

In Situ Thermal Performance of APP-Modified Bitumen Roof Membranes Coated with Reflective Coatings

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ABSTRACT

A multi-faceted field research program regarding seven atactic polypropylene (APP) modified bitumen membrane roof systems and four reflective coatings began in 1991.

This long-term project is evaluating the performance of various APP-modified bitumen membranes (both coated and uncoated), the comparative performance of coating application soon after membrane installation versus pre-weathering, coating performance, and aspects of recoating.

This paper is a progress report on the in situ thermal performance of the various types of coated membranes compared to the thermal performance of the exposed membranes. The thermal performance of an adjacent ballasted ethylene propylene diene terpolymer (EPDM) roofing system is also described.

INTRODUCTION

Recent research has established the benefits of reflective roof coatings as they relate to energy conservation and resultant cost savings due to reduced cooling loads (Anderson 1989; Griggs and Shipp 1988; Griggs et al. 1989). In fact, the success of recent research has initiated changes in roof coating terminology. Categories of products (which the roofing industry refers to as *liquid-applied reflective roof coatings*) have dramatically reduced cooling loads for buildings in warm climates. The high solar reflective coatings are now referred to as *radiation control coatings* (Anderson 1989).

However, minimal work has been done to study the comparative thermal performance of the more commonly utilized roof coatings. Therefore, the National Roofing Contractors Association (NRCA) and a national laboratory have collaborated on a test roof in the Chicago, Illinois, area. This new full-scale test roof has been given the project name "APP Weathering Farm." The test roof and coatings were installed during the spring and summer of 1991 to study the in situ performance of common roof coatings applied over various modified bitumen roof membranes.

Additional aspects of the APP Weathering Farm project are to study the thermal, mechanical, and durability performance of various membranes (coated vs. uncoated), the comparative performance of the coating with respect to application time (application soon after membrane installation vs. preweathering of membrane), coating performance, and aspects of recoating. The APP Weathering Farm is scheduled as a long-term research project (10+ years) to research the comparative performance of various types of roof coatings applied over different types of atactic polypropylene (APP) modified bitumen roof membranes.

This paper is a progress report, including background information and comparative data, on the in situ thermal performance of modified bitumen roof membranes coated with various types of reflective roof coatings. Future papers will report on the other research aspects of the project.

Background Information

Experience and research has taught roofing contractors, manufacturers, and building owners the weather-shielding benefits of various surfacings for roof membranes (Cullen 1963).

As smooth surface membrane roofing has progressed over time, industry has learned that light-colored, liquid-applied coatings can provide an excellent reflective surfacing for the otherwise exposed black asphalt of smooth-surfaced bituminous roofs. Shielding the black-colored asphalt surface from direct exposure to sun and weather is thought to prolong the life of smooth-surface bituminous roof membranes.

This comparative study should lend physical data to the current assumption that coatings can be useful for two real energy conservation solutions: to conserve energy and resources by extending the longevity of smooth-surface APP polymer modified bitumen roof membranes and to decrease energy consumption by reducing annual cooling loads and to minimize peak cooling loads.

To assist in understanding the implications of this roofing, coating, and thermal comparison study, a brief explanation of APP-modified bitumen roof membranes and commonly used coatings is presented.

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Modified Bitumen Roof Membranes

During the 1960s and 1970s, research began to extend and modify petroleum derivatives through polymer chemistry. The modification of roofing asphalts with various polymers was found to alter a bitumen's physical properties. This modification of roofing asphalts has helped spur the introduction of polymer-modified bitumen roofing materials.

In the category of modified bitumen roof membrane systems, there are two general types of membrane materials that have become quite popular—bitumens that are modified with atactic polypropylene (APP) polymers and bitumens modified with styrene butadiene styrene (SBS) polymers. APP polymers alter the asphalt's physical properties so that it takes on a plasticized nature; APP modified asphalt is, in effect, "plasticized" asphalt. Modification of roofing asphalt with SBS causes the asphalt to take on "rubberized" properties.

Both APP and SBS roll goods may be purchased as smooth-surface sheets or surfaced with mineral granules. The need for surfacing, either by coating or by factory-applied mineral granules, has long been recognized for SBS-modified products. However, because APP-modified membranes were previously thought less susceptible to ultraviolet degradation, they typically have been left unsurfaced. In recent years in the U.S., the premature demise of some smooth-surfaced APP membranes that have been left exposed to solar radiation has signaled the possible benefit that reflective surfacings or coatings may provide in extending roof service life (see Figure 1).

Basic Roof Coating Types

There are numerous types of coatings used in roofing. However, only three basic types of reflective coatings are commonly applied to bituminous roof membranes in the

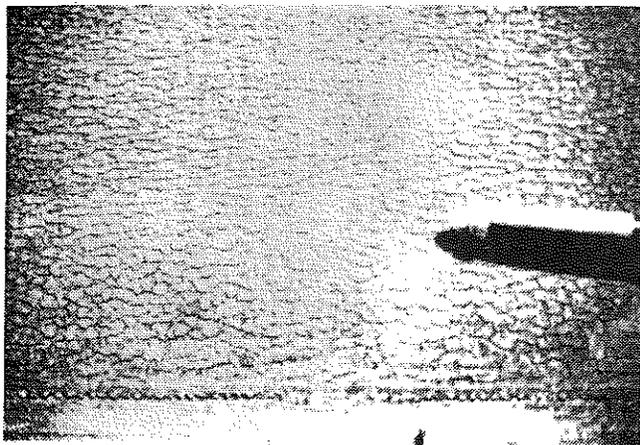


Figure 1 Surface craze cracking degradation evident on six-year-old uncoated APP-modified bitumen membrane.

U.S.—asphalt emulsions, latex (acrylic) coatings, and solvent-based aluminum asphalt.

Asphalt Emulsions Emulsified asphalt coatings consist of asphalt particles dispersed in water with clay (typically bentonite) as the emulsifying component. As with most other types of roof coatings, emulsions contain various organic and/or inorganic fibers and fillers to help reinforce the dried coating film.

Asphalt emulsions are available in their natural dark brown/black asphalt color or as reflective coatings that contain titanium dioxide or aluminum pigment. "Reflective" emulsions containing titanium pigments are a grayish color, and "aluminum" emulsions dry to a more silver shade.

Latex (Acrylic) Coatings Water-based latex roof coatings (also commonly referred to as acrylic coatings) contain various types and qualities of acrylic polymers to extend physical properties and improve durability. Latex coatings are available in numerous colors; however, most applied to bituminous roof coverings are white.

Solvent-Based Aluminum Asphalt ("Cutbacks") Solvent-based asphalt coatings are referred to as "cutback" coatings because the asphalt, which is a solid at ambient temperatures, is cut back with solvents to liquify the coatings for ease of application. Solvent-based asphalt coatings are available in their natural black color or as reflective coatings that contain aluminum flakes or pigments. Solvent-based aluminum coatings dry to an aluminum or silver hue.

Cured coatings may be different shades with varying degrees of reflectivity. Product formulation, extent of mixing, shelf life, type of application, and weather during application all may have effects on the finished brightness and resultant reflectivity of the installed coating once it has dried and cured.

Some Premature Degradation of APP-Modified Bitumen Membranes without Coatings—an Industry Problem

APP-modified bitumen roofing has been used throughout most of the U.S. for more than a decade. Industry is beginning to realize that APP-modified bitumen membranes should provide longer service life if coated with a reflective coating relatively soon after membrane installation to reduce the effect of solar radiation, which results in reduced heat gain and heat aging. This has led numerous manufacturers of APP-modified materials to offer longer warranties if the membranes are coated after installation (some manufacturers now require a coating to obtain a warranty).

DESCRIPTION OF APP WEATHERING FARM

Materials and Configuration

The APP Weathering Farm roof is installed on the office portion of a two-story building complex. The office

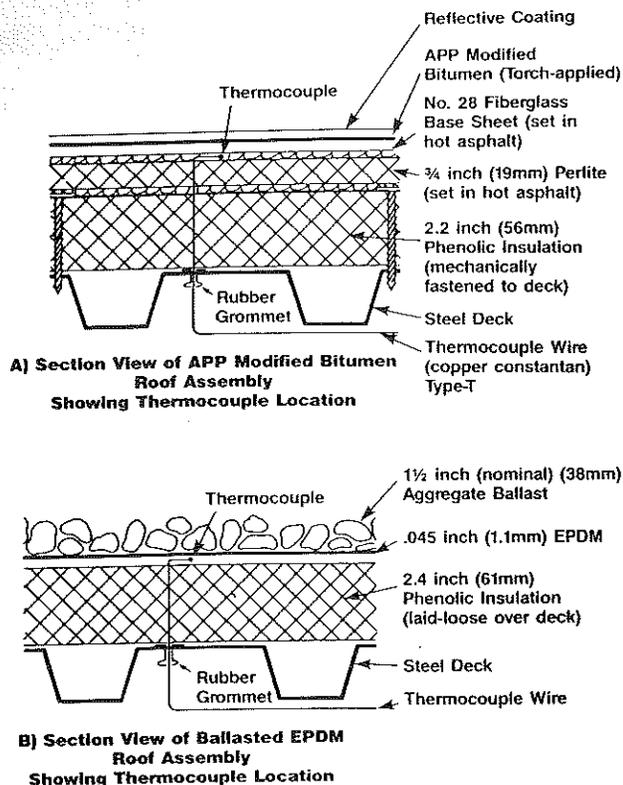


Figure 2 Detailed sections of APP roof membrane assembly and ballasted EPDM roof assembly showing thermocouple location.

portion of the building is an air-conditioned space. An interior concrete block wall separates the office from an adjacent sheet metal shop and warehouse space that is not air conditioned. The shop and warehouse portion of the building's walls are masonry and their exterior is light beige split-face concrete block. The exterior of the office area is dark red brick.

The roof's structural assembly consists of steel columns supporting steel trusses that are overlaid with galvanized steel roof decking. The framing is sloped so the roof deck slopes approximately 1/4 inch per foot ($\approx 2\%$).

Over the steel roof deck of the office portion, the roof system consists of (see Figure 2A)

- 2.2 inches (56 mm) of phenolic foam roof insulation installed in one layer and mechanically fastened to the metal deck,
- 3/4-inch (19 mm) perlite coverboard adhered to the primary insulation in solid moppings of hot asphalt,
- one ply of No. 28 glass-fiber-reinforced base sheet fully adhered in hot asphalt,
- one ply of smooth-surface APP-modified bitumen roofing torch applied to the base sheet and surfaced as shown in Figures 3 and 4.

Based on the insulation manufacturer's published in-service R-values, the total R-value of the roof assembly, including air films, is approximately 24 ($\text{h}\cdot\text{ft}^2\cdot^\circ\text{F}/\text{Btu}$).

To gain additional thermal comparison data, the ballasted ethylene propylene terpolymer (EPDM) roof over the shop space was included in the study.

The ballasted EPDM roof system over the shop and warehouse consists of the following (see cross section shown in Figure 2B):

- 2.4 inches (61 mm) of phenolic foam roof insulation, installed in one layer, loose-laid over the metal deck;
- one layer of .045 mil (1.1 mm) thick EPDM sheet roofing loose-laid over the insulation;
- surfaced with 1-1/2 inch (38 mm), nominal-sized, river-washed aggregate as ballast (approximately 1,000 pounds per 100 square feet [49 kilograms per square meter]). (The aggregate is a gray/tan color mix.)

Based on the insulation manufacturer's published in-service R-values, the total R-value of the ballasted EPDM roof assembly, including air films, is approximately 21 ($\text{h}\cdot\text{ft}^2\cdot^\circ\text{F}/\text{Btu}$).

For the office roof, seven different manufacturers supplied APP-modified bitumen membranes. Four coating manufacturers supplied three different types of reflective coatings—a titanium-pigmented reflective asphalt emulsion, a fibrated solvent-borne aluminum asphalt, and two different types of white latex coatings.

The APP sheets are installed parallel with the slope of the roof in "strapped" fashion (as opposed to "shingle" fashion—plies laid perpendicularly to the slope).

The roof area is divided into segments so that each type of membrane is coated with each type of coating (see Figure 4). Approximately 25% of the roof surface was left exposed as a control to allow a thermal and weathering comparison with the coated areas. The remaining 75% of

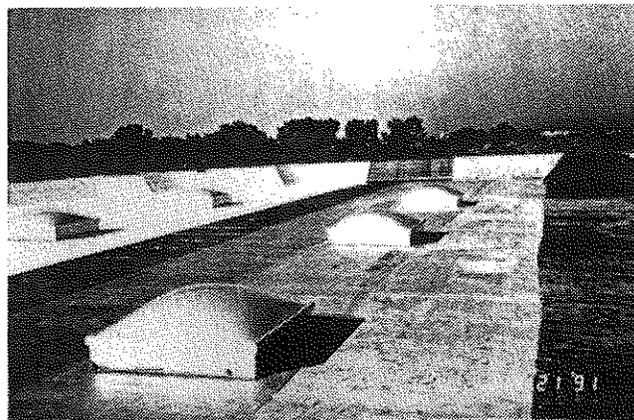


Figure 3 Panoramic view of APP Weathering Farm roof.

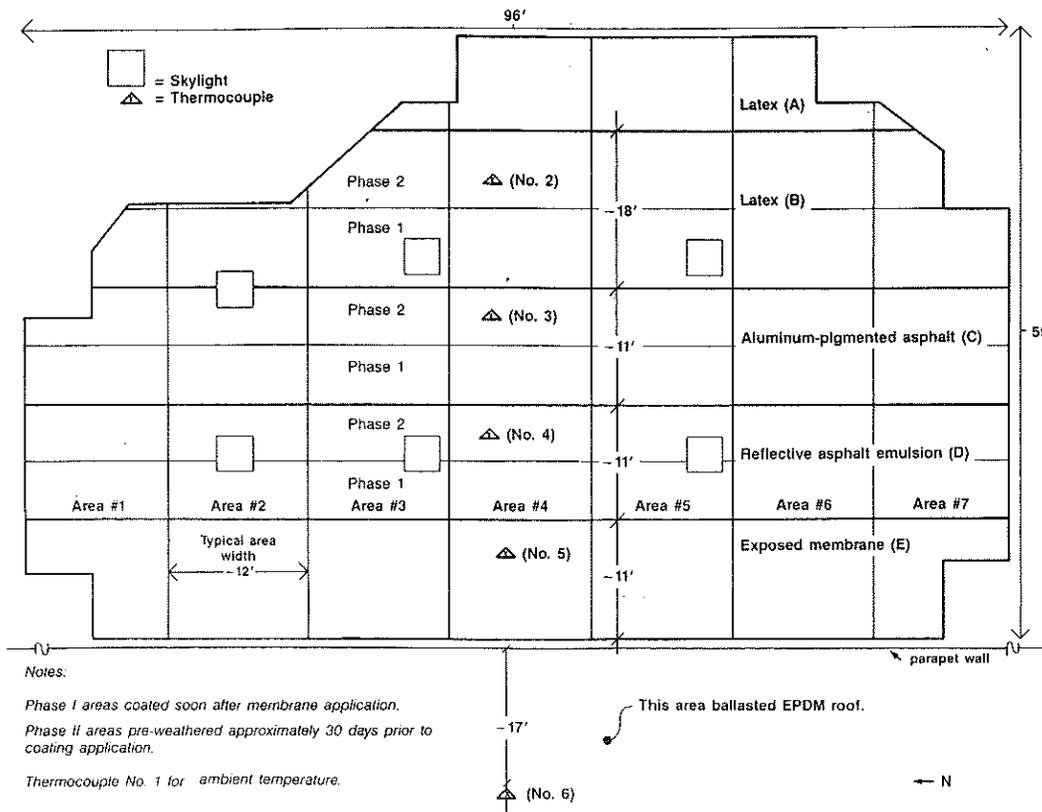


Figure 4 Plan view of APP Weathering Farm showing exposed and coated membrane layout and thermocouple locations.

the roof area is apportioned for each of the three types of liquid-applied coatings.

To compare the performance of coated, preweathered membranes with membranes that were coated soon after being installed, each of the areas designated to receive coating was divided in half. On one half, the coating was applied soon after the membrane was installed (shown as Phase I in Figure 4). On the other half of each of the areas receiving coatings, the membranes were allowed to pre-weather approximately 30 days prior to coating application (shown as Phase 2 in Figure 4).

Surface Preparation

Dust, dirt, and other contaminants hamper coating adhesion. Field experience and research have shown that some of the factory-applied parting agents (e.g., sand, mica, talc, polyethylene films, etc.) also inhibit thorough coating adhesion. Membrane manufacturers apply the parting agent(s) in the factory to keep the material from sticking together while in the roll. As could be expected, membrane surface preparation is beginning to be recognized as an important first step in good roof-coating practice.

Prior to application of coatings, the membrane surface was prepared in accordance with the Asphalt Roofing Manufacturers' Association (ARMA) and the Roof Coating Manufacturers' Association (RCMA) guide for surface preparation (ARMA/RCMA 1991).

Coating Application

After the membrane surfaces were prepared, the coatings were installed. The coatings were applied using accepted industry techniques in typical fashions as follows:

1. **Asphalt emulsion** The reflective emulsion was applied in one application at approximately 3 gallons per 100 square feet (1.2 liters per square meter). The well-mixed emulsion was poured onto the membrane surface, then spread with a wide pushbroom.
2. **Latex** The white latex coating was applied in two applications at approximately 3/4 gallon per 100 square feet (0.3 liters per square meter). The latex was rolled on with 18 inch (460 mm) wide rollers; the second application was rolled on at 90 degrees to the first.
3. **Solvent-Based Aluminum Asphalt** The aluminum cutback was rolled on in one application at approximately 1 1/2 gallons per 100 square feet (0.6 liters per square meter).

Prior to applying the coating over the preweathered APP membrane, thermocouples were placed directly underneath the membrane (see Figure 2). After the coatings were installed, data collection was initiated.

Instrumentation

Copper constantan type-T thermocouples (all from the same spool of wire) were installed between the interface of the base sheet and the top surface of the perlite coverboard. Thermocouples were installed directly underneath each membrane surface configuration—the exposed membrane, the area to be coated with reflective asphalt emulsion, the area designated for solvent-borne aluminum, and the area for white latex coating. (Note: To gain additional thermal comparison data and insight into possible energy conservation differences, a thermocouple was also installed in the adjacent EPDM roof system over the shop area.)

A DC-powered, six-channel data logger and a cassette tape player were used to collect the temperatures of the membranes each minute, average them each hour, and store them for later data analysis. The data were transferred into spreadsheets for analysis.

Data Analysis

Data collection began on August 8, 1991. Figure 5 shows the recorded membrane temperatures for a week in August; shown are the three coated APP membrane temperatures along with the exposed black APP membrane, the ballasted EPDM membrane, and the ambient air temperature. The air temperature data were recorded at O'Hare Airport, which is approximately two miles from the test site. The uncoated black membrane's temperature on sunny days is frequently 70°F (21°C) above the ambient air temperature. The highest recorded exposed membrane temperature for the first year of data collected was 169°F (76°C) on June 13, 1992. Figure 6 shows comparative peak temperatures of exposed, coated, and ballasted roof areas for a typical sunny day in August 1991.

The asphalt emulsion and solvent-based aluminum asphalt appear to perform about the same during daylight hours. The temperature rise above ambient air is 50°F to 60°F (10° to 15.5°C) during the peak cooling period of the day, although, when examining peak temperatures, the reflective-emulsion-coated membrane registers slightly cooler (2° to 7°F [1° to 4°C]) than the solvent-borne, aluminum-coated membrane.

The white latex coating clearly shows the most significant reduction in temperature rise above ambient. The peak surface temperature shown in Figures 5 and 6 on August 11 is 104°F (40°C) compared to the black at 156°F

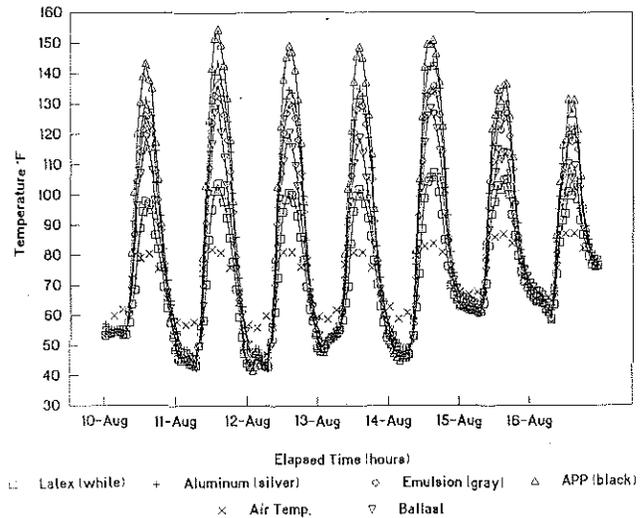


Figure 5 Hourly membrane temperatures for week of August 10-16, 1991.

(69°C). For this day, the latex-coated membrane's peak temperature is only a 21°F (12°C) rise above ambient, whereas the black exposed membrane rose 73°F (41°C) above ambient.

On clear nights, all four roof surfaces drop below ambient temperature by 10°F to 15°F (-12° to -9°C). On August 15 and 16, there was considerable cloud cover and the roof surface temperature can be seen to be much closer to the outside temperature.

Figure 7 is a similar type of plot except it shows temperatures for a very cold period in January 1992. On the morning of January 15, about two inches (51 mm) of snow fell, which kept the roof surface temperature very near the ambient air temperature. The evening of January 15 was cloudy, tending to keep the surface temperature similar to the ambient air temperature. The fact that all these thermocouples register nearly the same temperature illustrates the good precision in the data acquisition system.

The evenings of January 17 and 18 were cloudless nights. Notice all the roof membrane temperatures dropped below the ambient. However, the solvent-based aluminum distinctly does not get as cold as all the others. These data suggest that the infrared emittance of this coating is probably lower than the others.

(NOTE: On cloudless nights, the sky temperature is much colder than the ambient air temperature. Long-wavelength heat can be radiated to the cold night sky from

| AMBIENT | EXPOSED | ALUMINUM | REFLECTIVE EMULSION | BALLASTED EPDM | WHITE LATEX |
|---------|---------|----------|---------------------|----------------|-------------|
| 83 °F | 156 °F | 143 °F | 136 °F | 130 °F | 104 °F |
| | | | | | |

Figure 6 Example of temperature comparisons for a typical warm, sunny day (August 11, 1991).

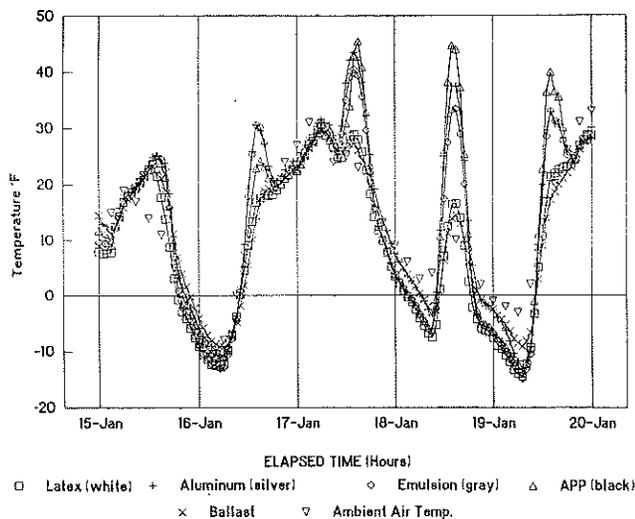


Figure 7 Minimum membrane temperatures experienced over test period to date. Shows data from January 15-20, 1992.

roof surfaces. Roof surfaces, which have a low infrared emittance, will radiate less and thus maintain a higher nighttime temperature than surfaces with a higher infrared emittance. The difference in radiant cooling of the roof coatings that will increase the nighttime heat loss to a different degree is not included in the calculations of energy savings shown later in this paper. Usually roof materials are assumed to have about the same infrared emittance even though their solar reflectance can be quite different.)

Reviewing the nighttime temperatures of the aluminum and emulsion coating in the summer (Figure 8) indicates that this phenomenon also holds true. The aluminum coating does not get quite as cold as the emulsion by 2°F to 4°F (1°C to 2°C).

Each of the coatings' solar reflectances was measured at a national university using a solar reflectometer. The aluminum coating was found to have a solar reflectance of 0.48 compared to 0.28 for the emulsion and 0.61 for latex "B." The uncoated black APP surface measured 0.074 for solar reflectance. This would suggest that the two nonwhite coatings should not have the similar temperature behavior that the data illustrate. However, coating thickness (mass) may play a role in the temperature moderation of the membrane under the thicker reflective emulsion coating. Another possibility that will be explored is the possible variation of coating thickness on the roof compared to the thickness of samples used to make the solar reflectance measurements in the laboratory. Convective heat transfer effects, which are not usually contemplated, may also be a factor.

(NOTE: At any instant, total heat radiation falling on a roof surface must equal the sum of radiation that is transmitted, or reflected, or absorbed. Since roofs are usually opaque to solar radiation, the transmission is zero. Thus, absorption plus reflectance equals 1.0.)

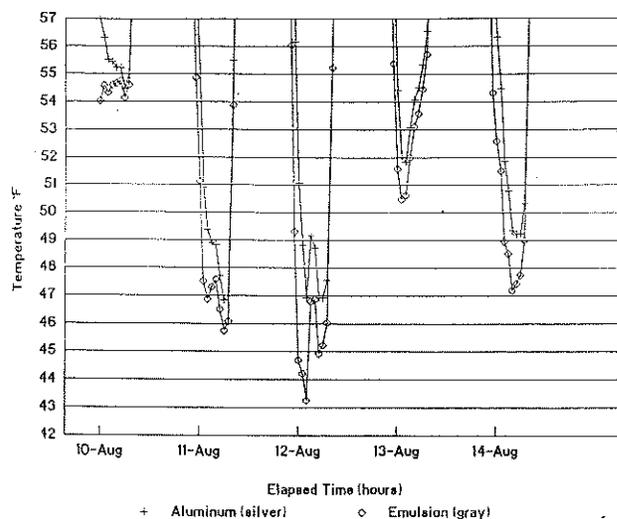


Figure 8 A nighttime membrane temperature comparison of the aluminum (silver color) and emulsion (gray) coatings.

The emittance of these coatings has not been measured, but most simplified models use only solar reflectance to predict the reduction in building cooling loads and increases in heating loads.

(NOTE: Emittance is the property of the roof surface that describes the ability to emit energy as compared to emission by a black body at the same temperature. A black body, in turn, is defined as a perfect absorber of radiation for all wavelengths. Infrared emittance refers to emittance on only the radiation with wavelengths in an infrared portion of the thermal radiation spectrum.)

A difference in reflectance of 0.20 (between .48 and .28) used in simple prediction models result in significant building energy load estimation differences. Further modeling and reflectance and emissivity measurements will be made to resolve this uncertainty between theoretical predictions and measured performance.

The impact is quite important. Using the "Guide for Estimating Differences in Building Heating and Cooling Energy Due to Changes in Solar Reflectance of a Low-Sloped Roof" (ORNL 1989) and estimating the installed cost for aluminum coating with a solar reflectance of .48, the theoretical simple payback for an office building in Chicago is 10 to 16 years; in Orlando, 8 to 13 years; and in Phoenix, 5 to 8 years. This is compared to the gray emulsion coating with a solar reflectance of .28, with theoretical simple paybacks of 26 to 40 years for Chicago and 21 to 31 years in Orlando.

(NOTE: These figures include estimated assumptions for cost of material, labor to install, and energy consumption. The figures do not consider coating life or any costs associated with recoating (if necessary). The figures also do not account for the benefits of extended membrane service life and its associated cost savings. Considering the thermal performance of the gray emulsion, i.e., its ability to

moderate or lower roof membrane temperature more than the aluminum coating, the actual paybacks for the emulsion may be sooner than theoretically estimated.)

These paybacks are based on insulation R-values of 20 for Chicago and 16 for Orlando and Phoenix. Lower insulation R-values would reduce these simple paybacks. For example, the simple estimated payback for the aluminum coating for an office building with only R-8 in Chicago would be five to nine years and, if located in Phoenix, three to five years.

The white latex coating has an initial reflectance of .61, which is not considered very high. There are numerous radiation control coatings on the market with reflectances above .8. Using the formula for estimating simple paybacks (Griggs et al. 1989) for this coating based on energy savings only (not factoring in extended roof membrane life) for a Chicago office roof with R-20 is 12 to 18 years; for Orlando with an R-16 roof, 9 to 14 years; and for Phoenix with R-16, six to nine years. For a Phoenix office roof with only R-8 of conventional insulation, these simple paybacks are only three to five years.

However, the major discovery thus far is that predicting the impact of these middle-reflectance-range coatings by a single-reflectivity measurement is not necessarily going to lead to the right coating decision in terms of thermal performance for a given geographical region or area. A second major issue that this research project will help to resolve is the effects of actual weathering, under real field conditions, on the reflectance of these common coatings.

The real paybacks due to the reduced energy consumption benefits of the coatings and the actual extent of extended roof membrane longevity due to the protective coatings may be dramatic in certain geographic/climatic regions.

Based on reflective measurements and the use of these measurements in a simple model to predict the differences in building energy use, the field data tend to support the computer predictions for the uncoated and white latex coating but not the solvent-based aluminum and gray emulsion. Additional reflectivity measurements and modeling are needed to resolve why these two nonwhite coatings behave so similarly considering their different reflectiveness. At this time, it is speculated that the infrared emittance is smaller for the solvent-based aluminum coating

than all the others; however, test data are required to confirm this hypothesis.

Thermal Considerations

Figure 9 shows average, maximum, and minimum roof surface temperatures for the five test locations for three periods—August and September 1991, October to December 1991, and January to March 1992. Notice that the average temperature for the "black" exposed membrane and solvent-based aluminum coating is almost identical for all three seasons. Another observation from Figure 9 is that the average membrane temperature under the gray emulsion is almost the same as the membrane temperature under the ballasted EPDM for all three weather periods.

Considering that temperatures of dark, smooth-surfaced membranes readily reach more than 160°F (71°C) and have been recorded at 192°F (89°C) (Cullen 1992), reflective coatings can greatly reduce temperatures of bituminous (both built-up and modified bitumen) membranes.

After approximately one year of weathering, the white latex coating (the lightest colored and most reflective) provides the most thermal radiation reflection for the membrane, thereby only allowing the membrane to heat up about 20°F more than the ambient temperature for typical sunny days. The uncoated roof frequently rises 70°F or more under similar conditions.

The gray emulsion and the silver-colored, solvent-based aluminum coatings provide somewhat comparable moderation of roof membrane temperatures despite the significantly different reflectivity measurements of clean laboratory samples, although during these first few months of weathering, the gray emulsion has provided cooler (138°F [59°C] at maximum temperature) membrane temperatures than the silver-colored, solvent-based aluminum coating (143°F [62°C]). As shown in the example temperature reading in Figure 6, the gray emulsion only allows the membrane to heat up about 53°F above ambient, whereas the aluminum-coated membrane heated to about 60°F above ambient. The increased mass and light-gray colored surface of the washed river rock ballast surfacing moderated the black-colored EPDM membrane by about 47°F above ambient.

In comparison with the thermal data collected during sun loading conditions, after about one year of weathering,

| Period | Exposed | | | Reflective Emulsion | | | Aluminum | | | White Latex | | | Ballast | | |
|---------------|---------|-----|-----|---------------------|-----|-----|----------|-----|-----|-------------|-----|-----|---------|-----|-----|
| | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min |
| Aug-Sept 1991 | 77 | 155 | 18 | 72 | 138 | 20 | 75 | 143 | 21 | 65 | 115 | 20 | 70 | 130 | 21 |
| Oct-Dec 1991 | 42 | 125 | -10 | 39 | 109 | -9 | 41 | 116 | -5 | 37 | 88 | -9 | 39 | 98 | -6 |
| Jan-Mar 1992 | 37 | 116 | -14 | 35 | 101 | -15 | 37 | 103 | -13 | 32 | 7 | -15 | 34 | 87 | -9 |

Figure 9 Average, maximum, and minimum membrane temperatures for all five test locations for three periods.

the white latex coating provided the most significant moderation of membrane heat gain. The average membrane temperature during August to September 1991 for the white latex was 65°F (18°C) compared to the black exposed APP membrane of 77°F (25°C). The ballast provided the next best protection from the sun's radiated heat; average temperature during August to September was 70°F (21°C), with the gray emulsion, 72°F (22°C) for the same period, only a few degrees different from that of the ballast.

Based on the initial findings of this project after one year of weathering, the white latex coatings, when relatively new, provided greater cooling-load savings than those of the other surfacings examined. Although all coatings tested did moderate roof membrane temperature, the gray-colored ballast and the light-gray-colored emulsion moderated membrane temperature better than the solvent-borne aluminum. This is an interesting observation, considering that reflectivity measurements would indicate a significant performance difference between the solvent-based aluminum coating and the gray emulsion.

The issue that will be watched carefully as the project continues is whether the roof temperature reductions from those of the uncoated membrane in the cooling season are maintained over the years, considering weathering, oxidation, and the aging process, i.e., dark materials generally lighten in color and light-colored materials darken.

Weathering Protection and Coating Performance

After one year of weathering, the exposed membranes have undergone some mild surface changes. Several of the exposed membrane surfaces have oxidized and lightened slightly from black to dark gray.

There have been changes in some of the coated areas as well. One of the latex coatings (coating "A") has severely cracked and is beginning to peel. The aluminum coating has stretch cracks over certain membranes with certain reinforcements. Some of the stretch cracks in the aluminum coating in area 1 are significant, with a few in excess of 3/8 in. (10 mm) wide.

The coatings' performance will be monitored in comparison with that of the exposed membranes and will be reported in future papers.

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Inc., Field's Corp. (reflective asphalt emulsion), Karnak Corp. (solvent-based aluminum asphalt), and Monsey Products Co. (latex "B"); the other latex coating manufacturer (latex "A") wished not to be named. Acknowledgments also go to Hans Rosenow Roofing Company for generous contributions of its new office roof space, labor, and miscellaneous materials, and to superintendent Ernie Rosenow for his coordination of the labor and assistance in application sequencing that went into installation of the APP Weathering Farm; Oak Ridge National Laboratory, for its contribution of a data logger and associated equipment and the expertise of its knowledgeable personnel. A fond thank you goes to Rene Dupuis for his idea to study coated modified bituminous membranes at the Weathering Farm. Gratitude is extended to the National Roofing Contractors Association for its continued commitment to roofing technology and its investment in research that benefits the entire building and construction industry as well as the roofing community. Thanks to Dave Yarbrough at Tennessee Technical University for measuring solar reflectance of the coated membrane samples. Part of this work was sponsored by the Office of Buildings Technologies, U.S. Department of Energy, under contract no. DE-AC05-84OR21400.

REFERENCES

- Anderson, R.W. 1989. Radiation control coatings: An underutilized energy conservation technology for buildings. *ASHRAE Transactions* 95(2).
- ARMA/RCMA. 1991. Methods for preparation of modified bitumen membranes for the application of surface coatings. Asphalt Roofing Manufacturers Association/Roof Coating Manufacturers Association.
- Cullen, W.C. 1963. Solar heating, radiative cooling, and thermal movement—Their effects on built-up roofing. NBS Technical Note 321. Gaithersburg, MD: National Institute of Standards and Technology.
- Cullen, W.C. 1992. Temperature variations caused by solar heating and radiative cooling. *Professional Roofing*, April.
- Griggs, E.I., and P.H. Shipp. 1988. The impact of surface reflectance on the thermal performance of roofs: An experimental study. ORNL/TM-10699. Oak Ridge, TN: Oak Ridge National Laboratory.
- Griggs, E.I., T.R. Sharp, and J.M. MacDonald. 1989. Guide for estimating differences in building heating and cooling energy due to changes in solar reflectance of a low-sloped roof. ORNL-6527. Oak Ridge, TN: Oak Ridge National Laboratory.

BIBLIOGRAPHY

- Bonahoom, L. 1991. Test roof serves as "Weathering Farm" for modified bitumens. *Professional Roofing*, June.
- Fricklas, D. 1991. Weathering begins to take its toll. *Roofing, Siding and Insulation*, August.
- Kim, W.A. 1991. Roofs in a can: Selecting a roof coating. *Canadian Roofing Contractor*. April, July, and December.
- Moore, F. 1991. Preparing and applying roof coatings to modified bitumens. *Professional Roofing*. August.
- Sofranec, D. 1991. Coatings prolong roof life. *Roofing, Siding and Insulation*, May.