BEYOND "COOL" TO "SUSTAINABLE" REFLECTIVE ROOF COATINGS

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INTRODUCTION

High-performance, white, reflective roof coatings have gained a measure of acceptance as a means of cooling dark, hot roof surfaces and thereby positively impacting energy consumption, electrical demand, and the corresponding local atmospheric conditions. This article addresses some of the controversial issues related to cool roofing. Field data show the change in reflective properties of coatings over time, the value of highly reflective roof surfaces (even in northern climates), and the role of reflective roof coatings in increasing the effectiveness of insulation and extending the life of the entire roof system. Data reveal the effectiveness and efficiency of roof-mounted cooling equipment over cool reflective roof surfaces and relate cool reflective roof performance to occupant productivity and broader sustainable building goals.

For the purpose of this article, highly reflective roof coatings are considered to be light in color, exhibit elastomeric properties, meet the Energy Star® definition of 0.65-minimum initial solar reflectance, and demonstrate the ability to emit absorbed heat from the roof surface (minimum thermal emittance value of 0.80).

ISSUE 1: Do reflective roof surfaces – specifically coatings – become dirty over time, lose much of their effectiveness to cool, and must they be cleaned regularly?

A study of 20 coated roofs was conducted to determine the loss of solar reflectance over time. Roofs included those with coatings over: metal; EPDM membrane; PVC membrane; gray, granular-surfaced modified bitumen; and spray polyurethane foam (SPF). Locations included the northern tier states of Minnesota, Illinois, Colorado, and Washington. Environments included rural, urban, and industrial. Roof substrates were from zero to 15 years old and reflectance measurements were on coating applications of three months to over seven years. Coatings studied included a variety of acrylic chemistries, one solvent-based polyurethane, and one water-based polyurethane. All were white and none was washed prior to testing.

Figure 1 – Albedometer measuring foam roof reflectivity.

COATING AGE (YEARS)	REFLECTANCE AVERAGE
3 months	77
1	64
2	67
3	63
4-7	60

Figure 2 – Reflectance averages.

Initial solar reflectance of the coatings was between 0.82 and 0.84, with the lone exception being the polyurethane, at only 0.77. *Figure 1* shows one of the tests being performed per ASTM E-1918 procedures. *Figure 2* summarizes the range of readings and provides a simple average based on a grouped length of coating exposure. Results were sufficiently consistent and general enough to be considered independent of the substrate, location, and specific product (with the exception of the white polyurethane that registered the greatest reduction in solar reflectance, from 0.77 to 0.53 after five years on a metal surface).

This limited study showed an average loss of approximately 24% to a reflectance of 0.63 after three years and then leveling off to an average of 0.60 from three to seven years. Excluding the polyurethane coating data point, the reflectance of coatings aged three to seven years remained at the 0.63 average. These results are consistent with prior field studies (Bretand Akbari, 1997; Wilkes et al., 2000; Miller et al., 2002) that demonstrated an initial loss of solar reflectance in the range of 0.20, from 0.80 initially to about 0.60 over time, with the loss leveling off after the first several years.

The general consistency of loss in reflectance may be attributable to similar soiling independent of the product, location, etc. (Berdahl et al., 2002). In general, one may expect up to a 25% reduction in the solar reflectance of white-coated roofs, with most of the loss occurring in the first year and then leveling off. Based on these limited exposures, one may also expect results are independent of the low-slope roof substrate to which the coating is applied. In conclusion, this study demonstrates a solar reflectance in the 0.60-0.65 range can be maintained without cleaning. Other studies have shown that approximately 90% of the original solar reflectance can be restored with modest cleaning.

ISSUE 2: In cold climates, defined as north of the Mason-Dixon Line, do cool reflective roof surfaces produce a "heating penalty" in winter that negates cool roof benefits in the summer?

Figure 3 – Photo of roof on December 15, 2003. The PVC membrane is on the top, in white; the EPDM membrane is in the foreground.

Figure 3 shows a roof in Minneapolis, MN with white PVC membrane and black EPDM membrane side-by-side. *Figures 4* and *5* are infrared thermal images of the two membranes, taken on December 15, 2003 at an ambient temperature of 30°F on a sunny day. The white membrane measured 29˚F and the black membrane measured 42˚F. A simple linear heat transfer equation was used to calculate the heat transfer through the roof system. The heating benefit was calculated assuming a 100,000 sq. ft. building with an R=22.2. The heating benefit for having a dark-colored roof was $1.36/hr.

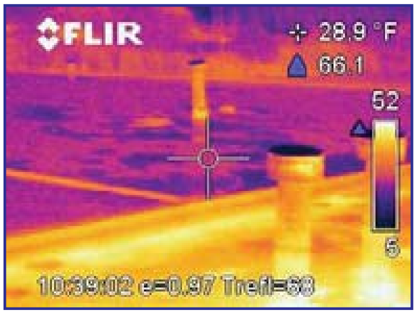

Figure 4 – Temperature of PVC membrane.

Figure 5 – Temperature of EPDM membrane.

Figure 6 shows the same roof instrumented to detect temperature of the black and white roof, as well as ambient temperature, over time. When the black roof peaks at about 160˚F, the white roof reaches approximately 105˚F. Applying the same equation and assumptions, the cooling benefit of having a light-colored roof was $5.76/hour. These one-hour examples demonstrate over four times more savings with the white cool roof in summer than the heating benefit of the black roof membrane in winter. This is only a one-hour comparison in winter versus summer.

Along with these real roof data, one must also consider common-sense factors that will impact total costs of heating and cooling during each season: snow on the roof for most of winter, short winter days, percentage of cloudy days during winter versus summer, temperatures below 30˚F for much of the winter, and many days during the summer that do not reach 90˚F as depicted on July 15. As an example, *Figure 7* demonstrates that the temperature differential between the black roof and the white roof for the entire month of January is

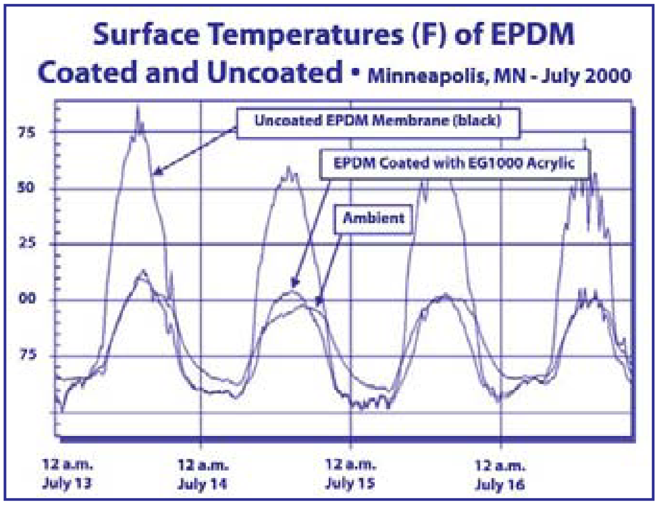

Figure 6 – Temperature of coated and uncoated EPDM.

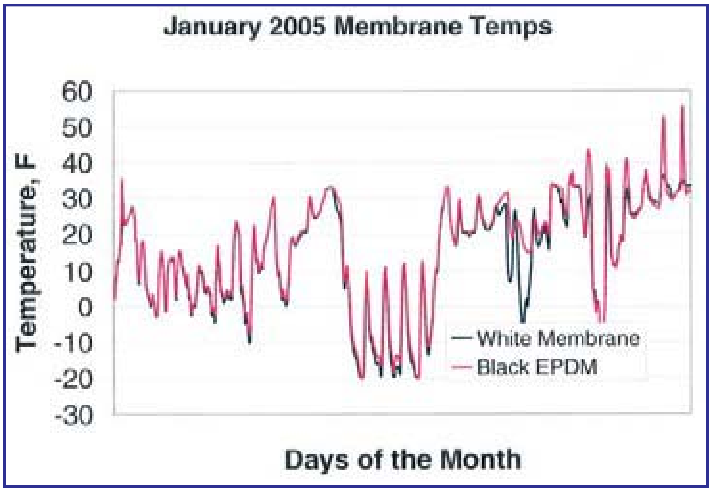

Figure 7 – January 2005 membrane temperatures.

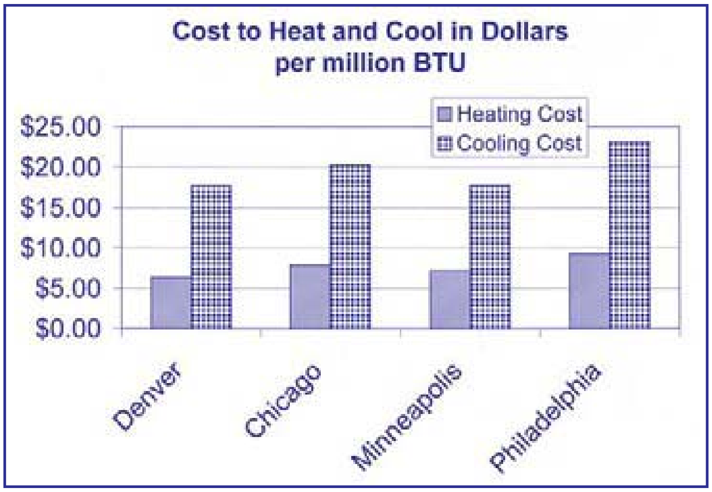

Figure 8 – Cost per million BTU to heat and cool.

zero, primarily due to snow cover!

Along with consideration of peak demand and distribution charges for electricity used for cooling, one may consider the comparative costs of energy used in heating and cooling. *Figure 8* compares energy costs to heat and cool for four northern tier cities. While there is some variation based on the fuel source in different locales, the cost per BTU for electricity to be used in cooling is at least 2.5 times the cost per BTU used in heating.

These roof data, combined with the common-sense factors described above, demonstrate the winter heating penalty of a white roof is negligible from a total energy cost standpoint. Additional information presented in the rest of this paper reinforces the additional benefits of the white-coated roof in northern climates.

ISSUE 3: Should insulation always be the FIRST priority in assessing energy performance of a building or roof assembly, or are there benefits of cool reflective roofs that go beyond insulation?

Insulation is an absolutely essential component in roofs in cold climates to reduce heat loss by conduction through the roof. Insulation is also important in reducing heat gain into the building by conduction during the summer months.

By comparison, cool reflective roofs reduce the membrane surface temperature through improved radiative properties and, therefore, reduce summer heat gain into the building as well. In addition, cool reflective roofs positively impact the energy performance of a building in ways that insulation cannot.

Efficiency and Cost Performance of Roof-mounted Cooling Equipment

Figure 9 shows a York air-handling unit (AHU) instrumented with a thermocouple to measure air temperature that is pulled into the unit's compressor at 30 inches above the roof surface. *Figure 10* charts weather conditions for the first week of September 2004 in Rockford, MN. Note that ambient air temperature through the week is just over 80˚F until September 5, when it rained and then maintained a cooler, mid-60˚ tem-

Figure 9 – York HVAC unit with sensors (circled).

perature range. *Figure 11* shows the same time period indicating the air temperature at 30 inches above a black membrane roof and a white reflective membrane roof as air is brought into the respective AHU. Notice on a calm day, such as September 1, the incoming air temperature over the black membrane peaks at 102°F, while the air temperature over the white reflective roof peaks at about 88°F. On Tuesday, due to higher wind conditions, the difference in air temperature at 30 inches above the two roof surfaces is only about 5°F.

Figure 12 charts compressor discharge temperatures above the black and white reflective roofs for the respective AHUs during the same period. The difference in compressor discharge temperature is approximately 7°F during the first few days of the month, preceding the rain event. *Figure 13* shows power demand for each unit, demonstrating a difference of approximately 0.8 kW (16%) reduction in demand for the AHU over the white reflective roof, which equates to approximately a 16% savings in kWh, assuming all other factors are equal. The white reflective roof produces a direct HVAC energy savings of 16% over the black roof when ambient air temperatures are only 80°F in Minnesota.

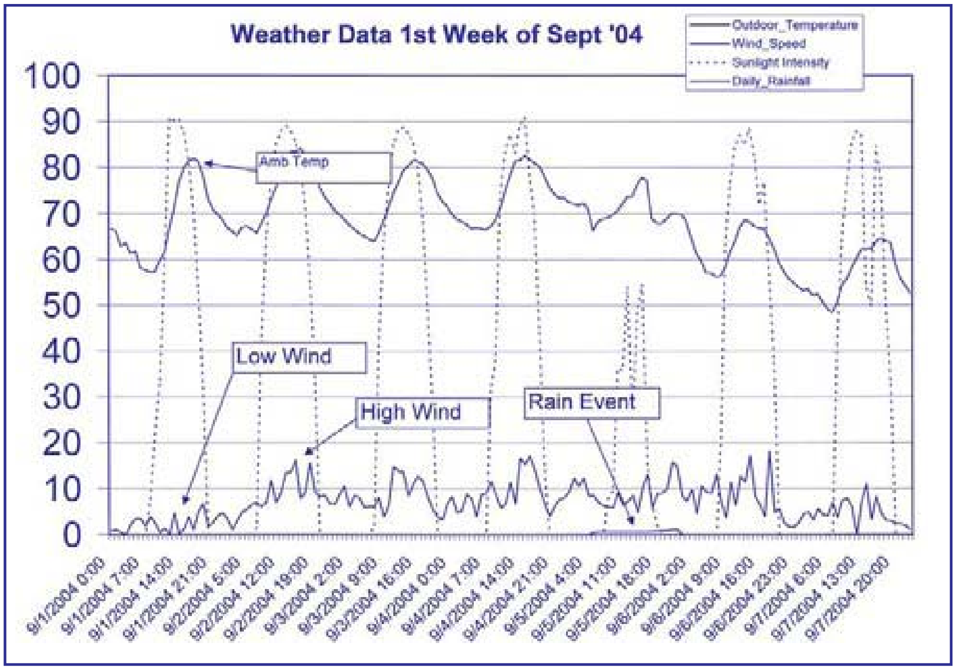

Figure 10 – Weather data for September 2004.

In the example above, when the ambient air temperature was in the low 80°F range, the inlet air temperature at 30 inches above the black surface was in the upper 90°F range. These are nearly optimal conditions as HVAC units are designed for operating at temperatures in the 90s and efficiency ratings are actually performed at 95°F. *Figure 14* charts the loss in efficiency of a York 4-ton, high-efficiency AC unit with a SEER rating of 12.2 (York, 2003), as temperatures increase above the 95°F level.

For example, when inlet air temperature entering the unit rises to 115°F, the input power requirement increases by 12% as the unit capacity drops by 10%. The data indicated the manufacturers' theoretical calculation of efficiency loss may be conservative in comparison to real roof data. What will the inlet air temperature be for the AHU when ambient temperatures reach 100°F or more and the temperature differential from the black roof to the white reflective roof approaches 50°F or more? White cool reflective roofs allow roof-mounted cooling equipment to run more efficiently and may reduce the cooling equipment capacity requirements in some instances. Calculations show the potential for energy savings with the AHU during hot summer months of 15% to 30% with the cool white reflective roofing surface. This increase in efficiency is independent of the R-value of the roof assembly.

It is well documented that the leading cause of increased peak demand is cooling. Increased electric demand at high temperatures is the primary reason for the proliferation of peak-demand generators being built and is often the primary reason for brownouts and service interruptions costing millions of dollars per occurrence. Cool white roofs have demonstrated the ability to cool the roof surface, increase the efficiency of HVAC units, and reduce peak electrical demand.

Increasing Effective R-Value with Cool Reflective Roof Coatings

Figure 15 gives R-value measurements with temperature changes for polyisocyanurate (PI) board and for extruded polystyrene (XPS) board. Data were generated per ASTM C 578-04 for XPS and per ASTM C 1289-03

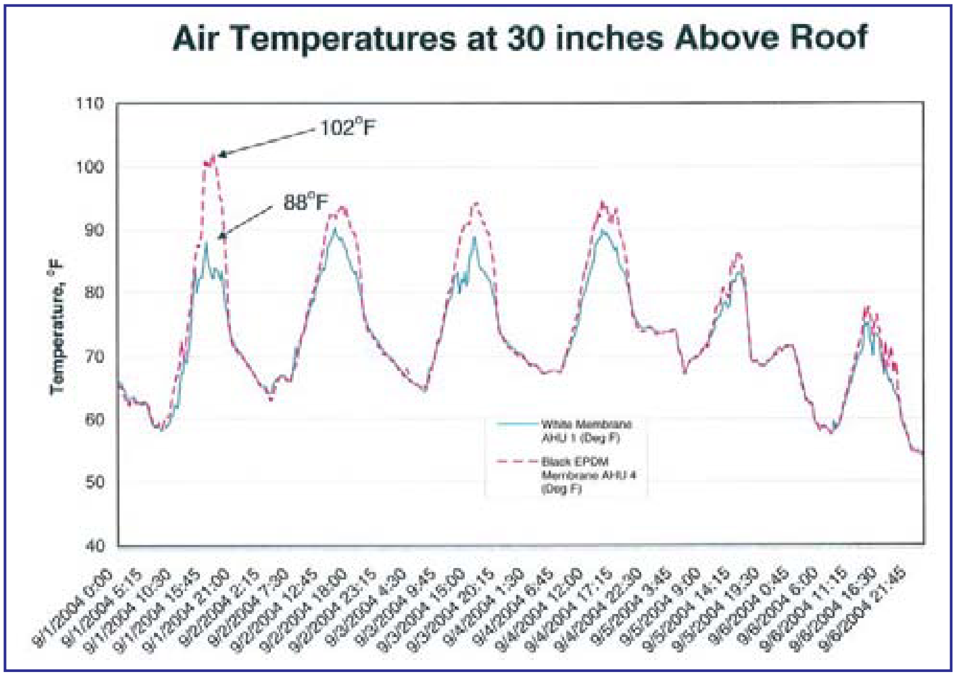

Figure 11 – Air temperature 30 inches above roof.

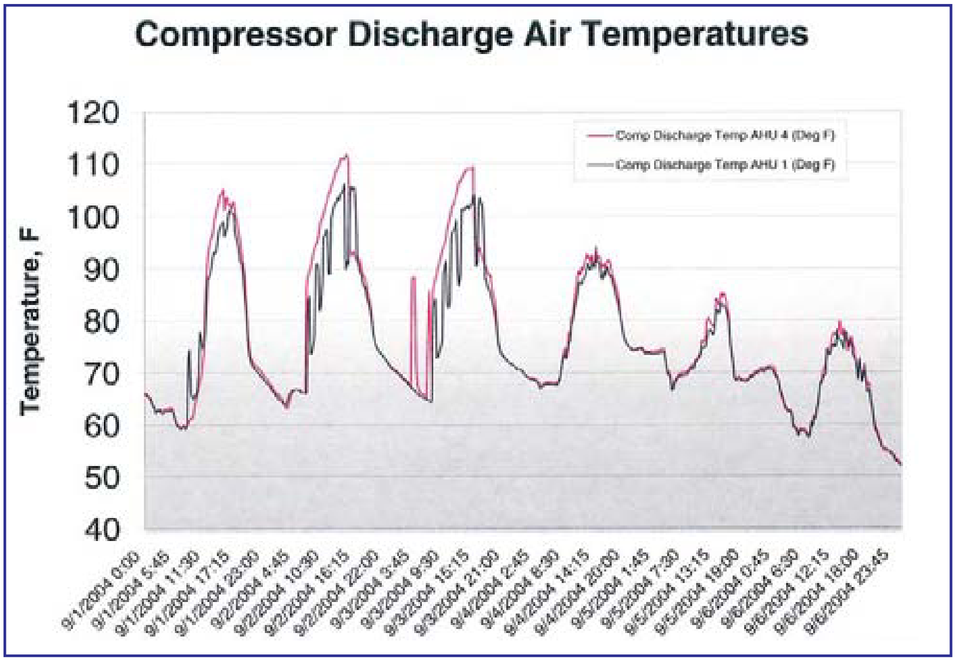

Figure 12 – Compressor discharge temperatures.

for PI for representative boards. Note that PI demonstrates a maximum R-value of 6.0 at 50˚F and then rapidly drops off to an R-value of 4.6 at 100˚F, a loss of over 23%. XPS exhibits only an 8.5% loss in R-value over the same temperature range and actually exhibits a higher R-value than PI at 100˚F. At any temperature above 50˚F, it is apparent the effective R-value of the roof system will be enhanced if the roof assembly is kept cool.

Figure 6 describes the temperature difference of a black roof surface (160˚F) versus a white reflective coated roof surface (105˚F) on the same building. During summer peak heat periods, one may expect insulation in roof assemblies will reach well over 100˚F, with corresponding R-values dropping dramatically. Insulation under a white-coated cool roof may be 25% to 50% more effective in resisting thermal conductivity under summer heat loads in all regions of the United States. These simple facts support why ASHRAE 90.1 (ASHRAE, 1999) included the roof cooling tradeoff provision of white reflective roofs for R-value from insulation. High temperatures lower the effective R-value of the most widely used types of insulation.

Aging of Insulation

The aging/soiling of white highly reflective coatings has been addressed, indicating a 20-25% loss in solar reflectance over time (see *Figure 2*). The most common types of insulation board used in roof assemblies also age and exhibit a corresponding loss in performance. All cellular plastic insulation materials that rely on a blowing agent other than air exhibit thermal resistance aging; typically, about 20% over the first couple of years (for PI the R-value decreases from 7.5 to 6.0).

Secondly, linear dimensional stability standards for PI have recently been reduced from 4% to 2%. This allows approximately two inches of length shrinkage and one inch of width shrinkage in a 4 x 8-ft. sheet over time, reducing the thermal performance in the roofing assembly.

And finally, if moisture penetrates the roof assembly, a dramatic reduction in thermal resistance may occur. All of these factors contribute to the aging of insulation boards in roofing assemblies and a loss in thermal conductivity of at least 20% over a five-year period, a figure similar to the loss in solar reflectance due to soiling of a reflective roof surface.

BENEFITS BEYOND ENERGY COST SAVINGS

Reflective Roof Coatings May Extend the Life of the Roof Substrate

Reflective roof coatings provide a protective layer over black roof substrates, forming protection against the harsh weathering process by reflecting the damaging UV sunlight, reflecting the IR energy to help cool the roof surface, and by keeping the moisture off the roof substrate so it is no longer directly exposed to the weather. The cool reflective coating will slow the rate of degradation or weathering.

Details of the weathering mechanism of asphalt are explained by Kirn et al. (1994) and others with indications that the rate of deterioration can be slowed by as much as 75%. This study indicates that the life of asphalt roof systems could potentially be extended by three to four times the ordinary lifespan. The MRCA Roof Coatings Research study (Carlson et al., p. 19, 2004) of coatings applied to asphaltic membranes appears to support the performance of reflective coatings as a "weather shield and viable means of protecting the underlying membrane from the adverse effects of direct exposure to sun and weather." The MRCA

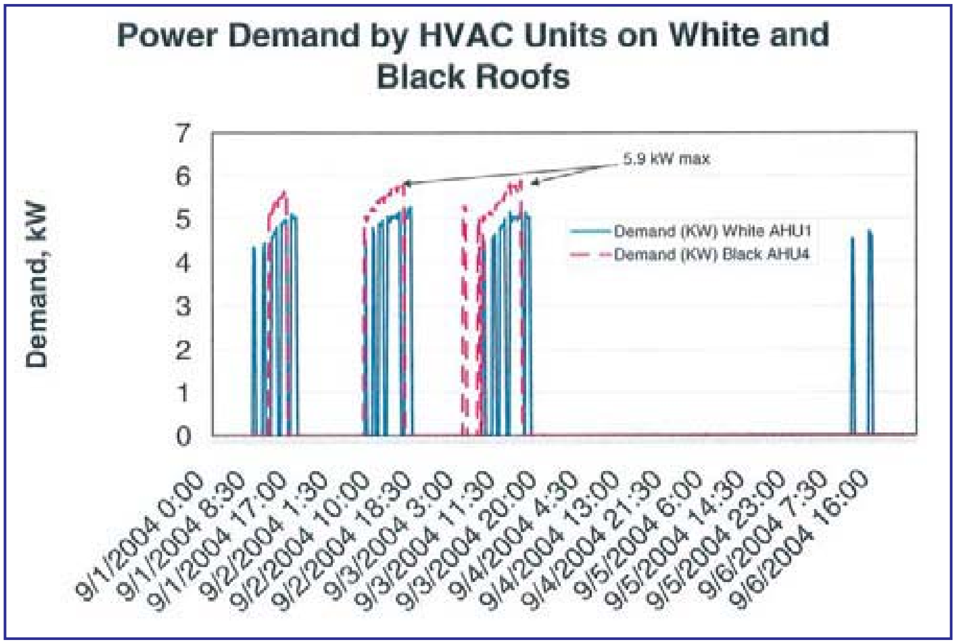

Figure 13 – Power demand of HVAC units.

study was five years in duration with field study applications performed from Minnesota to Missouri to Texas. The study also demonstrates that reflective roof coating technology exists today to perform well over asphalt substrates in a wide variety of conditions.

Cool Reflective Roof Coatings May Also Contribute to Improved Worker Performance

The average life of the typical commercial building is about 40 years, and building costs are the second largest costs for businesses after staff costs (Oseland, 1999). Office, production, and warehouse space may account for 8% to 30% of business revenues for rent/lease, depreciation, operating expenses (including energy), and the like. Studies done by the EPA (1989) and by BOMA (1998) indicate that offices in North America typically spend 100 times the cost/sq. ft. for staff as compared to energy, and the productivity offset is approximately 5 minutes/day/person to pay for the energy costs. This indicates a slight increase in worker productivity can produce a much greater cost benefit than a dramatic improvement in energy savings and a 1% increase in productivity can be equivalent to the total cost of energy for the building.

Many studies have been conducted on the relationship between thermal comfort and productivity in both offices and production plants, including studies of mental performance, work rate, manual dexterity, accident rate, speed of figures, absenteeism, etc. For example, Schweisheimer (1962), in studying manufacturing processes involving machine operation with high levels of physical work, concluded that performance dropped by 10% at 84°F and by 38% at 95°F. Liddament (1996) also demonstrated that productivity improvement could be achieved without air conditioning by using various passive cooling techniques. An exhaustive study of the literature on factors affecting productivity (Yoseland et al., 1999) provides an estimate that improvement of physical conditions (including thermal comfort) may produce an increase in productivity of up to 15%.

This is significant in considering the many buildings used in manufacturing and distribution around the United States that are not air-conditioned, have minimal insulation, and even limited ventilation. Many of these buildings may also have black roofs, since 80% of all commercial/industrial roofs in place today are of either asphalt or

YORK 4-TON HIGH EFFICIENCY HVAC UNIT

OUTDOOR TEMPERATURE, °F	POWER INPUT kW	TOTAL CAPACITY, MBH
95	4.50	60.00
105	4.80	57.00
110	4.95	55.50
115	5.10	54.00

Figure 14 – York performance data.

EPDM. There is an opportunity to increase the productivity in many operations by utilizing a cool reflective roof to improve working conditions.

BEYOND COOL TO SUSTAINABLE

Recognition is growing that cool reflective roof surfaces contribute to high-performance, advanced building design by positively impacting energy consumption and electrical demand and its corresponding atmospheric implications. Sustainable construction practices go beyond energy usage to consider more comprehensive green building goals as defined by programs such as LEED (Leadership in Energy and Environmental Design).

This article has addressed how cool reflective roof coatings may:

- Increase efficiency and cost performance of roof-mounted AHU;
- Reduce peak electricity demand during cooling season;
- Increase effectiveness of roof insulation at temperatures over 50°F;
- Reduce aging of dark, asphaltic roof membranes and frequency of replacement; and
- Indirectly improve worker performance, productivity, and satisfaction.

Scientists at Carnegie Mellon University (2004) compiled a quantitative representation of the potential national impact of restoring half of the 12 billion square feet of U.S. office buildings with a highly reflective coated roof over the next five years. At $.08 per kWh (2003 average energy cost), annual cooling energy savings would be $130 million and 1.6 billion kWh, amounting to:

- 40% of the energy production of the Hoover Dam;
- The energy usage of 59,000 U.S. households;
- The gasoline used by 80,000 cars in a year;
- Emission reductions of 16.9 million pounds at a cost savings of U.S. $55.5 million annually;
- Water consumption reduction of 3.2 billion gallons/year at a cost savings of U.S. $6.4 million annually; and
- A peak load reduction estimated at 840 MW with a value of U.S. $1 billion.

SUMMARY AND CONCLUSION

Reflective roof coatings maintain approximately 75% of their initial solar reflectance on all major roof substrates, through a wide geographic sampling, and over an extended period. Aged white coating solar reflectance values of 0.60 compared to black roof surfaces with solar reflectance of 0.10 contribute to a temperature differential of 50˚F or more.

Heat transfer data for black roofs in winter and white roofs in summer, in combination with the 2.5 times cost differential per BTU for heating and cooling, along with common-sense weather considerations, demonstrate no significant energy penalty for a reflective roof.

In warm climates, a white reflective roof should probably be considered at the same priority level as insulation. The reflective roof will reduce heat gain through the roof assembly due to its radiative properties, will increase the performance and efficiency of the HVAC equipment mounted on the roof, and will increase the effectiveness of the insulation itself. These are all benefits that go beyond the addition of R-value.

Reflective roof coatings provide a layer of protection against the elements of weather and the sun, reducing the rate of aging of the roof system components and extending

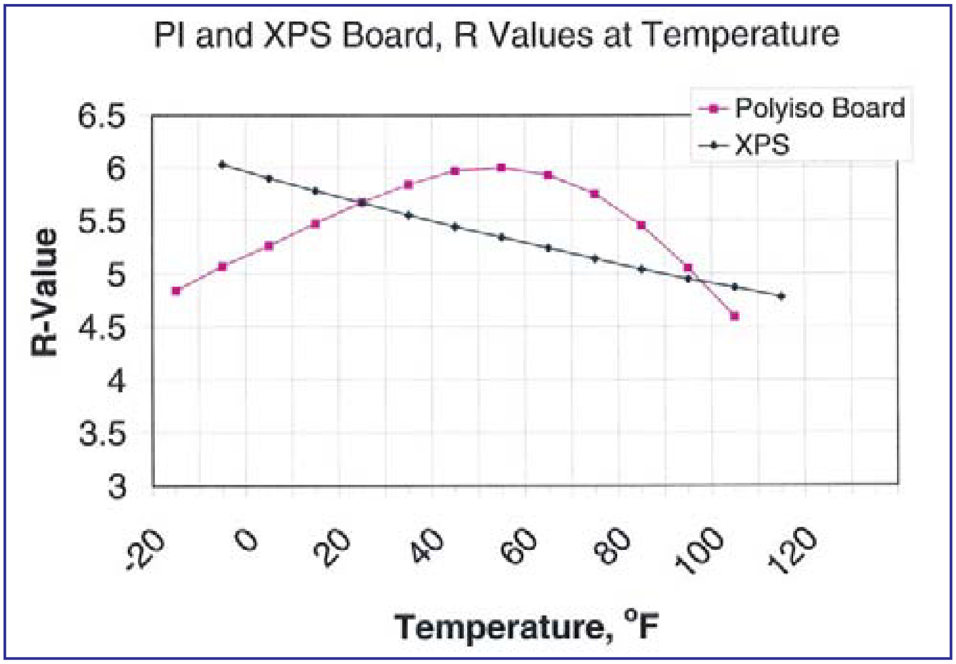

Figure 15 – R-value measurements with temperature changes for polyisocyanurate (PI) board and for extruded polystyrene (XPS) board.

the life of the roof assembly. Less frequent replacement means less material in landfills.

There is a relationship between thermal comfort and worker satisfaction, performance, and productivity. In many production and distribution facilities and potentially in office areas, one can correlate thermal comfort to a cool reflective roof.

Cool roofing, and specifically, reflective roof coatings, contribute to advanced energy performance of buildings and to the broader sustainable building goals the roofing industry needs to embrace.

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ROOF KNOWLEDGE ASSESSMENT

Test your knowledge of roofing with the following questions, developed by Donald E. Bush Sr., PE, RRC, FRCI, chairman of the RRC Examination Development Subcommittee.

1. **What are the performance requirements of insulation used in conventional sandwich-style roof assemblies with an adhered membrane?**

2. **What is the minimum compressive strength of roof insulation generally recommended to resist traffic loads, hail, dropped tools, and miscellaneous missiles' impact on the roof?**

3. **Water vapor generally can flow wherever air can flow. Why does the absorption of water vapor or liquid water into the insulation material drastically reduce the insulating value of the insulation?**

4. **Prior to installing a sprayed urethane foam recover system over an existing built-up roof, the substrate must be properly prepared. After investigating the roof system for entrapped moisture and adequate anchorage, what preparation of the membrane is required?**

5. **What weather conditions are required during SPF spraying operations?**

Answers on page 12