The Long Term Thermal Performance of Radiation Control Coatings

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The potential energy efficiency benefits of “white roofs” are well known, but very little long term thermal performance data has been published on their aging effects at well characterized field test sites. These coatings are expected to remain effective for at least 5 to 20 years in most roofing applications. Results from a well characterized field study at the Oak Ridge National Laboratory in East Tennessee is presented. Continuous hourly surface temperatures and heat fluxes have been measured on four roof systems for 4 years. The aging effect is most dominant in the first year but does level off after the first year. The effect of light washing is shown and the relative benefits of light coatings on roof systems with R-values from 2 to 18 are shown. With utilities considering the addition of RCC incentives for DSM programs, these unique results collected by an objective third party will be of extreme interest. RCC can provide both annual building cooling savings and peak load reductions. Long term performance data such as presented here is needed to estimate the true life-cycle benefits of this promising building energy efficiency option.

Introduction

During the summer in the southern U. S., dark colored roof surface temperatures may routinely exceed 180°F due to the absorption of solar radiation. [1] Elevated roof surface temperatures contribute to roof heat gain and can result in increased air conditioning loads. Some residential and the majority of large commercial and industrial buildings in the United States have flat or low-sloped roofs, representing a total surface area of approximately 1100 square miles. [2] Therefore, energy efficiency innovations related to low-sloped roof systems can produce a significant national energy savings. It was in recognition of this fact that the Roof Thermal Research Apparatus (RTRA) at the Oak Ridge National Laboratory (ORNL) was established in 1982 as a platform for conducting research on low-sloped roofing systems.

Besides the increased cooling load, another effect of elevated roof temperatures is a shortened roof lifespan, which is speculated to be, due to stresses generated by cyclical thermal expansion and contraction and to the breakdown of temperature sensitive adhesives. Measurements made on an EPDM (ethylene propylene diene monomer) roof membrane on the low-slope roof of the Envelope Systems Research Apparatus at ORNL indicated that peak temperatures during the summer can reach 194°F with coincident ambient temperature in the low 90’s and that minimum temperatures during the winter may drop to -2°F3 with coincident ambient temperature of 5°F.

To reduce cooling loads and to lengthen roof membrane lifespans, the paint and coatings industry has developed a number of products which can be categorized as “Radiation Control Coatings” (RCCs). These materials are applied over existing roofs to increase solar reflectance. [4-13] The result will be lower daytime temperatures which reduce the air conditioning load and lengthen the roof surface lifespan. This paper presents experimental results which describe the thermal performance of RCCs on the Roof Thermal Research Apparatus at the Oak Ridge National Laboratory.

For those buildings in predominately cooling climates where the annual heating load is small or nonexistent, the thermal effect of a RCC is to produce an annual energy savings. For those in “mixed” climates, the thermal effect of a RCC in the wintertime becomes important. During the wintertime, roof heat gain offsets a portion of the building heating load. RCCs can reduce this desirable heat gain, thereby creating a heating season penalty. The relative magnitudes of the summertime cooling load reduction and the wintertime heating load increase are important parameters when evaluating the energy economics of RCCs.

Another important issue when evaluating the life-cycle energy savings of a roof system incorporating a RCC is how well the thermal performance endures field conditions. The main problem for a RCC is the surface contamination that occurs due to the accumulation of airborne dirt particles. This coating of dirt reduces the solar reflectance and hence the thermal performance. RCCs have been monitored continuously for three years during uninterrupted exposure to the environment. This paper describes the degradation in thermal performance that occurred. It has become the practice for some companies who market RCCs to offer annual cleaning services to building owners in order to maintain a high surface reflectance. The effect of washing on RCC membrane temperature was also investigated in this study.

This investigation contributes to the better understanding of the energy efficiency benefits of RCC by (1) Determining the magnitude of the summer heat gain reduction and the winter heat loss increase due to RCCs in a well characterized test site. (2) Determined the effects of more than 3 years of field exposure on the thermal performance of a RCC and the effects of washing the membrane surface. (3) Validate a model for development of a general RCC applications manual.

Procedure

Experimental Apparatus

The RTRA at the Oak Ridge National Laboratory is a highly instrumented building designed to test the thermal performance of low-sloped roof systems in actual field conditions. The RTRA is nine feet tall and has outside dimensions of 10 ft X 28 ft. It is constructed of masonry block with R-8 insulation on the outside and with a well insulated, concrete slab-on-grade floor. The temperature and relative humidity inside the RTRA are controlled and measured. Information on instrument accuracy is shown in Table 1. Fans are used inside to promote a uniform temperature distribution on the interior surface of the roof section. This approximates the thermal boundary condition that exists on the inside surface of a roof deck when a dropped ceiling is used as a return air plenum. As shown in Figure 1, the roof can support up to four test panels, each measuring 4 ft X 8 ft. Test panels are instrumented with temperature and heat flux sensors. A complete weather station is mounted on the RTRA roof which monitors incoming solar and infrared radiation, ambient air temperature, wind velocity, precipitation, relative humidity, and barometric pressure.[18] A PC-based data acquisition system collects data once a minute, then calculates an hourly average for long-term storage and analysis.

The vicinity surrounding the RTRA can best be described as commercial. There are paved roads, parking lots, other buildings, and grassy areas close to the RTRA. The area further away is heavily wooded. There are no obvious sources of airborne dust or dirt. The surrounding vegetation is predominately deciduous trees. The test panels are not shaded by the surrounding buildings.

The RCC selected for testing was a white “elastomeric acrylic” in a water-based formulation. Nine coats of the RCC were applied, 8 to 24 hours apart, with a 1/2 in. “nap” paint roller until a thickness of 0.04 inches (1 mm) was obtained. This exceeded the minimum 0.02 inches (0.5 mm) recommended by Anderson et al.[11] to ensure maximum solar reflectance. The final surface appearance was slightly wavy.

Table 1. Accuracy of the Roof Thermal Research Apparatus Weather Instrumentation

Instrument	Range	Accuracy
Air temperature	-40 to 120°F	±1.7°F
Relative humidity	0 to 100%	±3%
Wind speed	1 to 100 mph	±2 mph
Wind direction	0 to 360°	±2°
Barometric pressure	28 to 32 in Hg	±0.02 in Hg
Pyranometer	0 to 2800 W/m^2	±5.5%
Pyrgeometer	0 to 700 W/m^2	±8%

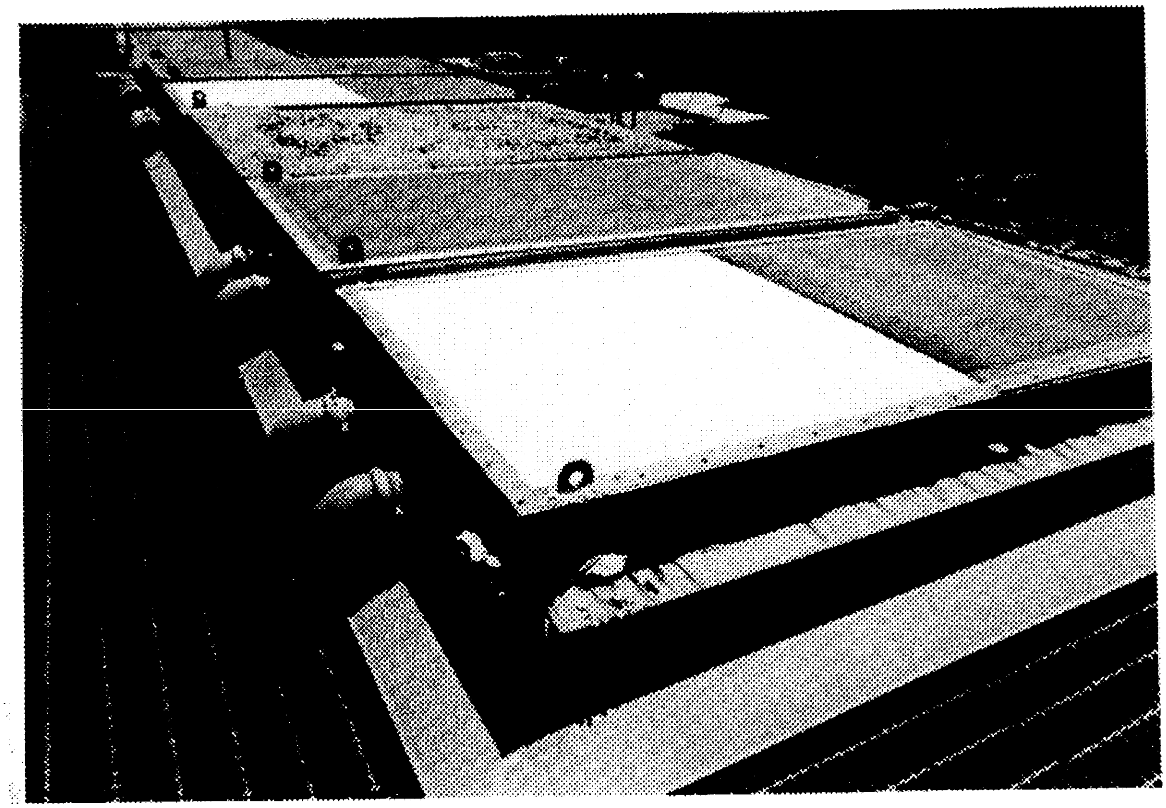

Figure 1. Roof Thermal Research Apparatus (RTRA) Used to Test Well Characterized Roof Specimens

For this study, two side-by-side test sections, each 4 ft X 4 ft, were tested. As shown in Figure 2, the central 2 ft X 2 ft section of each panel was instrumented with temperature sensors and a heat-flux transducer (HFT). Measurements were made in this central section because heat conduction through the roof is one-dimensional in this section. Each section consisted of three sheets of nominal 0.50 inch Douglas fir plywood and a l/4-inch-thick, black, single-ply EPDM membrane. The nominal R-value for the roof section was 2.2 hr-ft^2-°F/BTU which is similar to measured R-values on many of the buildings in mixed climates which have 20-30 year old low-sloped roofs. On one of the two sections a 0.04 inch thick layer of RCC was applied. A 2 in X 2 in heat flux transducer was mounted between two of the layers of plywood in the center of the measurement region. Copper-constantan thermocouples, all cut from the same spool to reduce relative errors, were placed: at the bottom surface of the plywood sandwich facing the conditioned space, at the top surface of the plywood sandwich in contact with the EPDM membrane, and in between the top two layers of plywood adjacent to the heat flux transducer.[17] Prior to the final installation, the thermal resistance of the roof section center pieces were measured in accordance with ASTM C 518.14 Additionally, the embedded heat flux transducers were calibrated in a stack of Douglas fir plywood in the same configuration as that installed in the RTRA. The test sections were installed on the roof of the RTRA in mid-July 1990.

Computer Model

In order to extrapolate these field results to other applications a computer model is needed. The heat flux predicted by the STAR (Simplified Transient Analysis of Roofs) computer program is compared to the measured heat flux passing through the RTRA roof.[16]

STAR is a transient, one-dimensional, finite difference model for heat conduction. It can simulate heat flow in multilayer roof systems with materials that have thermal conductivities and specific heats that vary with temperature. The program can use two different types of boundary conditions. The first type uses specified inner and outer surface temperatures. The second type accounts for the convection and radiation heat exchanges with the outdoor and indoor environment using measured values of air temperature, total incident solar radiation, wind speed, total incident infrared radiation, and relative humidity.

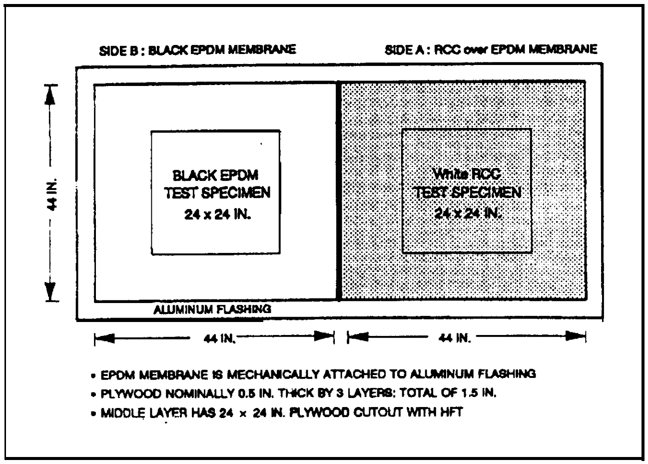

Figure 2a. Roof Thermal Research Apparatus (RTRA) Test Section Details: a.) Platform View

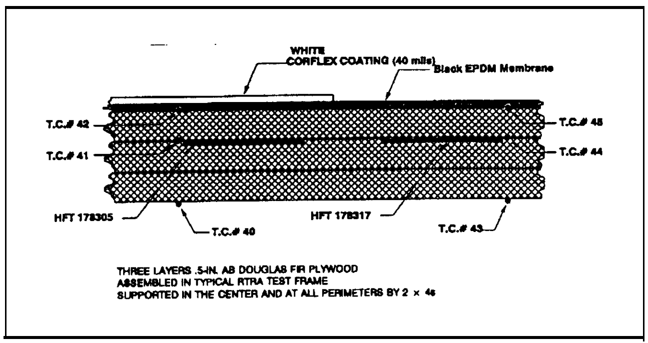

Figure 2b. Roof Thermal Research Apparatus (RTRA) Test Section Details: b.) Cross Section View

Results

To obtain a sampling of the summertime and wintertime thermal performance, several weeks from the months of August and January were selected for analysis. The weeks with the clearest sky conditions were chosen so that the radiative performance of the roof surfaces could be more clearly examined.

Incident Solar Incoming Sky Infrared Radiation

Incident solar radiation has one of the strongest effects on the thermal performance of dark colored roofs. Figure 3 shows the variation of the incoming solar radiation for the August 1990 and January 1991 weeks as measured by the pyranometer mounted to the top of the RTRA. Also plotted is the incident infrared radiation, as measured by the RTRA's pyrgeometer.[17] This is a measurement of the long-wavelength radiation emitted by the sky and the surrounding buildings and landscape which strikes a horizontal surface near the roof test panels. This is only the incoming infrared radiation, not the net infrared radiation which would account for the infrared radiation emitted by the roof. The figure shows how the infrared component exceeds the solar component during cloudy periods and at all other times except for a few hours on either side of noon. It should be noted that the pyrgeometer measures just the incoming infrared and not the net radiation exchange between the roof surfaces and the surroundings.

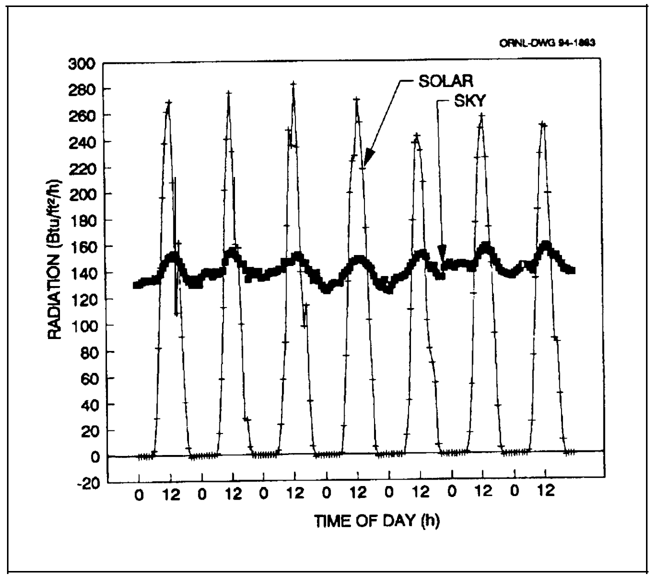

Figure 3a. Incident Solar and Sky (infrared) Radiation: a.) August 13-19, 1990

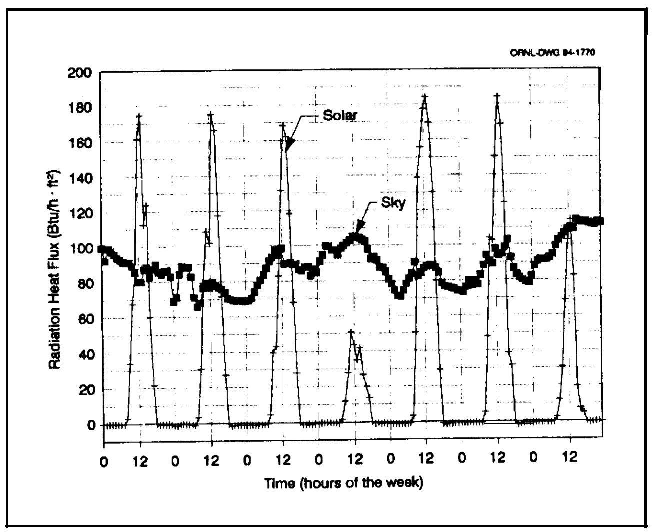

Figure 3b. Incident Solar and Sky (infrared) Radiation: b.) January 21-27, 1991

Membrane Surface Temperatures

One important measure of RCC thermal performance is membrane temperature. Figure 4 illustrates the variation of white RCC, black EPDM, and ambient air temperatures during the weeks chosen for analysis. During the August week, Figure 4a shows peak temperatures for the black EPDM were over 160°F, exceeding the ambient temperature by 70°F. The white RCC membrane temperature reached a maximum of 100°F, or 6°F above ambient, at noon on the last day of the week. The importance of the nighttime infrared emission from the roof surface to the sky can be seen as both surface temperatures drop below the ambient air temperature. During the January week, the peak temperature for the black EPDM was 100°F, exceeding the ambient temperature by 45°F. The average ambient air temperature for this week was 31.3°F. At all times during the week, the ambient air temperature remained below 50°F. Since this is below the heating balance point (no-load) temperature for residential and most small commercial buildings, any heat loss through the roof could be considered an addition to the heating load.

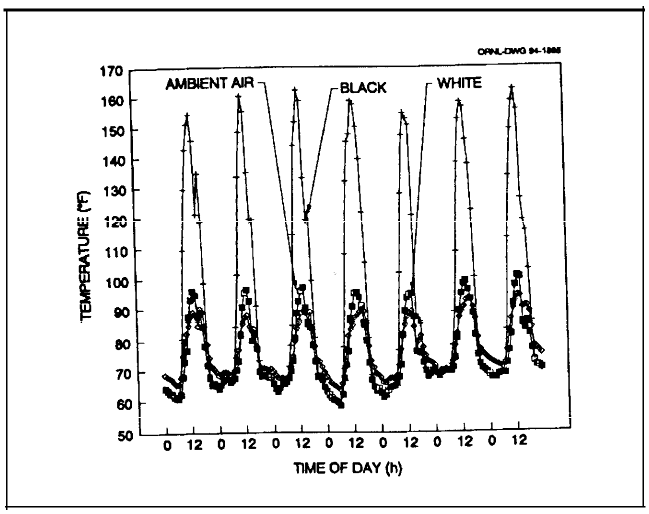

Figure 4a. Hourly Surface and Ambient Temperatures: a.) August 13-19, 1990

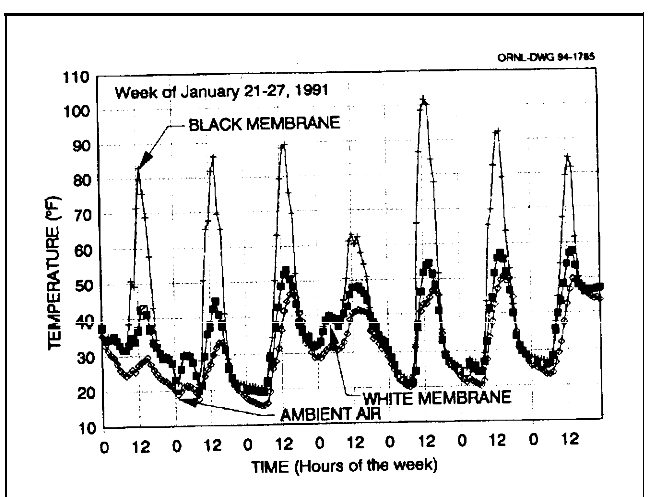

Figure 4b. Hourly Surface and Ambient Temperatures: b.) January 21-27, 1991

The surface temperature difference between the black EPDM and the white RCC can be more clearly seen in Figure 5. During the August week, the largest difference occurred at noon on each day when the black exceeded the white membrane temperature by 59 to 66°F. During the January week, the largest temperature difference was 48°F.

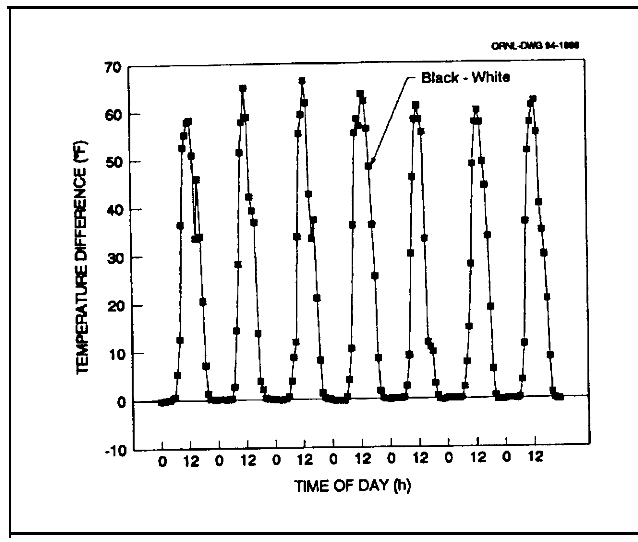

Figure 5a. Hourly Surface Temperature Differences: a.) August 13-19, 1990

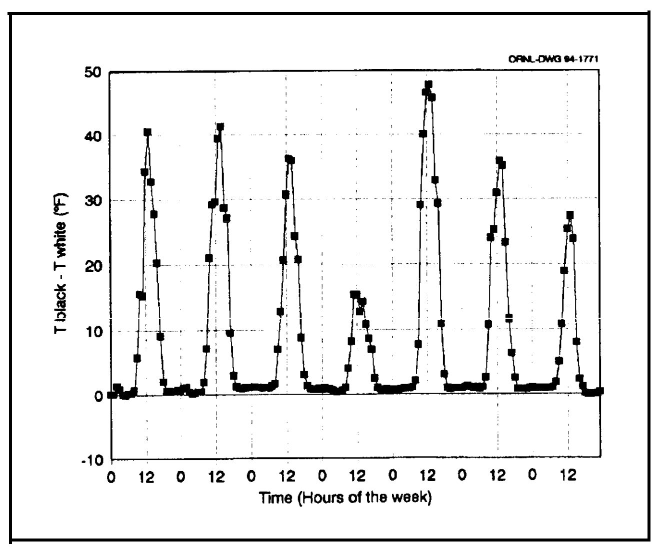

Figure 5b. Hourly Surface Temperature Differences: b.) January 21-27, 1991

Measured Roof Heat Flux

Another important measure of thermal performance is the heat flux that is allowed to pass through the roof system. While the absolute value of heat flux is strongly dependent upon the thermal conductivity and thermal capacitance of the roof system, important insight can be gained by examining the difference in the heat flux passing through two roof systems that are the same, except for the radiative properties of the outer surface. The hourly heat flux through both roof sections is shown in Figure 6a and 6b. In this analysis, positive values of heat flux indicate heat flow into the building (i.e. heat gain). In the summertime, a roof heat gain can contribute to the cooling load and energy cost. The peak heat flux through the roof section covered by the black uncoated EPDM membrane is four to five times that passing through the RCC-covered roof section. At night, the heat flow direction changes and passes from the conditioned space through the roof section to the outdoors. In the wintertime, a roof heat gain can reduce a building's heating load. Figure 6b shows that energy is always leaving the conditioned space through the roof covered by the white RCC. For the black EPDM roof section, the heat flux is positive for a few hours around noon of each day, except for the cloud-covered fourth day.

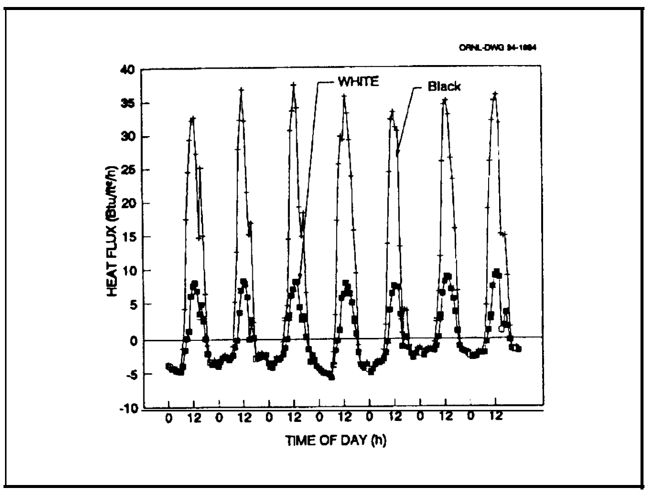

Figure 6a. Hourly Heat Flux into the Roof from the Outside: a.) August 13-19, 1990

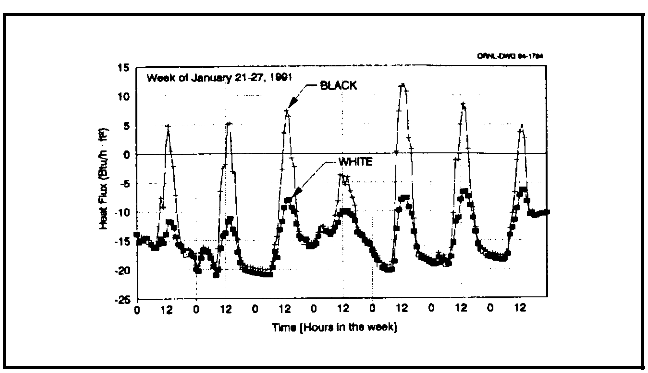

Figure 6b. Hourly Heat Flux into the Roof from the Outside: b.) January 21-27, 1991

Figure 7a and 7b show the cumulative heat gain for two different roof systems for weeks in August and January, respectively. In addition to the plywood roof system, the principle focus of this study, another roof system consisting of three inches of HCFC 14 lb foam insulation on top of a metal roof deck was examined to obtain data on the effect of roof system R-value on RCC thermal performance. White and black EPDM membranes were placed on top of two side-by-side 4 ft X 4 ft sections. The R-value of the foam roof system at a mean temperature of 75°F was approximately 18 hr-ft^2-°F/BTU. Table 2 shows that during the week of August 13-19, 1990, the black EPDM-over-plywood cumulative heat gain was 1305 BTU/ft^2, which is six times higher than the value shown for black EPDM-over-foam. If we assume that this represents an additional cooling load for a 10,000 square foot office building equipped with a chiller operating with a system COP of 2, then the additional August electrical power bill would be approximately $425 (at $.05/kwh).

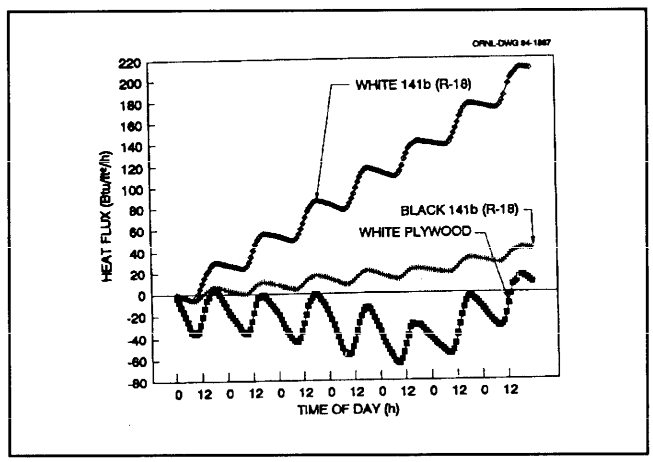

Figure 7a. Cumulative Heat Flux into the Roof from the Outside: a.) August 13-19, 1990

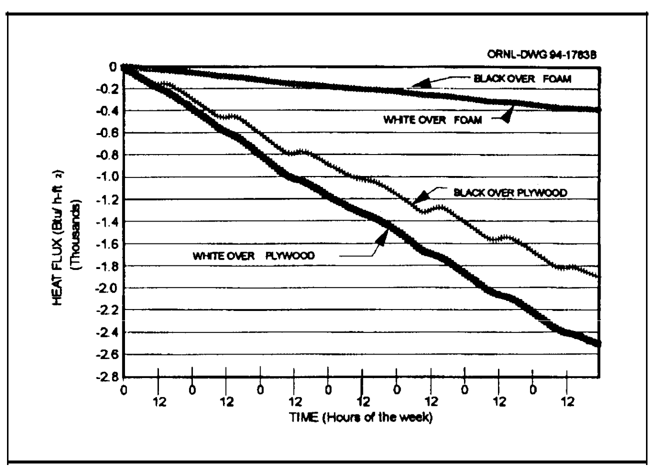

Figure 7b. Cumulative Heat Flux into the Roof from the Outside: b.) January 21-27, 1990

However, the presence of the white RCC coating on top of the plywood roof section reduced the week's heat gain to nearly zero. As shown in Figure 7a, the daytime gains were offset by the nighttime losses. For this to translate into a near-zero cooling load, the building would have to possess sufficient thermal mass to store the energy entering the roof during the day and to discharge the energy leaving through the roof at night. If this condition exists, it is interesting to note that the white-over-plywood would actually outperform the white-over-foam as well as the black EPDM-over-foam. However, if there was insufficient thermal mass, the white-over-foam system would be preferable because of the smaller daytime heat gains. The August week results are summarized in Table 2.

Figure 7b shows the cumulative heat loss for the January week. All four roof sections show an energy loss; however, the losses for the plywood roof sections are much greater than for the foam sections. For the plywood roof sections, the penalty associated with having a white RCC rather than a black surface was a 32% increase in the weekly heat loss. Table 3 summarizes the results for the January heat loss.

While the direct comparison between the summertime and wintertime thermal performance is of questionable value when developing general RCC usage criteria, it does offer an interesting snapshot of these specific roof systems in these specific weather conditions. As shown in Table 4, the net energy savings produced by the RCC-over-plywood was 695 BTU/ft^2. The corresponding savings for the white EPDM-over-foam was 90 BTU/ft^2. As reported by previous workers, the potential savings yielded by a RCC drops with increasing roof system R-value. The ratios of summer heat gain reduction (savings) to winter heat loss increase (penalty) were almost the same (approximately 2.l-to-l) for both plywood and foam backed systems even though the white surfaces are not identical. (The white EPDM is factory processed while the white RCC is field applied.) Additionally, the savings-to-penalty ratio of 2.l-to-1 falls within the range of computational calculations of Griggs and Courville[9] whose annual savings-to-penalty ratios ranged between 1.1-to-1 and 2.9-to-1 for East Tennessee.

Effects of Field Exposure on Solar Reflectance

Between July 1990 and July 1993, the physical appearance of both membranes has changed as they were allowed to weather in an undisturbed and uncleaned manner. The new jet-black EPDM turned gray. Over the same time period, the new bright-white RCC took on a slightly dirty appearance. Anderson et al.[11] reported that RCCs of the type used in this investigation are resistant to changes induced by exposure to solar radiation. This suggests that the main effect of field exposure is surface contamination by airborne particulate. Membranes on roofs which are not cleaned periodically can be expected to weather in a similar way. It is therefore important to consider the effect of this field exposure on thermal performance.

Laboratory measurements of the RCC solar reflectance were performed at ORNL in August 1990 and January 1994 using a D & S Solar Reflectometer. In Table 5 for the white RCC, the results show a 26% drop in solar reflectance, from 0.798 to 0.589, over the 3.5 year period. The membrane received one soap-and-water washing in July 1993 as will be described later in the paper. For the black EPDM, the value of solar reflectance did not change. A field test of the comparative thermal performance of a series of roofing coatings including a white latex (acrylic) found that after one year the solar reflectance dropped from 0.56 to 0.43 a change of -23%.[12]

Table 2. Cumulative Heat Gain Reductions (Cooling Load Savings) for Two Roof Sections During the Week of August 13-19, 1990.

Roof Membrane	Plywood Roof Section	Foam Roof Section
Black EPDM/Heat Gain	1305 BTU/S.F.	210 BTU/S.F.
White RCC/Heat Gain	10 BTU/S.F.	40 BTU/S.F.
Heat Gain/Reduction	1295 BTU/S.F.	170 BTU/S.F.
% Heat Gain/Reduction	99%	81%

Table 3. Cumulative Heat Loss Increases (heating season penalty) for Two Roof Sections During the Week of January 21-27, 1991

Roof Membrane	Plywood Roof Section	Foam Roof Section
Black EPDM/Heat Loss	1900 BTU/S.F.	310 BTU/S.F.
White RCC/Heat Loss	2500 BTU/S.F.	390 BTU/S.F.
Heat Loss/Increase	600 BTU/S.F.	80 BTU/S.F.
% Heat Loss/Increase	32%	26%

Table 4. Comparison of Thermal Performance from August and January Weeks

	Plywood Roof Section	Foam Roof Section
Summer Heat Gain Reduction	1295 BTU/S.F.	170 BTU/S.F.
Winter Heat Loss Increase	600 BTU/S.F.	80 BTU/S.F.
Net Energy Savings	695 BTU/S.F.	90 BTU/S.F.
Savings/Penalty Ratio	2.2	2.1

Table 5. The Effect of 3.5 Years of Field Exposure on Solar Reflectance for RTRA's Roof Panel Surfaces

Surface	August 1990	January 1994	% Change
White RCC	0.798	0.589	-26%
Black EPDM	0.068	0.068	0

Effects of Field Exposure on Membrane Temperatures

Figure 8 illustrates how the maximum membrane temperatures varied over the four summers. These data are based on the monthly average of the weekly maximum membrane temperature differences. For example, in August 1990, the average of the maximum weekly temperature differences was 67°F. After the first year, this value dropped to 52°F. The average maximum ambient August temperature in 1990 was 88.4 F compared to 87.4°F in 1991, relatively the same. The reason for the drop in temperature difference was the increase of the white RCC temperature from 8 to 200 F above ambient. The change during the second and third years was not as dramatic. It is noteworthy that the RCC still resulted in a maximum weekly temperature difference of 47°F even after three years of continuous unwashed field exposure. It is also interesting to note that even though the black EPDM physically appeared to "gray", the maximum hourly temperature rise above ambient remained between 74 and 78°F. This is attributed to the fact that the value of the solar reflectance for the black EPDM did not change.

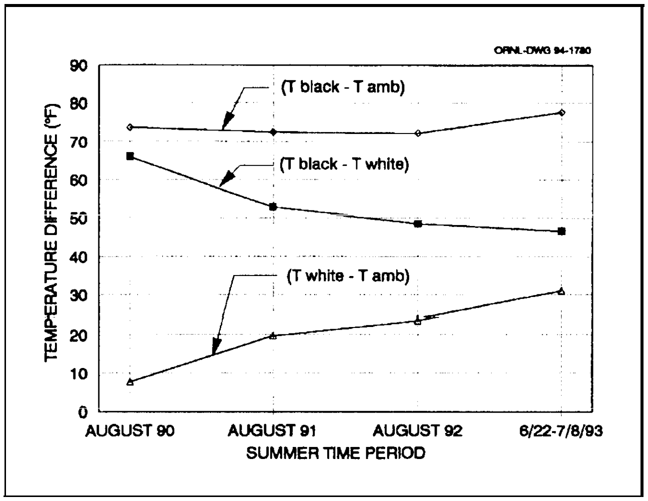

Figure 8. Maximum Temperature Difference Between Black and White RCC Membrane from August 1990 to August 1993

The maximum weekly temperature differences for August 1990 and 1992 were plotted versus ambient air temperature in Figure 9. It is apparent that the maximum white membrane temperature increased approximately 12°F as the surface aged and collected dirt.

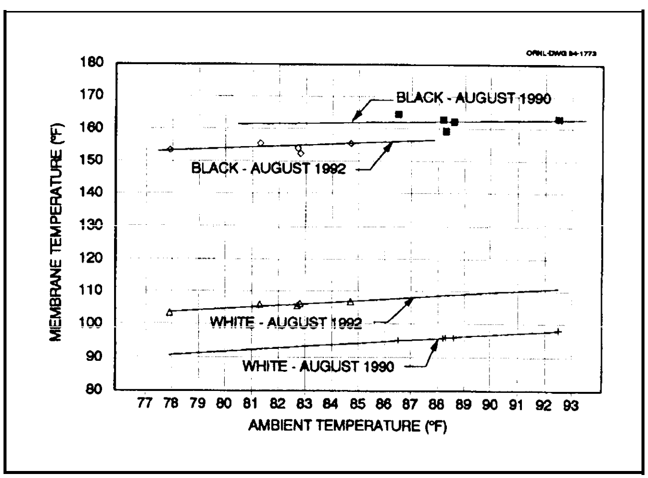

Figure 9. Maximum Temperature Difference Between Black and White RCC Membranes Versus Ambient Air Temperature

Peak Load Savings Potential

There is a time dependent dimension associated with the monetary value of energy savings. For many electric utilities in the southeast, a central challenge is the economical generation of sufficient power to meet the demand that occurs during hot summertime afternoons. The peak hour is typically between 5:00PM and 6:00PM for the cooling dominated and mixed climates. Figure 10 shows the monthly average roof heat flux through the black and white membranes as well as the difference between them. The largest drop occurs during the first two years.

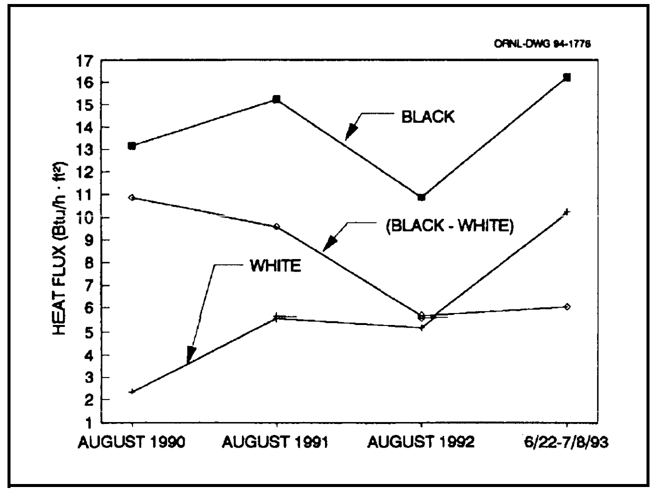

Figure 10. Heat Flux into the Roof from the Outside During the Utility Coincident Peak Demand Period (5:00 PM - 6:00 PM) from August 1990 to August 1993

Effects of Field Exposure on Heat Flux

The values of roof heat flux versus ambient air temperature for August 1990 and 1992 are plotted in Figure 11. The relationship is very linear for the white RCC as can be seen in Figure 11. There was a definite shift upwards of white roof RCC heat flux between 1990 to 1992. The relationship was much less linear for the black EPDM. The variation in the black EPDM heat flux is not random scatter but evidence that the black membrane is strongly dependent upon the immediate value

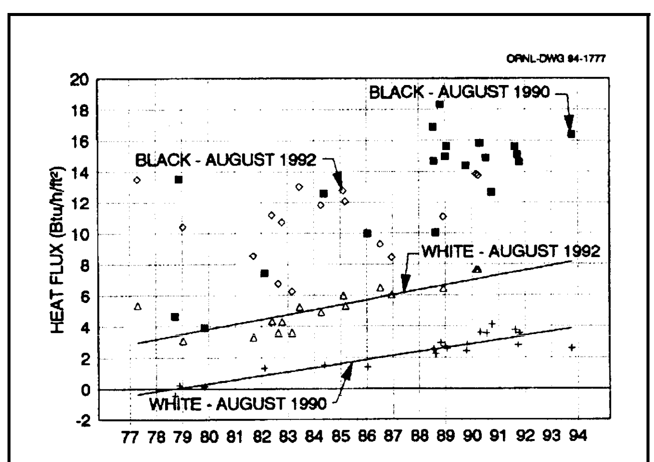

Figure 11. Heat Flux into the Roof from the Outside During the Utility Coincident Peak Demand Period (5:00 PM - 6:00 PM) Versus Ambient Air Temperature

of incident solar radiation. In Figure 12, the six data points in Figure 11 which were within ⁺/- 0.2°F of 88.8°F were plotted versus the incident solar radiation. The small amount of scatter remaining in Figure 12 can be attributed to slight differences in measured wind velocity. Figure 12 also shows the very weak dependence of the white RCC on the incident solar radiation due to its high solar reflectance. As shown previously, the white RCC temperature correlates very well with ambient air temperature.

Figure 13 shows the average roof heat flux between 8:00AM and 7:00PM which corresponds to the period of time when the direction of heat flux is down from the outside through the roof and into the conditioned space.

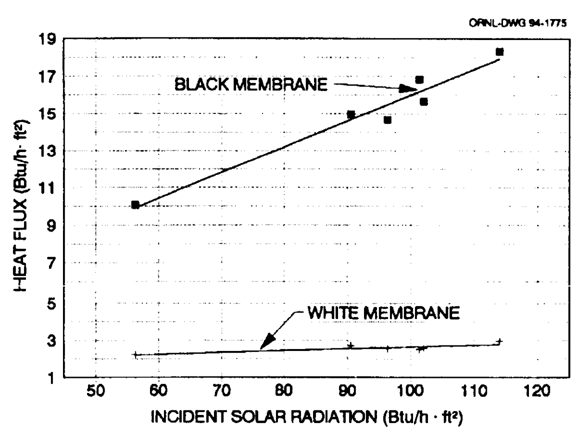

Figure 12. Dependence of Black and White RCC Membrane Temperature on Incident Solar Radiation

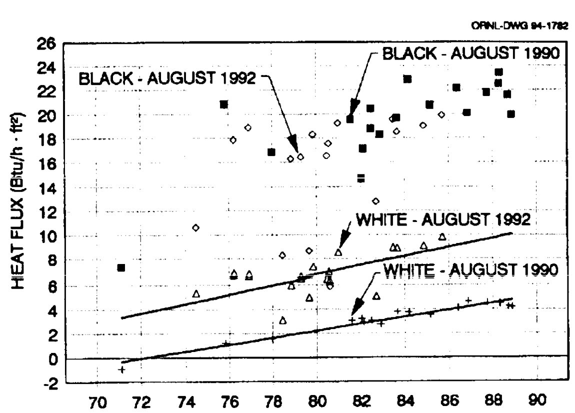

Figure 13. Average Heat Flux into the Conditioned Space from the Outside During Daytime Hours (8:00 AM - 7:00 PM)

This time period also corresponds to typical business hours when a certain level of human comfort must be maintained in an office building. ‘Roof heat gain during this time period in August can be expected to contribute to the overall building’s cooling load. The effect of the first two years of field exposure is most noticeable in the increased heat flux through the white RCC.

For buildings which are used on a 24-hour basis or which have sufficient thermal mass to dampen out the oscillation in the interior air temperature, Figure 14 is important. The 24-hour average heat flux is plotted versus ambient temperature. Once again, the upwards shift of the white RCC heat flux is the key feature.

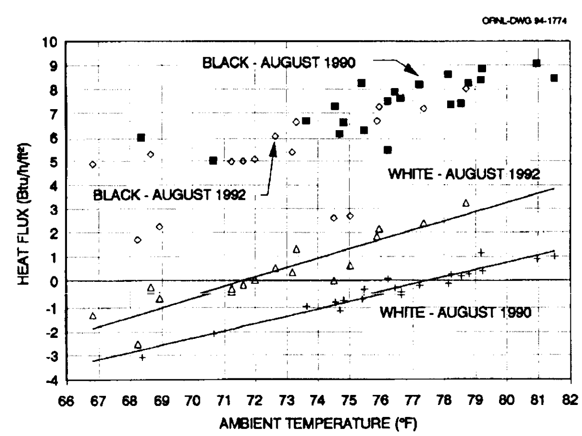

Figure 14. Average Heat Flux into the Conditioned Space from the Outside for a 24-hour Period

Effect of Washing

Because of the reduction of RCC thermal performance that occurs, the effect of washing the membrane is a potentially viable maintenance practice meriting consideration. On July 16, 1993 the surfaces of both the black EPDM and the white RCC were given a dishsoap-and-water washing. The membranes were scrubbed lightly with a broom and completely rinsed. The RCC appearance did not return to the bright-white associated with the new application. The coating appeared to be permanently stained.

The thermal effect of washing is fairly subtle as illustrated in Figure 15. The newly washed August 1993 white RCC temperature elevation above ambient was still 2°F greater than the value for August 1992. One way to judge the effect is to compare the August 1993 results in Figure 15 with the June 22-July 8, 1993 results in Figure 11. The white RCC temperature was elevated to 31°F temperature above ambient in June-July 1992 while it was only elevated to 26°F above ambient in August 1993. When viewed in this before-and-after comparison, the effect of washing seems to be a reduction of the maximum membrane temperature of approximately 5°F. Building owners should consider a springtime roof-wash of their RCC to increase the solar reflectance. The specific method for performing an effective and environmentally safe RCC cleaning is an important consideration. An annual cleaning could also be combined with an annual roof inspection of membrane weathering, flashing details, and other recommended roof maintenance activities which could prolong the service life of the roof system.

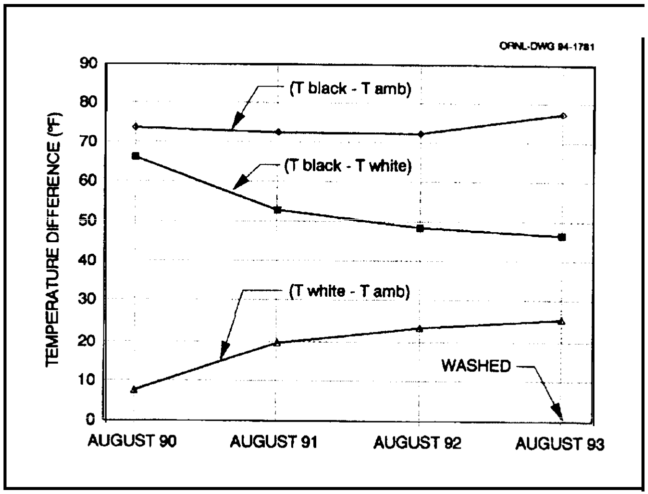

Figure 15. Effect of Soap-and-Water Washing on the Maximum Temperature Difference Between the Black and White RCC Membranes

Experimental Data Comparison with STAR Model

The preliminary computational results compare the white RCC roof heat flux values predicted by STAR with the actual measured values for the week of August 23-29, 1993. The computations take into account the temperature dependent conductivity of the plywood. The function used to describe this dependence is based upon a curve fit of k-values generated by PROPOR and is given below

$$k(T) = 0.3795 + 0.00375 \ X \ T \left[\frac{BTU}{hr\text{-}ft\text{-}^{o}F} \right]$$

where T is temperature in °F. The product of plywood density and specific heat, ρC_p, were assumed to be constant at 0.29 BTU/ ft^3 °F.

Fifteen nodes were used to model the 1.5 inch thick plywood roof section. The computations in Figure 16 were based upon the weather boundary conditions for the period of August 23-29, 1993, for the outside roof surface and a solar reflectance value of 0.589 which was measured in the lab on a specimen sliced and removed from the RTRA roof section. For the boundary condition on the inside surface of the RTRA roof section, measured temperatures were used. Figure 16 shows good agreement between the measured heat flux and the computed heat flux.

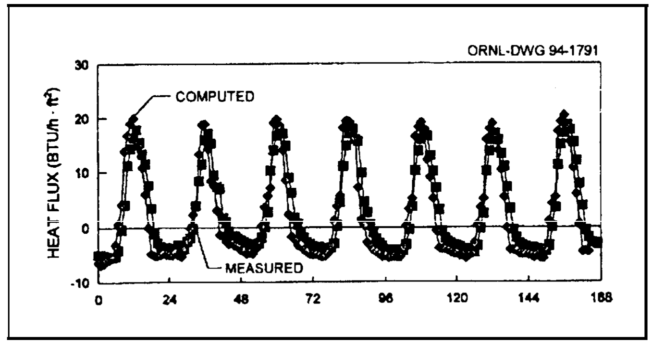

Figure 16. Computed Versus Measured Heat Flux for White RCC. August 12-29, 1993. Weather boundary conditions. Solar reflectance = 0.589.

Discussion

The suitability of RCCs for a particular application depends on many factors including the specific building envelope features, local climatic and solar conditions, HVAC efficiency, HVAC scheduling and operation, the R-value and thermal capacitance of the roof, and energy costs relative to RCC lifecycle costs. The results from this work can be generalized using solar reflectance values as inputs to either a building simulation program or the evaluation method developed by Griggs and Courville. [9] It is hoped this ongoing work will be able to couple the STAR model with a whole building model to provide a well validated tool for development of a RCC guidebook.

Conclusions

The summer peak temperatures of a freshly installed RCC membrane were approximately 60°F lower than those on an uncoated black EPDM membrane. The roof heat gain through the white RCC section was reduced to 1% of the heat gain through the black EPDM section. This heat gain reduction would contribute to a cooling-load savings. The winter peak temperatures of the RCC were 40°F lower than that of the black EPDM. The weekly heat loss through the RCC-covered roof was 32% greater than the loss through the black EPDM-covered roof. This heat loss would increase the cost of heating. For this East Tennessee location with an R-2 roof section, the ratio of the cooling-load savings to heating-load penalty was approximately 2.1 to 1.

The greatest drop in thermal performance of RCCs occurs within the first one or two years. The rate of degradation appears to be less during the third year. The key effect of field exposure is surface contamination which reduces the RCC solar reflectance and causes an increase in peak membrane temperatures and roof heat flux. Laboratory measurements indicate that solar reflectance for the RCC dropped from 0.798 to 0.589 (26%) between August 1990 and January 1994, a period of 3.5 years.

The effect of washing during the third year reduced the peak membrane temperature of the RCC by approximately 5°F. Building owners should consider a roof wash each spring.

The major conclusion from the STAR model comparison with the measured aged field data is that significant agreement exists between measured and computed heat flux. The STAR model should be used along with a whole building model to couple RCC site specific aged field data to a general guidance document.

Acknowledgments

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