COOL METAL ROOFING TESTED FOR ENERGY EFFICIENCY AND SUSTAINABILITY

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ABSTRACT

High solar reflectance and high infrared emittance roofs incur surface temperatures that are only about 5°F (3°C) warmer than the ambient air temperature, while a dark absorptive roof exceeds the ambient air temperature upwards of 75°F (40°C). In predominantly warm climates, the high solar reflectance and high infrared emittance roof drops the building's air conditioning load and reduces peak energy demands on the utility. In North American climates, being predominantly cold, a more moderate reflectance and a low (not high) emittance result in a warmer exterior roof temperature, which reduces heat loss from the building.

Temperature, heat flow, reflectance, and emittance field data have been catalogued for a full 3 years for 12 different painted and unpainted metal roofs exposed to weathering on an outdoor test facility at Oak Ridge National Laboratory (ORNL).

Habitat for Humanity homes were tested by the Florida Solar Energy Center (FSEC) for a full summer in Fort Myers, Florida. The houses were side-by-side, unoccupied and had different roofing systems designed to reduce the attic heat gain. Measurements showed that the white reflective roofs reduced cooling energy consumption by 18-26% and peak demand by 28-35%.

Results show that a judicious selection of the roof surface properties of reflectance and emittance represent the most significant energy and cost saving options available to homeowners and builders in predominantly hot climates.

INTRODUCTION

Determining how weathering affects the solar reflectance and infrared emittance of metal roofs is of paramount importance for documenting the magnitude of the comfort cooling and heating energy load consumed by a building. The building's load, is directly related to the solar irradiance incident on the building; to the exterior temperature; to the level of roof, wall and foundation insulation; to the amount of fenestration; and to the building's tightness against unwanted air and moisture infiltration. The solar reflectance and infrared emittance and the airside convective currents strongly affect the envelope's exterior temperature. Our data show that in moderate to predominantly hot climates, an exterior roof surface with a high solar reflectance and high infrared emittance will reduce the exterior temperature and produce savings in comfort cooling. For predominantly heating-load climates, surfaces with moderate reflectance but low infrared emittance will save in comfort heating, although field data documenting the trade-off between reflectance and emittance are sparse.

Full building field tests in Florida and California using before-after experiments have examined the impact of reflective roofing on air conditioning (AC) energy use. In Florida tests measured air conditioning electrical savings averaged 19% (7.7 kWh/Day) (Parker et al., 1998). Even greater fractional savings have been reported for similar experiments in California (Akbari, et al., 1997).

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Experimental Initiatives

The Buildings Technology Center (BTC) of ORNL has instrumented and field tested steep-slope- and low-slope-roof test sections of painted and unpainted metals for the past three years on a test building called the Envelope Systems Research Apparatus (ESRA). The low-slope assembly (Figure 1) consists of white-painted polyvinylidene fluoride (PVDF) galvanized steel[1]; off-white polyester; 55% Al-Zn coated steel[2] painted with a clear acrylic dichromate layer; unpainted galvanized steel; and unpainted 55% Al-Zn-coated steel. Five painted metal panels are being tested on the steep-slope assembly (Figure 1). Three panels of white-painted PVDF galvanized steel; three panels of 55% Al-Zn-coated steel painted with a clear acrylic dichromate layer; six panels of bronze-painted PVDF aluminum; and three panels of black-painted PVDF galvanized steel[3] were exposed to weather in east Tennessee. An asphalt-shingle roof section was included as the base of comparison. Salient features of the ESRA facility are fully discussed by Kriner and Miller (2001). Exposure sites were also setup to field test the identical painted and unpainted metal samples at Monroeville, PA, Fort Lauderdale, FL, Nova Scotia, Canada and Bethlehem, PA.

Florida Solar Energy Center (FSEC) instrumented seven side-by-side Habitat for Humanity (HFH) homes in Fort Myers, Florida with identical floor plans and orientation, but with different roofing systems designed to reduce attic heat gain (Figure 2). Six houses had R-19 ceiling insulation, and the seventh house had an unvented attic with insulation on the underside of the roof deck rather than the ceiling. All seven residences have a three bedroom, one bath floor plan and are of identical construction and exposure. Identical two-ton split system air conditioners with 5 kW strip heaters were installed in each of the seven homes. The houses underwent a series of tests in order to ensure that the construction and mechanical systems performed similarly. The following three-letter identification codes are used in the text, and the solar reflectance and infrared emittance of new material are also provided each roofing system :

Description of Test Roof on each HFH House	Label	Solar Reflectance	Infrared Emittance
• Dark gray fiberglass shingles	RGS	0.082	0.89
• White barrel-shaped tile	RWB	0.742	0.89
• White fiberglass shingle	RWS	0.240	0.91
• Flat white tile	RWF	0.773	0.89
• Terra cotta barrel-shaped tile	RTB	0.346	0.88
• White 5-vee metal	RWM	0.662	0.86
• Sealed attic with insulation on the roof plane	RSL	0.082	0.89

The salient features of the Habitat for Humanity homes and their respective roofs field tested in Fort Myers, Florida are fully described by Parker et al. (2001).

DISCUSSION

Reflectance and Emittance Surface Properties

The solar reflectance and the infrared emittance of a roof surface are important surface properties affecting the roof temperature, which in turn drives the heat flow through the roof. The reflectance and emittance are phenomenon occurring just a fraction of a micrometer within the irradiated surface. The solar reflectance gages the percentage of the sun’s energy that a roof deflects off the building, and the infrared emittance is the percentage of infrared heat that a roof releases from the building. Reflectance and emittance are expressed as mathematical ratios. The reflectance (ρ) determines the fraction of radiation incident from all directions that is diffusely reflected by the surface. The emittance (ε) describes how well the surface radiates energy away from itself as compared to a blackbody operating at the same roof temperature. The emittance of painted metal is about 0.90 while unpainted metal has values of about 0.10. The impact of emmittance on roof temperature is just as important as that of reflectance.

Reflectivity measurements were made every 3 months on the ESRA’s steep- and low-slope metal roofs; these measurements are shown in Figure 3. Each metal roof is described generically using an R*xx*E*yy* designation. R*xx* states the solar reflectance of a new sample, 1.0 being a perfect reflector. E*yy* defines the

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[1] A zinc-coated steel sheet dipped in continuous coil form through a molten bath of zinc.

[2] This steel is exposed to a molten bath composed of 55% Al-43.5% Zn -1.5% Si at a temperature of 1100°F (593°C). The coating is solidified rapidly to enhance both the microstructure and the corrosion resistance.

[3] Black-painted polyvinylidene fluoride (PVDF) laminated with amorphous photovoltaic cells.

infrared emittance of the new sample, 1.0 being blackbody radiation. For example, the asphalt-shingle roof is labeled R09E91 in Figure 3. Its freshly manufactured surface properties are therefore 0.09-reflectance and 0.91-emittance. Kriner and Miller (2001) identify the R*xx*E*yy* designations for the different painted and unpainted test metals tested at ORNL.

After 3½ years of exposure, the white and bronze painted PVDF metal roofs, R64E83 and R07E87 respectively, have lost less than 5% of their original reflectance. The coated steel painted with a clear acrylic dichromate layer, R64E08, shows only a 12% loss in reflectance. In comparison the asphalt shingle roof, R09E91, increased a percentage point in reflectance after the 3½ years of exposure (Figure 3). The reflectance comparison is very important, because both R64E83 and R64E08 roofs reflected about 50% more solar energy away from these test roofs than did the asphalt shingle roof. Even more promising is the observed durability of the surface of the painted metals; reflectance remained fairly level. Less heat is therefore absorbed by the "cool" painted metal roofs and the building load and the peak utility load are reduced as compared to darker more absorptive roofs (i.e.,R09E91).

Testing conducted at the roof slopes of 4-in of rise per 12-in of run (i.e., Steep Slope Roof [SSR] in Figure 3) and at ¼-in of rise per 12-in of run (i.e., Low Slope Roof [LSR] in Figure 3) further show that the slope of the roof has little effect on the loss of reflectance for the painted metal roofing having the PVDF finish. The painted metal appears to have excellent corrosion resistance. Their surface opacity have limited any photochemical degradation caused by ultraviolet light present in sunlight over the 3-years of testing. All painted metal roofs have maintained their original manufactured appearance. After 3½ years of exposure, rains with a measured ph of 4.3 in East Tennessee (National Atmospheric Deposition Program) have not etched the metal finish. ORNL scientists detected evidence of biological growth on some of the test roofs (Miller et al. 2002); however, the PVDF surface finish does not appear to allow the growth to attach itself and atmospheric pollution is washed off by rain.

Most dramatic are the trends observed in the solar reflectance and the infrared emittance of the painted metal roofs tested at different exposure sites across the country. Similar reflectance was measured in the hot, moist climate of Florida as compared to the predominantly cold climate of Nova Scotia (Figure 4). The Environmental Protection Agency's Energy Star® Program requires field testing at three different building sites; however, the results for painted metal show the reflectance to be very similar whether exposed in Florida, Nova Scotia or Pennsylvania. Also solar reflectance and infrared emittance measures collected from the test fence exposure sites in Florida, Nova Scotia, Pennsylvania and also at Oak Ridge (Figure 4) are very similar to the reflectance and emittance measures recorded for the test roofs exposed on the ESRA in Oak Ridge (Figure 3). For this 3½ year time limited study, the changes in solar reflectance and infrared emittance of the painted PVDF metals is independent of climate! The results show that fence exposure data are a viable alternative for certifiying the painted PVDF metal roofs as Energy Star compliant, because they yielded very similar trends as the identical roofs exposed on the ESRA.

The emittance of the painted metal roofs did not change much after 3½ years of weathering. In fact, the data in Figure 4 shows that the emittance increased slightly over time. The coated steel painted with a clear acrylic dichromate layer, R64E08, has a much lower emittance than the white PVDF (R64E83) roof. Note however that the emittance of several of the freshly manufactured coated steel samples painted with the clear acrylic dichromate layer varied from a low of 0.08 to a high of 0.20, probably because of the coating. Emittance trends of the low-slope coated and unpainted steel increased while those of the painted metal remained relatively flat, Kriner and Miller (2001).

Thermal Performance of Painted Metal Roofing at ORNL

Increasing the solar reflectance or infrared emittance of a roof will reduce the exterior temperature, which in turn results in reduced building load. Solar reflectance effects naturally occur during the sunlight hours, while the effects of emittance occur continuously as long as there is a temperature difference between the metal and the radiant sky[4].

Temperature data for metal roof surfaces on the steep-slope assembly of the ESRA are shown in Figure 5. These data are for a week of summer and winter weather having clear skies. Note that each label on the abscissa in Figure 5 is for midnight. The maximum daily ambient air temperature ranged from about 85°F to 95°F (29°C to 36°C) over the week in August. In February, the daily maximum air temperature ranged from 40°F to 60°F (4°C to 16°C). Peak air temperature usually occurs at about 4 P.M. with the peak roof temperature occurring slightly earlier at about 2 P.M.

The summer roof temperature for the R07E87, R26E90, and R09E91 (asphalt-shingle) sections all exceeded 160°F (71°C) and on some days reached a peak temperature of 165°F (74°C). The more reflective

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[4] Measures of the global infrared irradiance made by the BTC's field pyrgeometer used to calculate the radiant sky temperature from the equation for blackbody radiation: $q_{IR} = \sigma T_{sky}^4$.

R64E83 and R64E08 test sections had peak temperatures of about 115°F and 135°F (46°C to 57°C), respectively. The lower temperatures in turn imply less heat transmission into the building. On Aug 11, 2000, however, the R64E83 roof emittance was 0.826 as compared to 0.176 for the R64E08 test roof. Therefore, the 20°F (11°C) difference in roof temperature for the white PVDF versus the steel with clear acrylic layer is driven predominantly by the effect of emittance. The effect is even better depicted for the February data (Figure 5). During the evening hours, the lower emittance test roof (R64E08) maintains a temperature that exceeds the dew point temperature of the ambient air. Therefore, during the evening hours, less heat leaks to the outdoor ambient from the less emissive of the two metal roofs.

The temperature data of Figure 5 for the painted metals roofs were cast in terms of the average roof temperature averaged over the sunlight hours between 6 A.M. and 6 P.M. The averaged data were then fit using the solar reflectance and infrared emittance as independent variables, and the regression fits to these averaged roof temperature data are shown in Figure 6. Fixing the reflectance and decreasing the emittance causes the roof temperaturee to increase during August exposure. The hotter roof temperature in turn increases the heat entering the roof, which reveals why a low emittance is not thermally efficient on a hot summer day. For the August data one can see that a high solar reflectance and a high infrared emittance yields the coolest roof surface (Figure 6). The August data also reveals the interdependence of the infrared emittance and solar reflectance on roof heat flow. The lower the solar reflectance the greater is the effect of the infrared emittance on the roof temperature. Conversely the lower the infrared emittance the greater is the effect of the solar reflectance.

However, the effects of the infrared emittance observed in February are not as strong as those observed for the August data. Decreasing the infrared emittance caused less than a 5°F (3°C) increase in the average roof temperature; its effect is relatively flat in the winter. Decreasing the reflectance from 0.60 to 0.40 caused the average roof temperature to increase about 11°F (6°C). The results imply that the lowest heat loss from the roof occurs when the solar reflectance and the infrared emittance are low, and the effect of reflectance is more pronounced than is the effect of the emittance during this cold winter day.

Akbari and Konopacki (1998) performed DOE2.1e parametric simulations to estimate the impact of reflectance and emittance on the heating and cooling energy consumption for eleven metropolitan U.S. cities. Simulations were based on both old and new residential and commercial construction having respectively R-11 and R-19 levels of ceiling insulation. Nationwide, Akbari and Konopacki (1998) found that annually about $0.75 billion can be saved by widespread implementation of light-colored roofs in cooling dominant climates.

Their simulations also showed that the infrared emittance effects both cooling and heating energy use. In cooling dominant climates, a low emittance roof yields a higher roof temperature and in turn increases the cooling load imposed on the building. Akbari and Konopacki (1998) simulations showed that changing the infrared emittance from 0.90 (typical emittance of most nonmetallic surfaces) to 0.25 (emittance of a shiny metallic surface) caused a 10% increase in the annual utility bill. However, in cold climates, a low emittance roof adds resistance to the passage of heat leaving the roof, which results in savings in heating energy. Akbari and Konopacki (1998) showed that in very cold climates with little or no summertime cooling, the heating energy savings resulting from decreasing the roof emittance almost reached 3% of the building's annual energy consumption.

Therefore, the design of a metal roof should focus on the both the solar reflectance and infrared emittance of the surface. High solar reflectance and high infrared emittance yield significant thermal benefits in predominantly cooling climates, while a modest solar reflectance and low infrared emittance produce modest thermal performance gains in predominantly heating load climates. During winter exposure, moisture problems with icings and ice dams may possibly be reduced by a low emittance roof because the lower emittance retains heat and has an exterior temperature during the evening hours that may exceed the dew point temperature of the outdoor air (see Figure 5 for R64E83 and R64E08 during the hours around midnight).

Thermal Performance of Painted Metal Roofing at FSEC

While previous research efforts have investigated the thermal performance of various roofing systems, this particular study conducted by the FSEC and the Florida Power and Light Company represents the first time an attempt has been made to quantify roofing influence on cooling performance on identical, unoccupied, side-by-side residences. The project consisted of seven, single-family residential homes located in Fort Myers, Florida. The focus of the study was to investigate how various roofing systems impact air conditioning electrical demand. The houses underwent a series of tests in order to ensure that the construction and mechanical systems performed similarly. Details are not described here but can be found in the works by Parker, Sonne and Sherwin (2002).

The relative performance of the seven Habitat for Humanity (HFH) homes was evaluated for one month in the summer of 2000 under unoccupied and carefully controlled conditions. Table 1 summarizes the measured attic temperatures, cooling loads and savings for the seven homes over the unoccupied monitoring period; the data are ranked in descending order of total daily energy consumption. The average interior air temperature near the thermostat in all homes was within 1°F of each other. However, because of the large influence of the thermostat temperature, we adjusted the monitored cooling results in Table 1 to account for set point differences among houses, (Parker et al. 2001).

Not surprisingly, the control home (RGS) has the highest consumption (17.0 kWh/day). The home with the terra cotta barrel tile (RTB) has a slightly lower use (16.0 kWh/day) for a 7.7% cooling energy reduction. Next is the home with the white shingles (15.3 kWh/day) – an 10.6% reduction. The sealed attic (RSL) comes in with a 7.8% cooling energy reduction (14.7 kWh/day). The true white roofing types (> 60% reflectance) had the lowest energy use. Both the white barrel (RWB) and white flat tile (RWF) roofs averaged a consumption of 13.3 kWh/day for respectively a 18.5% and 21.5% cooling energy reduction. The white metal roof (RWM) showed the largest impact with a 12.0 kWh/day July consumption, yielding a 24% reduction in cooling energy consumption.

TABLE 1. Cooling Performance* During Unoccupied Period: July 8th – 31st, 2000

Site	Total kWh/day	Savings kWh/day	Thermo-stat (F)	Thermo-stat (C)	Mean Attic (F)	Mean Attic (C)	Max Attic (F)	Max Attic C)	Temp. Adjust. %	Field EER	Final Saving %
RGS	17.0	0.00	77.2	25.11	90.8	32.7	135.6	57.5	0.0	8.30	0.0
RTB	16.0	1.01	77.0	25.0	87.2	30.7	110.5	43.6	-1.6	8.12	7.7
RWS	15.3	1.74	77.0	25.0	88.0	31.1	123.5	50.8	-1.2	9.06	10.6
RSL	14.7	2.30	77.7	25.4	79.0	26.1	87.5	30.8	5.4	8.52	7.8
RWB	13.3	3.71	77.4	25.2	82.7	28.2	95.6	35.3	2.8	8.49	18.5
RWF	13.2	3.83	77.4	25.2	82.2	27.9	93.3	34.1	2.1	7.92	21.5
RWM	12.0	5.00	77.6	25.3	82.9	28.3	100.7	38.2	4.9	8.42	24.0

* Final savings are corrected for differences in interior temperature and AC performance among houses.

It is noteworthy that the average July outdoor ambient air temperature during the monitoring period (82.6°F [28.1°C]) was very similar to the 30-year average for Fort Myers (82°F [27.7°C]). Thus, the current data are representative of typical South Florida weather conditions. Relative to the standard control home, the data show two distinct groups in terms of performance:

- Terra Cotta tile, white shingle and sealed attic constructions produced approximately an 8-11% cooling energy reduction
- Reflective white roofing yielded a 19-24% reduction in the consumed cooling energy.

White flat tile performed slightly better than the white barrel due to its greater solar reflectance. The better performance of white metal is believed due to the effect of thermal mass. The metal roof incurred lower nighttime and early morning attic temperatures than did the tile or shingles, leading to lower nighttime cooling demand.

Peak Day Performance

July 26th was one of the hottest and brightest days in the data collection period and was used to view the effects of maximum solar irradiance on the candidate roofing systems and to also evaluate peak influences on utility demand (Table 2). The average solar irradiance was 371 W/m^2 and the maximum outdoor ambient air temperature was 93.0°F (33.8°C).

The roof decking temperature (Figure 7) and subsequently the surface temperature were highest for the sealed attic construction (RSL) since the insulation under the decking forced much of the collected solar heat to migrate back out through the shingles. The sealed attic construction experienced measured deck temperatures that were 20°F (11.1°C) higher each sunny day than the control house. The white roofing systems (RWM, RWF and RWB) experienced peak deck temperatures approximately 40°F (22°C) cooler than the darker shingles on the control house (RGS in Figure 7). The terra cotta barrel tile was about 29°F (16°C) cooler on this July 26th day of peak solar irradiance.

The measured mid attic air temperatures above the ceiling insulation further revealed the impact of the white reflective roofs with max attic temperatures about 35 to 40 °F cooler than the control home (RGS). As expected, the home with the sealed attic had the lowest attic temperatures reaching a maximum of 87.5°F (30.8°C) compared with the 77°F (25°C) being maintained inside. However, the sealed attic case has no insulation on the ceiling floor with only studs and sheet rock. Thus, from a cooling loads perspective, the low attic temperature with this construction is deceptive. Since ½ inch sheet rock has a thermal resistance R ≤ 1, a significant level of heat transfer takes place across the uninsulated ceiling. While this construction method reduced attic air temperatures, it did not reduce ceiling heat transfer as well as other options. Ceiling heat fluxes are actually higher. In this case, the ceiling and duct system is unintentionally cooling the attic space, which can lead to the false impression that roof/attic loads are lower.

These data show that during periods of high solar irradiance the performance of the sealed attic case (RSL) suffers significantly. The tile and white shingle roofs did better at controlling demand than did the sealed attic on this very hot day. However, the white metal roof performed best showing peak savings of about 35% over the RGS control.

TABLE 2.
Summer Peak Day Cooling Performance: July 26th, 2000

		Savings		Peak Period*		
Site	Cooling Energy	KWh	Percent	Demand (kW)	Savings (KW)	Percent
RGS	18.5 kWh		----	1.631	0.000	----
RTB	17.2 kWh	1.3	7%	1.570	0.061	3.7%
RSL	16.5 kWh	2.0	11%	1.626	0.005	0.3%
RWS	16.5 kWh	2.0	11%	1.439	0.192	11.8%
RWF	14.2 kWh	4.3	23%	1.019	0.612	37.5%
RWB	13.4 kWh	5.1	28%	1.073	0.558	34.2%
RWM	12.4 kWh	6.1	33%	0.984	0.647	39.7%

* Peak utility load occurred from 4 to 6 PM

CONCLUSIONS

The painted metal roofs have maintained their reflective surface; drops in reflectance are only about 5% after 3½ years of exposure. They appear to have an excellent corrosion-resistant surface whose opacity limits photochemical degradation caused by ultraviolet light present in sunlight. After 3½ years of exposure, rain has not etched the metal finish, and there is no evidence of any effects due to biological growth on the test roofs. Drops in solar reflectance are due more to airborne pollution than to any effect of the sun. Therefore, as roof slope increases, the washing action of precipitation increases, which helps to refresh the reflectance.

Exposure data for the more reflective painted metal roofs show the roofs qualify for the Energy Star® label for both steep-slope and low-slope roofing. In low-slope applications, the initial reflectance are boaderline; however, the painted PVDF metal roofs maintain their reflectance above 0.5 after the required 3 years of exposure.

The design of a metal roof for predominantly heating-load application should focus first on the level of roof insulation, secondly on the surface reflectance and finally on the emittance of the surface. A moderate solar reflectance with a low infrared emittance showed the least heat leakage from the test roofs during the winter. In predominantly cooling-load climates, the high solar reflectance and high infrared emittance of white-painted metal roofs yielded the best thermal performance. Here, design should focus on increasing both the emittance and reflectance to decrease the exterior roof temperature, which in turn decreases the heat leakage into the building.

The FSEC field study demonstrated that the roof and attic exert a powerful influence on the cooling energy used in the seven side-by-side Habitat for Humanity homes tested in South Florida. Each of the examined alternative roofing systems were found to be thermally superior to standard dark shingles, both in providing lower attic temperatures and lower AC energy use. The sealed attic construction provided modest savings to cooling energy, but no real peak reduction due to its sensitivity to periods with high solar irradiance. The HFH field study points to the need for reflective roofing materials or lightcolored tile roofing for good energy performance with sealed attics.

The HFH project revealed essentially two classes of performance for the 1,144 square foot homes. Analysis showed the white highly reflective roofing systems (RWF, RWB and RWM) provide annual cooling energy reductions of 600 to 1,100 kWh in South Florida (18-26%). Savings of terra cotta tile roofs are modest at 3-9% (100-300 kWh), while shingles provide savings of 3-5% (110-210 kWh). Sealed attic construction produced savings of 6-11% (220-400 kWh). The highly reflective roofing systems showed peak demand impacts of 28-35% (0.8-1.0 kW). White metal had the best cooling related performance. Its high conductivity coupled with nocturnal radiation resulted in lower nighttime and early morning attic temperatures that lead to a reduced cooling demand during evening hours.

REFERENCES

Akbari, H., S., Bretz, H. Taha, D. Kurn, and J. Hanford. 1997. “Peak Power and Cooling Energy Savings of High-albedo Roofs,” Energy and Buildings — Special Issue on Urban Heat Islands and Cool Communities, 25(2);117-126.

Akbari, H., Konopacki, S.J. 1998. “The Impact of Reflectivity and Emissivity of Roofs on Building Cooling and Heating Energy Use,” in Thermal Performance of the Exterior Envelopes of Buildings, VII, proceedings of ASHRAE THERM VIII, Clearwater, FL., Dec. 1998.

Miller, W. A., and Kriner, S. 2001. “The Thermal Performance of Painted and Unpainted Structural Standing Seam Metal Roofing Systems Exposed to One Year of Weathering,” in Thermal Performance of the Exterior Envelopes of Buildings, VIII, proceedings of ASHRAE THERM VIII, Clearwater, FL., Dec. 2001.

Miller, W.A., Cheng, M-D., Pfiffner, S., and Byars, N. 2002. “The Field Performance of High-Reflectance Single-Ply Membranes Exposed to Three Years of Weathering in Various U.S. Climates,” Final Report to SPRI, Inc., Aug., 2002.

Parker, D. S., Sherwin, J. R. 1998. “Comparative summer attic thermal performance of six roof constructions.” *ASHRAE Trans*., Vol. 104, pt. 2, 1084–1092.

Parker, D.S., Sonne, J. K., Sherwin, J. R. 2002. “Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida,” in ACEEE Summer Study on Energy Efficiency in Buildings, proceedings of American Council for an Energy Efficient Economy, Asilomar Conference Center in Pacific Grove, CA., Aug. 2002.

Parker, D.S., Sonne, J.K., Sherwin, J.R. and Moyer N. 2001. “Comparative Evaluation of the Impact of Rofing Systems on Residential Cooling Energy Demand in Florida,” Final Report FSEC-CR-1220-00, prepared for the Florida Power and Light Company, May 2001.

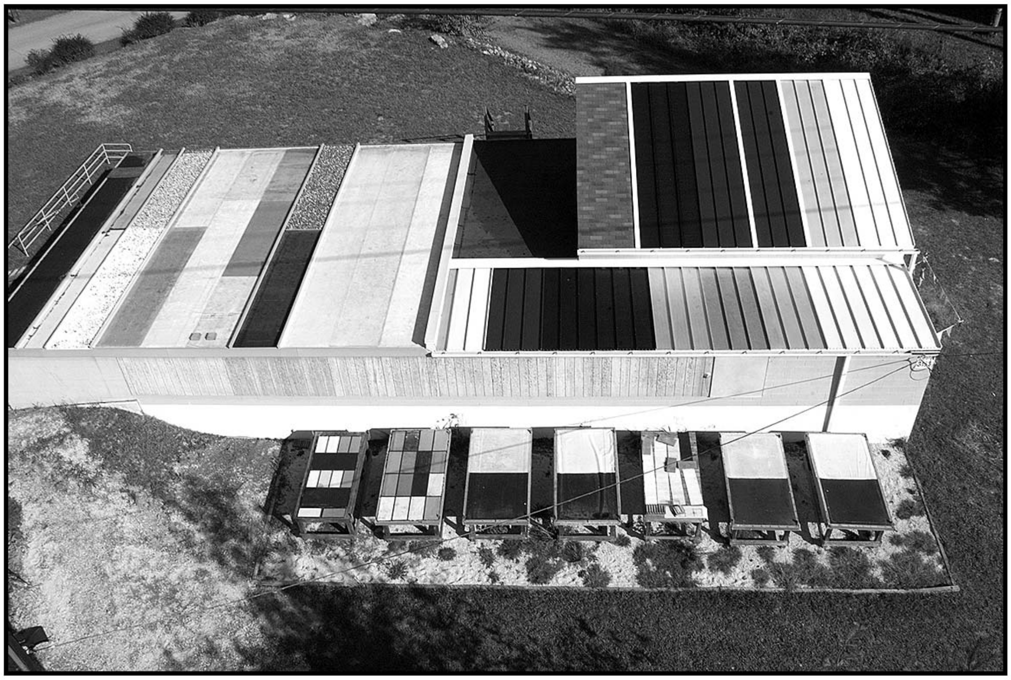

Figure 1. The Envelope Systems Research Apparatus used for testing painted and unpainted metal roofing.

Figure 2. Habitat for Humanity homes tested by the FSEC in Fort Myers, Florida.

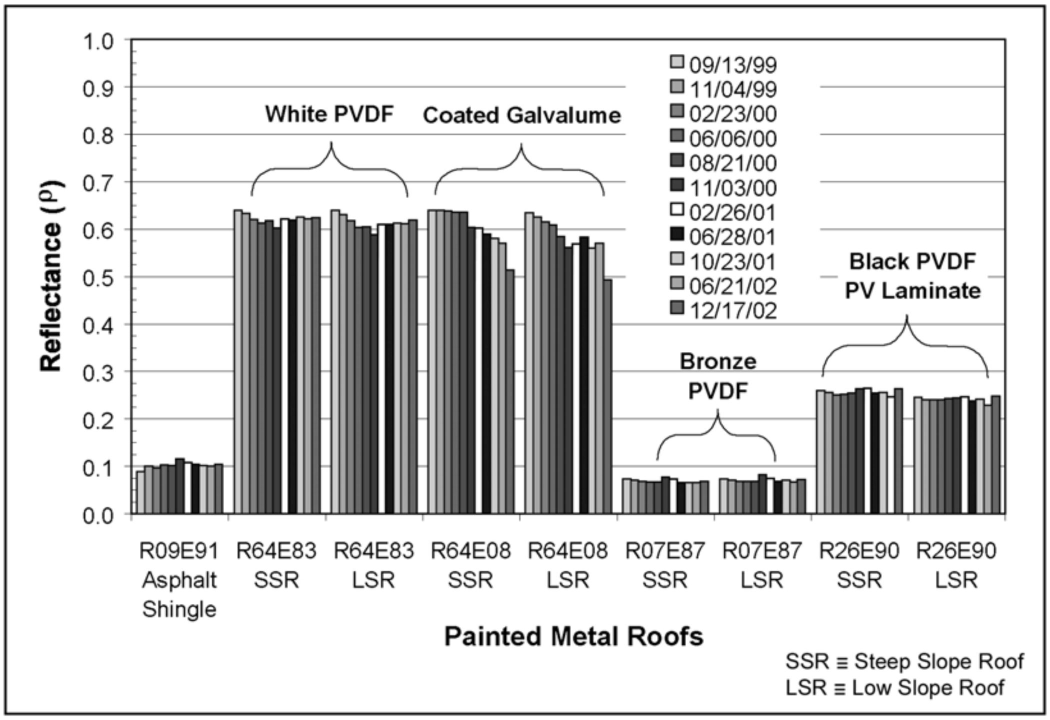

Figure 3. Solar reflectance of the painted metals exposed to weathering on the ESRA.

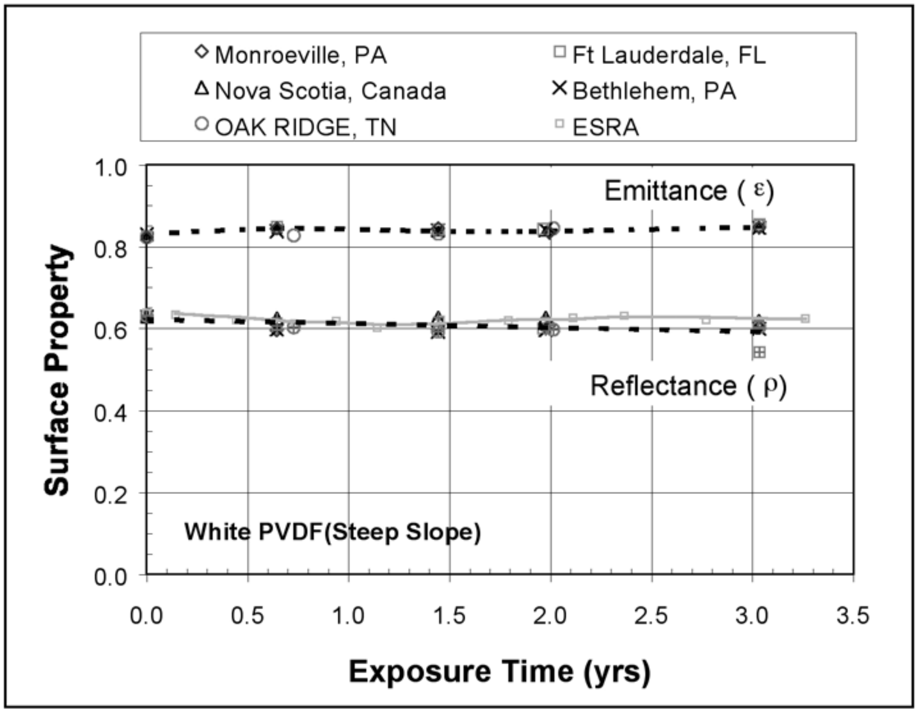

Figure 4. Solar reflectance and infrared emittance of white PVDF painted metal (R64E83).

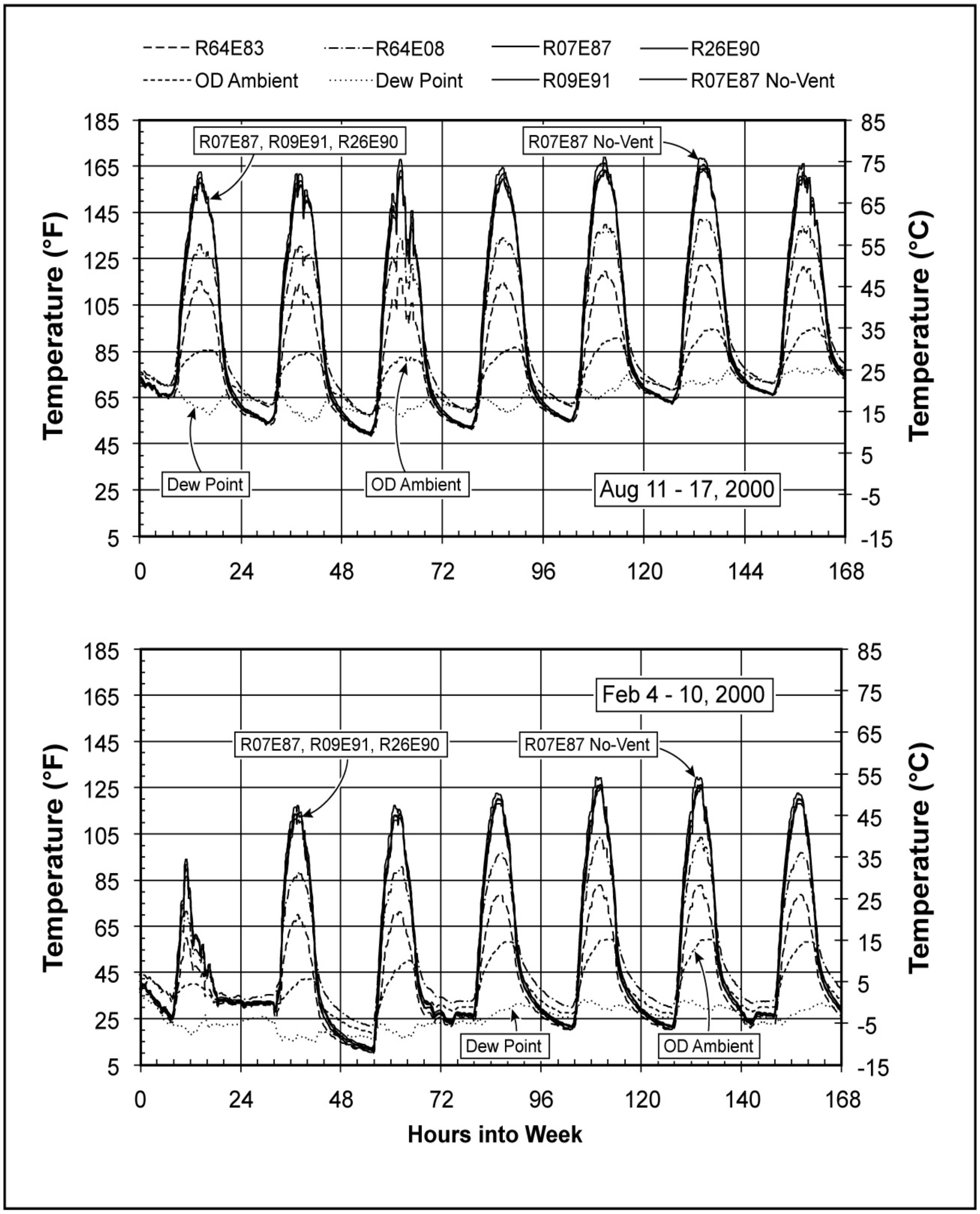

Figure 5. Field data collected for the steep-slope metal roof assembly for one week of summer and one week of winter data.

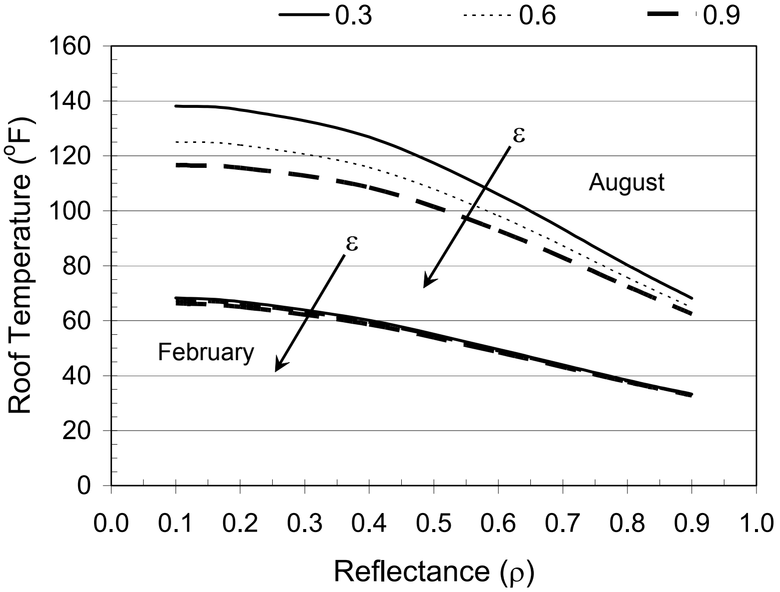

Figure 6. Roof temperature for painted metal roofs averaged over the sunlit hours.

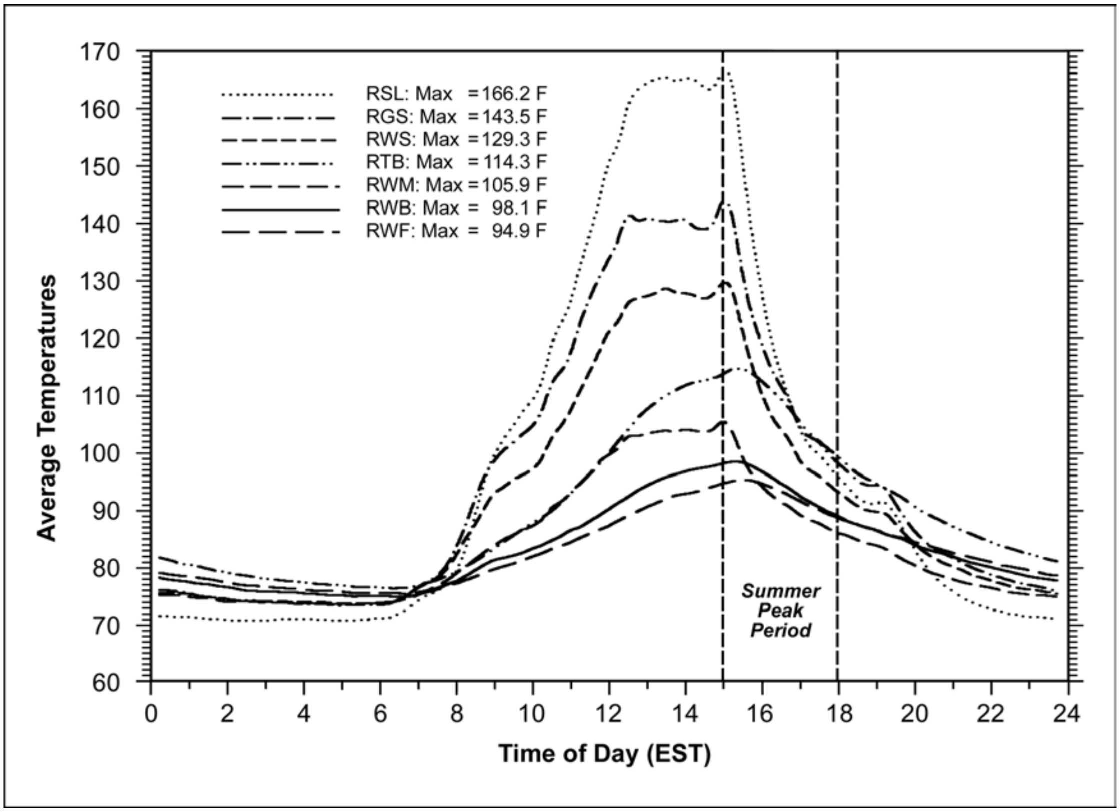

Figure 7. Deck temperatures measured on July 26, 2000.