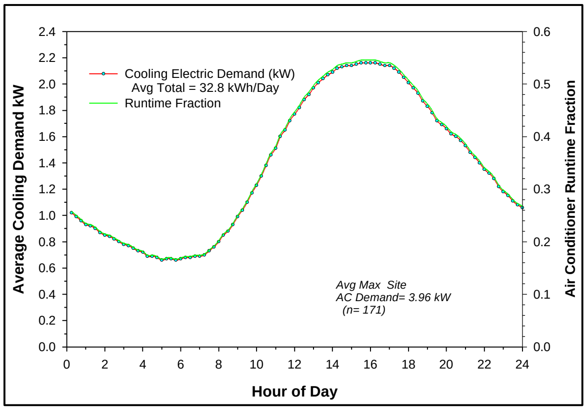

Figure 5. Average air conditioner power and average runtime fraction over an average summer day in a large sample of Central Florida homes.

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^oF)

RTF = typical air conditioner runtime fraction as determined from data in Figure 7

Generally, the duct heat gains will favor the double roof sealed attic construction which results 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:

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

Figure 6 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 7 breaks down the Q_{duct}, Q_{leak} and $Q_{ceiling}$ components of Figure 6 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.

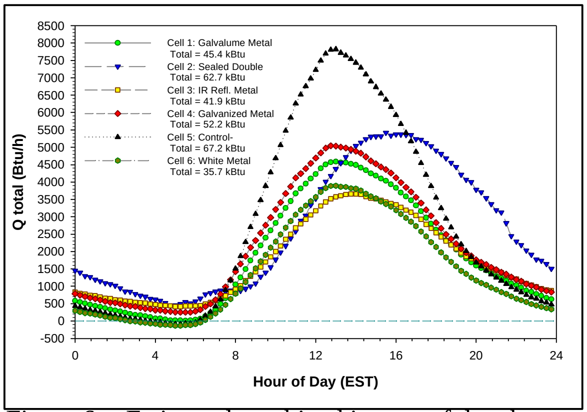

Figure 6. Estimated combined impact of duct heat gain, air leakage from the attic to conditioned space and ceiling heat flux on space cooling needs on an average summer day in a 2,000 ft^2 home.

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

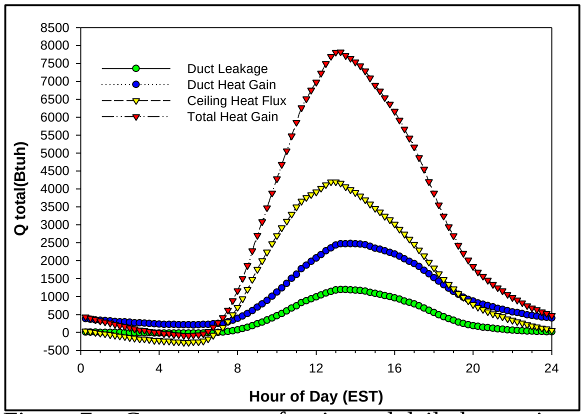

Figure 7. Components of estimated daily heat gain due to duct heat gain, air leakage from the attic to the conditioned space and ceiling heat flux for Cell #5.

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	45.4	-32.4%
Cell #2	Double roof deck (sealed attic)	62.7	- 6.7%
Cell #3	High reflectance ivory metal shingle	41.9	-37.6%
Cell #4	Galvanized metal roof	52.2	-22.3%
Cell #5	Black shingle (control cell)	67.2	0.0%
Cell #6	White metal roof	35.7	-46.9%

All of the alternative test cells do better than the standard reference cell. The estimation shows that the white metal roof with ventilation (Cell #6) does best, followed by the high reflectance metal shingle roof (Cell #3). The Galvalume® metal roof with a ventilated attic provides about a 30% reduction in heat gain. The galvanized roof with its significantly lower emissivity provides only about a 20% heat reduction. The sealed attic with the double roof provides the lowest reduction. The is primarily a result of the much greater measured heat flux across the uninsulated ceiling.

CONCLUSIONS

Our test results from the summer of 2002 suggest indicators of the relative thermal performance of finished and unfinished metal roofing systems under typical Florida summer conditions. 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 94^{o}F. The overall cooling related savings from this roof construction was on the order of 47% of roof-related heat gain.

The sealed attic double-roof system (Cell #2) provided the coolest attic space of all systems tested (average maximum daily mid-attic temperature was 81.1^{o}F) and therefore also the lowest estimated duct leakage and duct conduction heat gains. However, it also had the highest ceiling heat flux of all strategies tested, reducing its improvement over the standard dark shingle roof in the control home to only a modest 6.7% reduction to roof-related cooling energy. Note also that since this double roof configuration provided significantly cooler attic temperatures than the standard sealed attic tested during the previous two summers, higher total heat gains should be anticipated from standard sealed attics.

A major objective of the testing was to evaluate popular unfinished metal roofing systems and compare those 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 (0.40) 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 32% reduction in roof and attic related heat gain over the summer as compared with a 22% reduction for the galvanized roof. Moreover, as galvanized roofs are known to lose their solar reflectance rapidly over time as the zinc surface oxidizes, we expect to see a further decrease in performance in a second season of testing. Although white metal performs best, the Galvalume® metal roofing surface is a good second choice for cooling related climates, and does nearly as well as the IR selective ivory metal shingles.

At an average maximum mid-attic temperature of 93.3°F (23.4°F lower than the control dark shingle cell), the highly reflective ivory metal shingle roof (Cell #3) provided the coolest peak attic temperature of all cells without double roof deck. While the ivory metal shingle roof's reflectance was somewhat lower than the white metal roof's, 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 likely causes 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 all of the tested roof configurations yield lower heat gains during the summer cooling season than the control roof with dark shingles. One emerging fact from the recent testing 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 in Table 6 and in Figure 8 with the percentage reduction of roof/attic related heat gain (and the approximate overall building cooling energy savings). 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.

Table 6
Rank Order of Overall Estimated Energy Savings

	Roof-related Savings	Approximate Overall Savings
White metal with vented attic:	47%	15%
High reflectance ivory metal shingle with vented attic:	38%	12%
Galvalume® unfinished metal roof with vented attic:	32%	11%
Galvanized unfinished metal roof, vented attic:	22%	7%
Double roof with sealed attic:	7%	2%

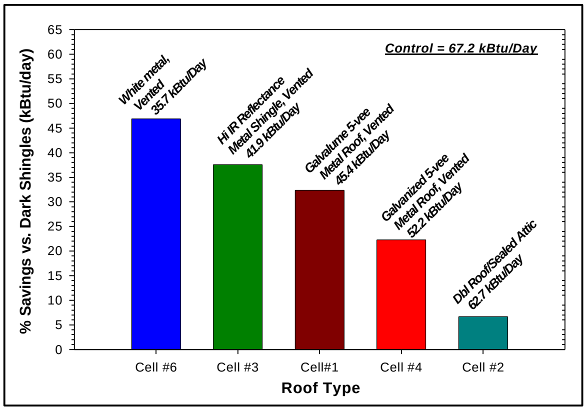

Figure 8. Percentage savings in daily total roof/attic related heat gain.

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. However, these results represent the first time that popular unfinished metal roofs have been comparatively evaluated.

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