PAINTED METAL ROOFS ARE ENERGY-EFFICIENT, DURABLE AND SUSTAINABLE

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ABSTRACT

High solar reflectance and high infrared emittance roofs incur surface temperatures that are only about 3°C (5°F) warmer than the ambient air temperature, while a dark absorptive roof exceeds the ambient air temperature upwards of 40°C (75°F). 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. Habitat homes were tested unoccupied for a full summer in Ft. Myers, Florida. Measurements showed that the white reflective roofs reduced cooling energy consumption by 18-26% and peak demand by 28-35%. The houses were side-by-side, and had different roofing systems designed to reduce the attic heat gain. 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.

INTRODUCTION

The total sales for new roof construction and reroofing is booming and nearly doubled between 1997 and 2000, from $20 billion to $36 billion (Good 2001). Of the sales volume in 2000, low-slope roofing accounted for 64% ($21.7 billion), while steep-slope "residential" roofing comprised about 35.6% ($14 billion) (Good 2001). Metal roofing has a 15% share in the commercial roofing market. However, metal historically has had a smaller share of only about 3% in the residential roofing market. The architectural appeal, flexibility, and durability of painted metal roofing has steadily increased, and as of 2002 its sales volume has again doubled since 2000 to 6% of the residential market, making it the fastest growing residential roofing product. Painted and unpainted metal roofs are becoming more and more popular for residential and commercial projects, both in steep-slope and low-slope applications. Metal roofing and its finishes are inert, safe materials that don't pose a health risk. Metal roofing is code compliant and tested for wind, fire, and hail resistance, and its non-combustibility reduces the spread of fire in and among buildings.

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 shows 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 AC 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).

To the authors' knowledge, the trade-off between climate and reflective roofs has only recently been investigated because of the time and patience required for documenting the weather's impact on exterior roof surfaces. Our research provides information on the weather's impact on the change in reflectance and emittance of roof materials, and also provides information on the decrease in building roof energy incurred by cool roofs. Metal substrate manufacturers and affiliates are keenly interested in documenting whether metal roofing can be marketed as energy-efficient, durable and sustainable roof systems with an effective service life of fifty years.

EXPERIMENTAL INITIATIVES

The Buildings Technology Center (BTC) of ORNL and the Florida Solar Energy Center (FSEC) are both working on independent field tests of painted and unpainted metal roof systems for the Cool Metal Roof Coalition (CMRC), a consortium of metal roofing industries. The American Iron and Steel Institute (AISI), the GALVALUME Sheet Producers of North America (NamZAC), the Metal Building Manufacturers Association (MBMA), the Metal Construction Association (MCA), and the National Coil Coaters Association (NCCA) are keenly interested in documenting whether their products can reduce the energy used for comfort cooling and heating of both residential and commercial buildings.

The BTC 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 Sysatems 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 east Tennessee's weather. An asphalt-shingle roof section was included as the base of comparison. It is warranted for a 15-year lifetime and has both Underwriter Laboratory and American Society for Testing Materials (ASTM) approval for residential roofing. Salient features of the ESRA facility are fully discussed by Kriner and Miller (2001).

FSEC instrumented six side-by-side Habitat for Humanity (HFH) homes in Ft. Myers, Florida with identical floor plans and orientation, R-19 ceiling insulation, but with different roofing systems designed to reduce attic heat gain (Figure 2). A seventh house had an unvented attic with insulation on the underside of the roof deck rather than the ceiling. All seven residences had a three bedroom, one bath floor plan and were of identical construction and exposure. The houses underwent a series of tests in order to ensure that the construction and mechanical systems performed similarly. The following three-letter codes were used to label each roofing system:

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[1] A zinc-coated steel sheet manufactured by the steel being 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) is laminated with amorphous photovoltaic cells.

Description of Test Roof on each Habitat House	**Label**
• Dark gray fiberglass shingles	RGS
• White barrel-shaped tile	RWB
• White fiberglass shingle	RWS
• Flat white tile	RWF
• Terra cotta barrel-shaped tile	RTB
• White 5-vee metal	RWM
• Sealed attic with insulation on the roof plane	RSL

The salient features of the Habitat homes and the respective roofs field tested in Ft. Myers, Florida are fully described by Parker, Sonne and Sherwin (2002).

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.

The Environmental Protection Agency (EPA) has implemented the Energy Star® Roof Products Program to help consumers identify energy-efficient, cost-effective roofing. Manufacturers must meet Energy Star® specifications for low- and steep-slope roof products in order to display the Energy Star® logo on their products. Low-slope roofing must have an initial solar reflectance ≥ 0.65, and the reflectance must be maintained ≥ 0.50 for 3 years after installation. Steep-slope roofing must have an initial solar reflectance ≥ 0.25, which must be maintained ≥ 0.15 for 3 years after installation. Three years of reflectance data must be documented for three existing roofs; one of the roofs must be located within a major urban area.

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 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, had a measured reflectance of only 10% (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. Even more promising is the observed durability of the surface of the painted metals; reflectance remaind 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). The urban heat content is also reduced because the "cool" painted metal roofs would not convect as much heat to the ambient wind blowing across the "cool" roof. Hence, the electrical energy generted by the fossil burning power plants is reduced, mitigating fossil fuel consumption as well as the air pollution levels of CO_2 generated at the power plant that would blanket and further exaserbate the heat content of the urban environment. Testing conducted at the roof slopes of 4-in of rise per 12-in of run (i.e., SSR in Figure 3) and at ¼-in of rise per 12-in of run (i.e., LSR in Figure 3) futher 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 3 ½ years of exposure, acid rains have not etched the metal finish. ORNL scientists detected evidence of biological growth on some of the test roofs; 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 EPA 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). 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 steep-slope assembly.

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 steel increased while those of the steep-slope remained relatively flat.

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 (29.4°C to 35.6°C) over the week in August. In February, the daily maximum air temperature ranged from 40°F to 60°F (4.4°C to 15.6°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 (71.1°C) and on some days reached a peak temperature of 165°F (73.9°C). The more reflective R64E83 and R64E08 test sections had peak temperatures of about 115°F and 135°F (46°C to 57.2°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 (11.1°C) difference in roof temperature for the white PVDF versus the steel with

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

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 Figure 5 data for the painted metal steep-slope roofs were cast in terms of the roof surface temperature averaged over the 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 (2.8°C) increase in the average roof temperature; its effect is relatively flat in the winter (Figure 6). Decreasing the reflectance from 0.6 to 0.4 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 0.9 (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 sumertime 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 can 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 Ft Meyers, 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 sumer 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. 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 5% cooling energy reduction. Next is the home with the white shingles (15.3 kWh/day) – an 8% reduction. The sealed attic (RSL) comes in with a 12% 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 a 22% cooling energy reduction. The white metal roof (RWM) showed the largest impact with a 12.0 kWh/day August consumption, yielding a 28% reduction in cooling energy consumption.

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

Site	Total kWh/day	Savings kWh/day	Save %	Thermo-stat (°F)	Mean Attic °F	Max. Attic °F	Temp. Adjust. %	Adjust Saving %	Field EER	Final Saving %
RGS	17.0	0.00	0.0	77.2°	90.8	135.6	0.0	0.0	8.30	0.0
RTB	16.0	1.01	5.9	77.0°	87.2	110.5	-1.6	7.5	8.12	7.7
RWS	15.3	1.74	10.2	77.0°	88.0	123.5	-1.2	11.4	9.06	10.6
RSL	14.7	2.30	13.5	77.7°	79.0	87.5	5.4	8.1	8.52	7.8
RWB	13.3	3.71	21.8	77.4°	82.7	95.6	2.8	19.0	8.49	18.5
RWF	13.2	3.83	22.5	77.4°	82.2	93.3	2.1	20.4	7.92	21.5
RWM	12.0	5.00	29.4	77.6°	82.9	100.7	4.9	24.5	8.42	24.0

* The numbers in Table 1 were adjusted to account for the differences in interior temperature and AC performance.

It is noteworthy that the average July outdoor ambient air temperature during the monitoring period (81.6°F) was very similar to the 30-year average for Ft. Myers (82°F). 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 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.

The roof decking temperature (Fig. 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. On average the shingles reached a peak temperature that was seven degrees hotter than standard construction. However, decking temperatures were almost 20°F hotter. The white roofing systems (RWM, RWF and RWB) experienced peak surface temperatures approximately 20°F cooler than the darker shingles (Fig. 7). The terra cotta barrel tile case was about 10°F cooler.

The measured mid attic air temperatures (Fig. 8) above the ceiling insulation further revealed the impact of the white reflective roofs with average peak temperatures about 20°F cooler than the control home (RGS). Whereas the attic in the control home reaches 110°F on the typical day, the attics with the highly reflective white roofing materials only rise to about 90°F. As expected, the home with the sealed attic had the lowest attic temperatures reaching a maximum of 83°F compared with the 77°F 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 only has a thermal resistance $R \leq 1$, 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 although not appreciably different from the other white roofing types. Also, the savings for the white roofs relative to the control were greater than for other days.

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 fresh-from-the-can appearance. They appear to have an excellent corrosion-resistant surface whose opacity limits photochemical degradation caused by ultraviolet light present in sunlight. After 3 ½ years of exposure, acid 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. Drops in reflectance are only about 5% after 3 ½ years of exposure. 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 six side-by-side Habitat 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 600-1,100 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.

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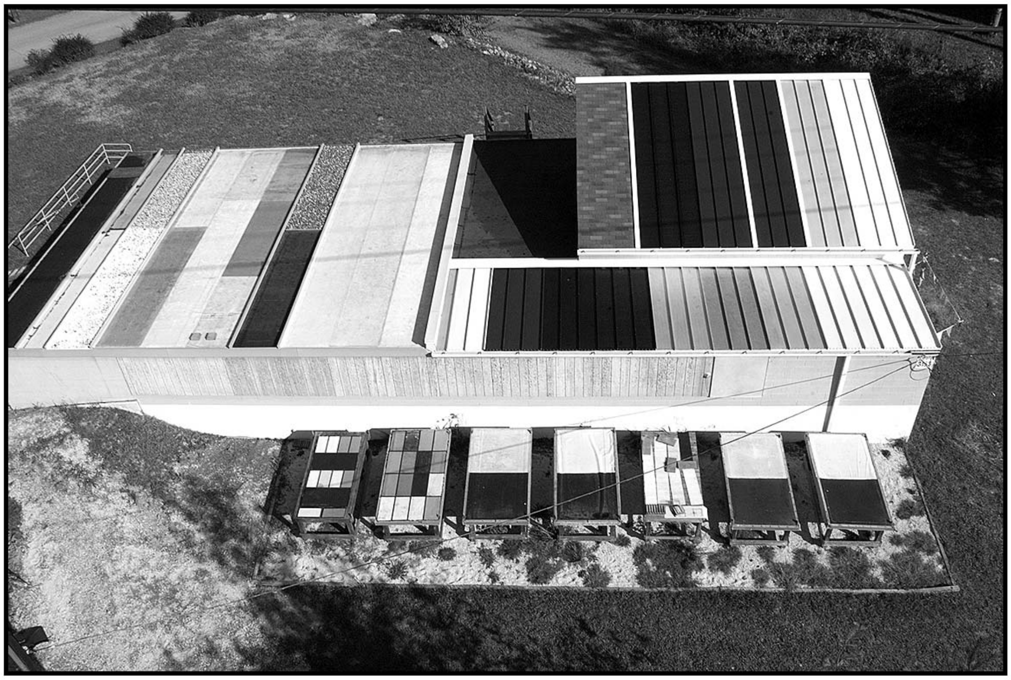

Figure 1. The Envelope Systems Research Apparatus used for testing painted and unpainted metal roofing.

Figure 2. Picture showing the Habitat for Humanity test homes in Ft. Myers, Florida.

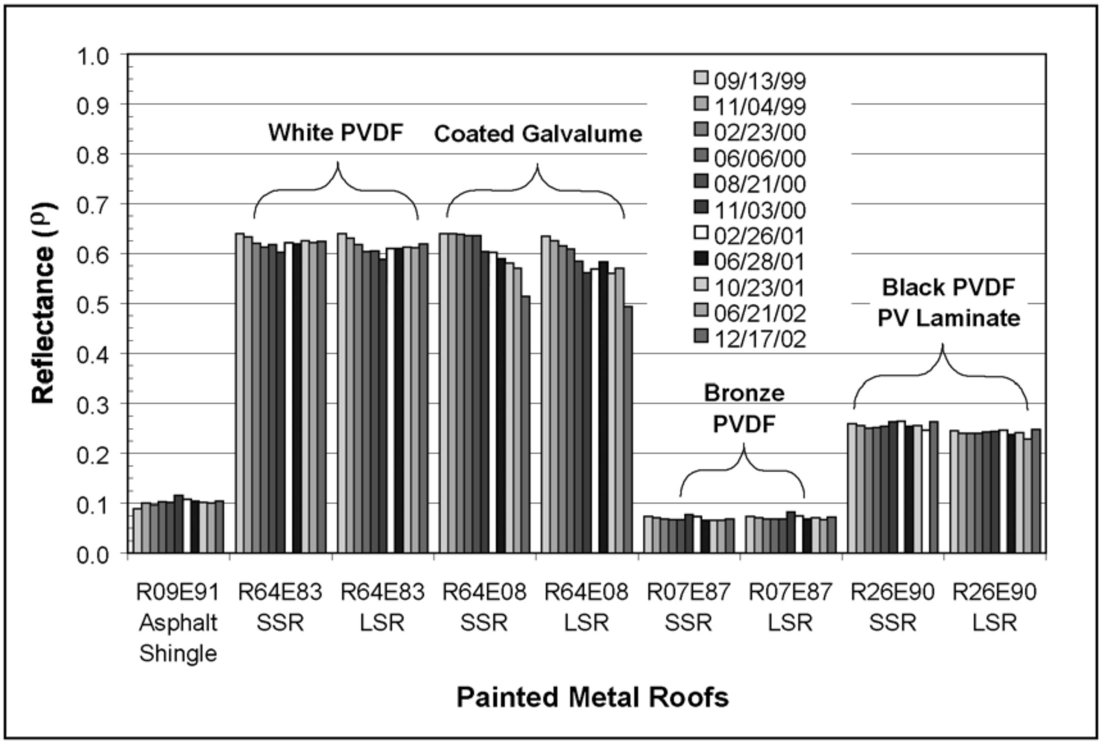

Figure 3. Solar reflectance of the painted metals exposed to weathering on the ESRA.

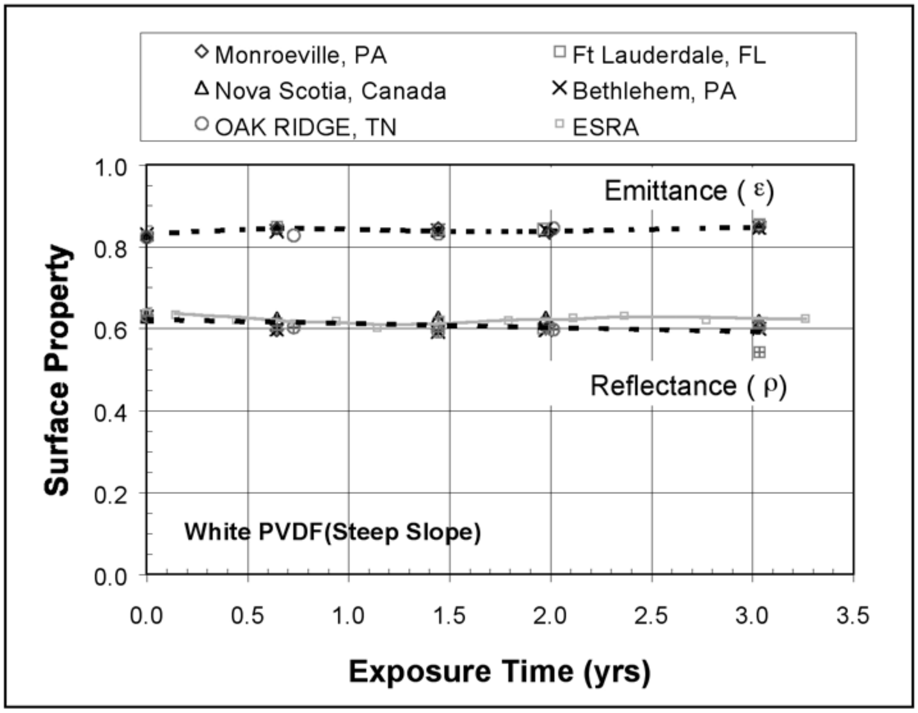

Figure 4. Solar reflectance and infrared emittance of white PVDF painted metal (R64E83).

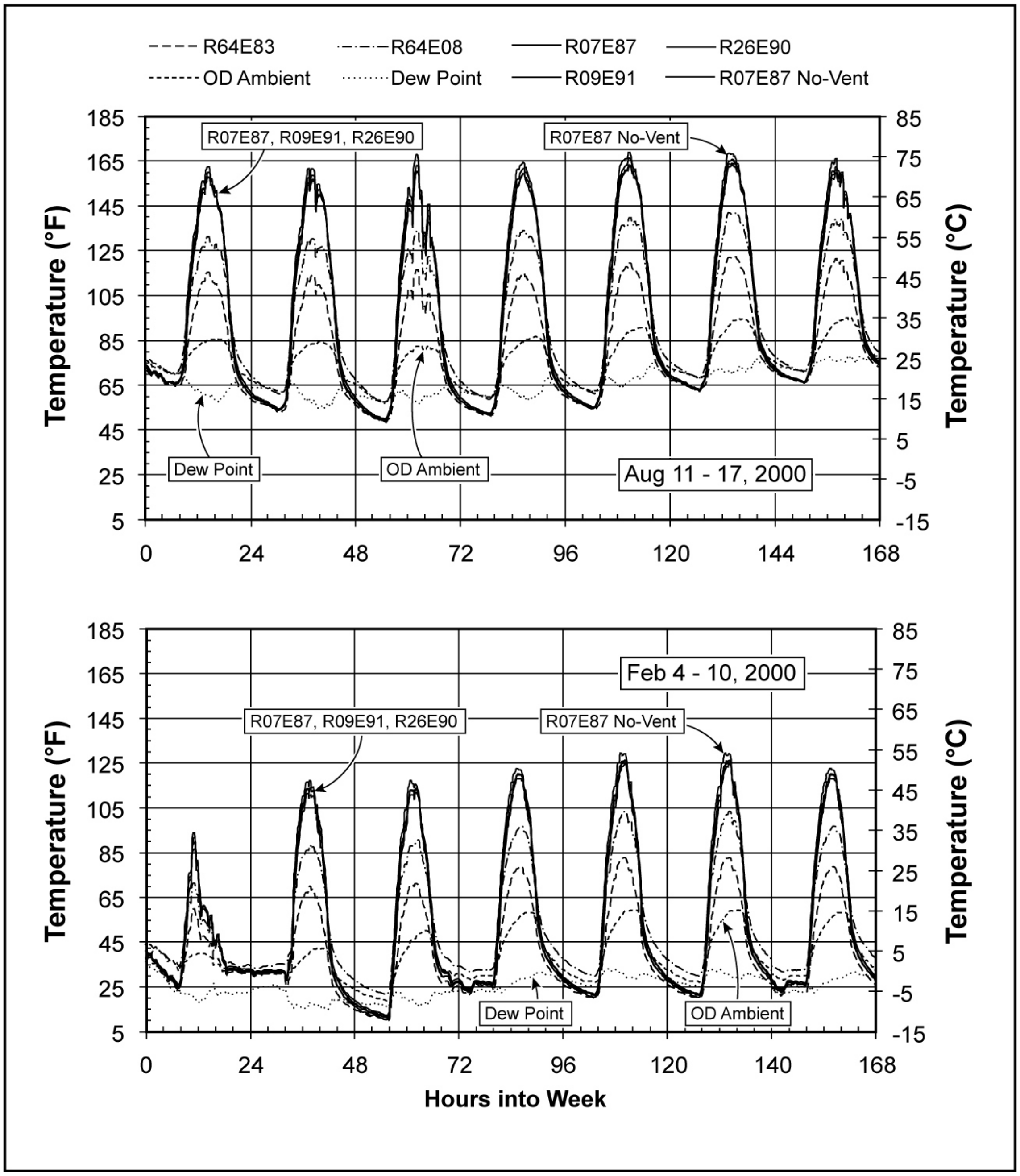

Figure 5. Field data collected for the steep-slope metal roof assembly for one week of summer and one week of winter data.

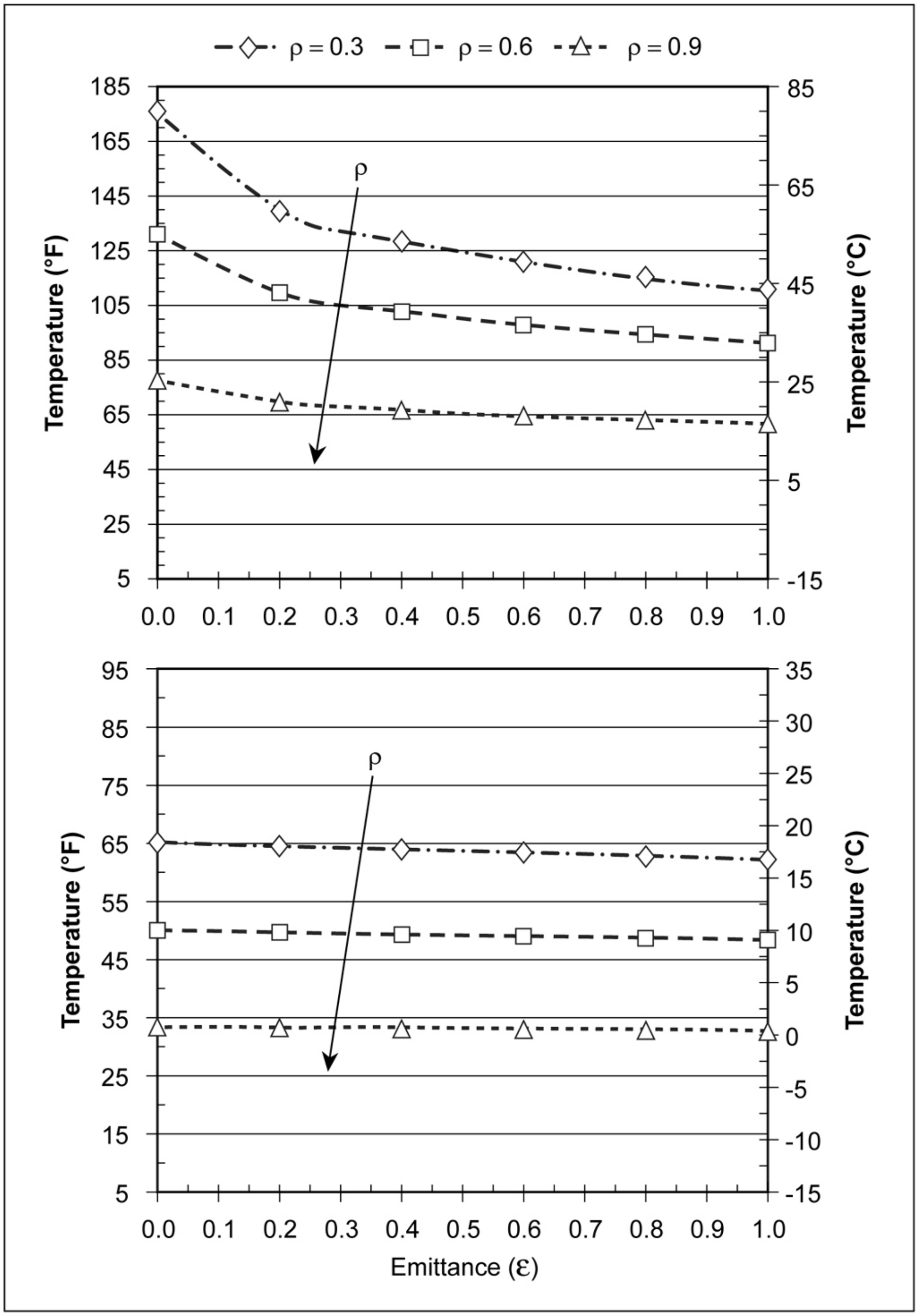

Figure 6. The effect of emittance and reflectance for field exposure data collected for summer (top) and winter (bottom) plots.

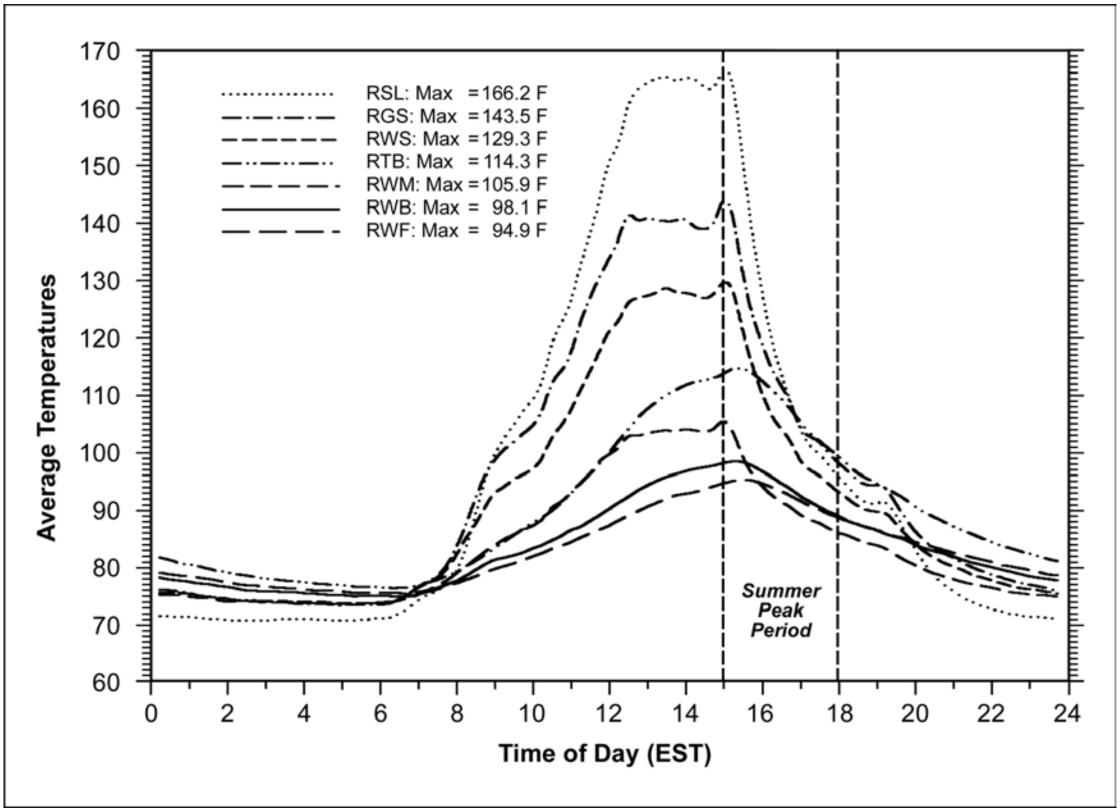

Figure 7. Roof decking temperature profiles measured for July 26, 2000.

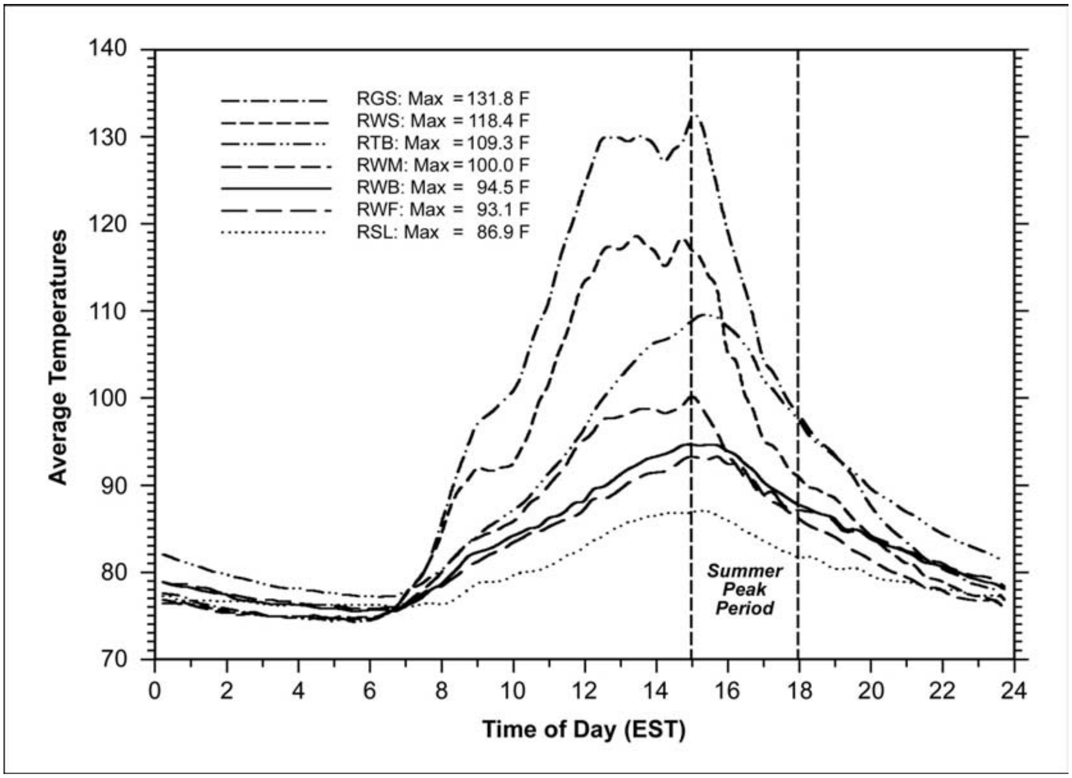

Figure 8. Attic temperature profiles measured for July 26, 2000.