Performance of Thermal Control Roof Coating

METAL BUILDING

Shenandoah Environmental and Educational Center

Owner: Georgia Power Company

Performance Analysis

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Radiation Control Roof Coating

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The 12000 ft^2 Environment and Education Center at Shenandoah, Shown in Figure 1, has been serving as a test center for energy efficient design studies for several years. The building has been extensively instrumented and monitored to determine how and where the building and its HVAC system use energy. Once energy inefficient problems are identified, changes are made and the effect of the changes determined. Since the building is representative of many other buildings in Georgia, improvements identified for the Environment and Education Center will be immediately applicable to other buildings of this type.

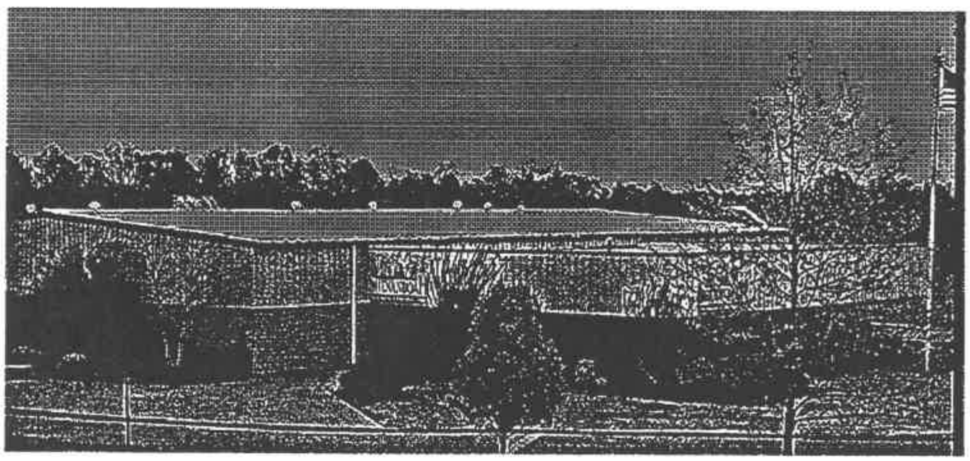

Figure 1 Shenandoah Environment and Education Center

One problem identified early was the extremely high roof temperatures reached on most days. The galvanized roof frequently reached temperature above 170°F. Although the roof is insulated, considerable energy reaches the attic area. The building initially used an open plenum return for the seven HVAC systems used to condition the seven zones. Any energy reaching the attic eventually appeared as a load on the mechanical systems. Ducting of the HVAC returns was one of the first changes made to the building. This change resulted in about a 30 percent reduction in the HVAC energy consumption, better temperature control and considerably better humidity control.

Although equipping each HVAC unit with an insulated return duct decreased the problem associated with the high roof temperatures, the nonventilated attic reached temperatures as high as 105°F during the peak of the summer. These temperatures increased energy conduction through the duct insulation and through the ceiling insulation into the conditioned space.

Roof Thermal Control Coating

It was decided in the Spring of 1995 to coat the roof with a coating that would reduce the roof temperature significantly. Reducing the roof temperature not only decreases the thermal load on the building, it increases the life of the roof by decreasing thermal stresses associated with the large temperature swings experienced by the roof. An ideal temperature control roof coating would have a low short wavelength absorptivity to reflect most of the solar radiation and a high long wavelength emissivity to radiate absorbed energy back to the sky. Several companies make roof coatings specifically for this purpose. The roof was coated with Duracool 1, an acrylic coating developed to control thermal gain and rust, on March 28 and 29, 1995.

A progress report detailing the initial short time performance was released in May 1995. Parts of that report are reproduced here in the interest of completeness.

Figure 2 gives the roof and ambient temperatures over the period when the roof was coated. Notice that there was a significant decrease in roof temperature beginning on the 29th. Peak roof temperature dropped from above 140°F prior to the 29th to below 80°F on the days immediately following the 29th. The roof was coated over a two day period beginning on the 28th. The slight increase in roof temperature during the first few days in April resulted from an increase in the ambient temperature. Notice that the roof temperature reached a peak near the middle of the day, while the ambient temperature reached a peak later in the afternoon. The building faces directly south with much of the roof tilted slightly south. With the solar energy peaking near the middle of the day, the roof peak temperatures appear when expected.

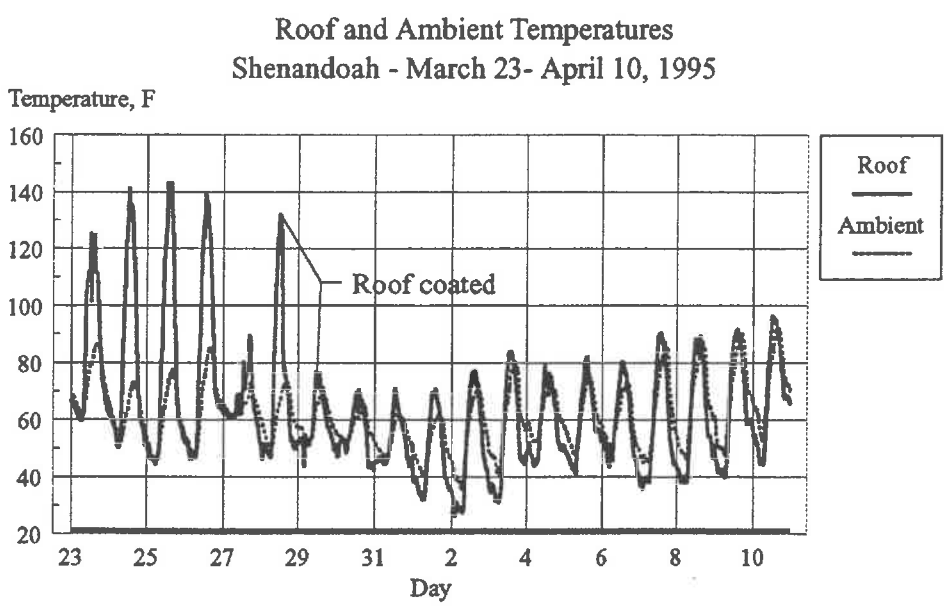

Figure 2 Roof and Ambient Temperatures - March 23 - April 10, 1995

Figure 3 gives the roof maximum monthly temperature for a twelve-month period prior to coating and a six-month period after coating. Notice that the roof temperature after coating was 50 - 90°F lower than the corresponding temperature before coating. A later figure will compare the ambient temperature and solar radiation for the two periods. Ambient conditions before coating were milder that those following coating, so the drops shown in Figures 2 and 3 resulted from the coating rather than ambient differences.

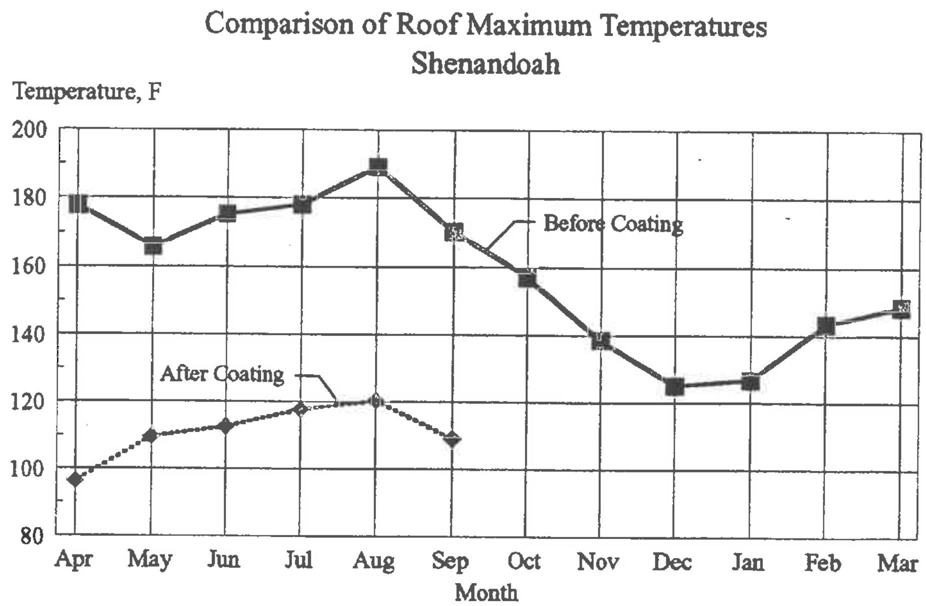

Figure 3 Comparison of Monthly Maximum Roof Temperatures

Figure 4 gives the roof to ambient temperature differential from 23 March to 10 April. Notice that the temperature differential decreased from peaks of 60 - 70°F before coating to less than 20°F following coating. Had this been a summer month higher differentials would have been experienced. This decrease in temperature differentials shows the coating has a low solar absorptivity, i.e., the coating is reflecting much of the solar energy incident on the roof. Also notice that the differential at night before coating was only 2-3°F below ambient. This differential after coating averaged about 12°F and reached as high as 20°F on April 7. This temperature decrease is indicative of a high long wavelength emissivity, i.e., the coating is radiating energy to the cool night sky. It is not clear whether this radiation will increase the heating load during the winter months. It is believed that this will not seriously increase the heating load.

Figure 5 compares the average monthly temperature for 1994 and for six months out of 1995. This shows that ambient temperatures were considerably higher for three months in 1995, slightly lower for two months and the same for one month compared to 1994. On average temperatures were considerably higher in the months following coating than they were for comparable months in the previous year.

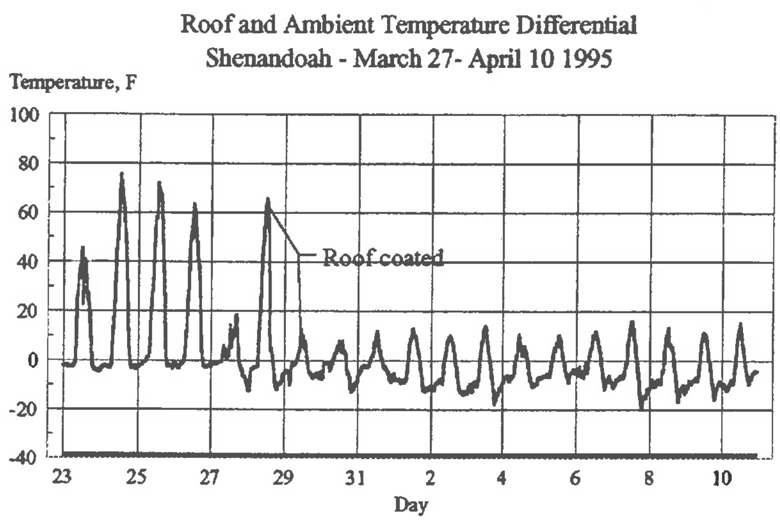

Figure 4 Roof To Ambient Temperature Differential - March 27 - April 10, 1995

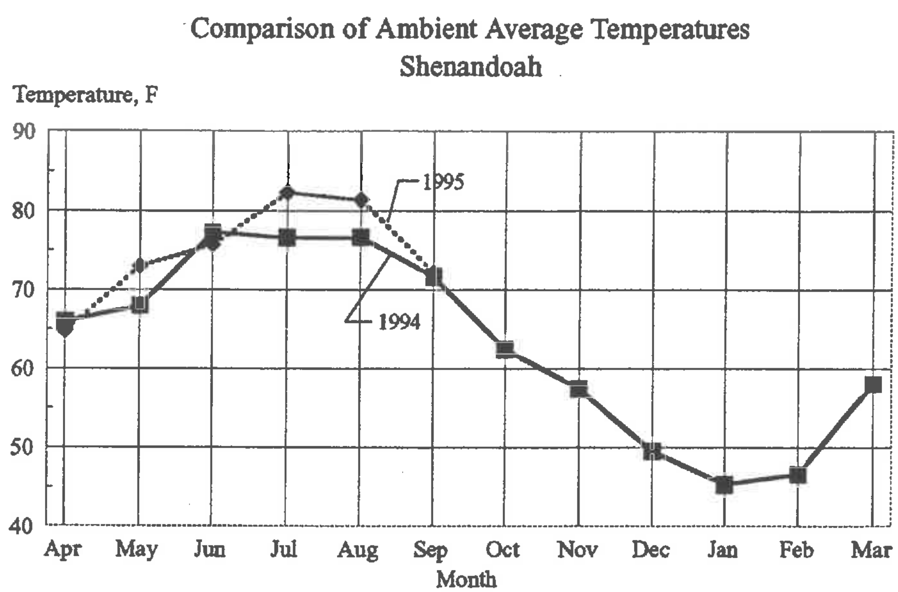

Figure 5 Comparison of Average Monthly Ambient Temperatures

Figure 6 gives the total horizontal solar radiation for the days immediate prior and immediately following coating. Notice that the radiation is quite high on most days and increases slightly in the days following coating. Figure 7 compares the total monthly horizontal solar radiation for a one year period before coating to six comparable months following coating. Notice that the solar radiation in 1995 was higher in four months, the same one month and lower one month when compared to comparable months in 1994. On average the total horizontal solar radiation in 1995 following the roof being coated is considerably higher that comparable months in 1994.

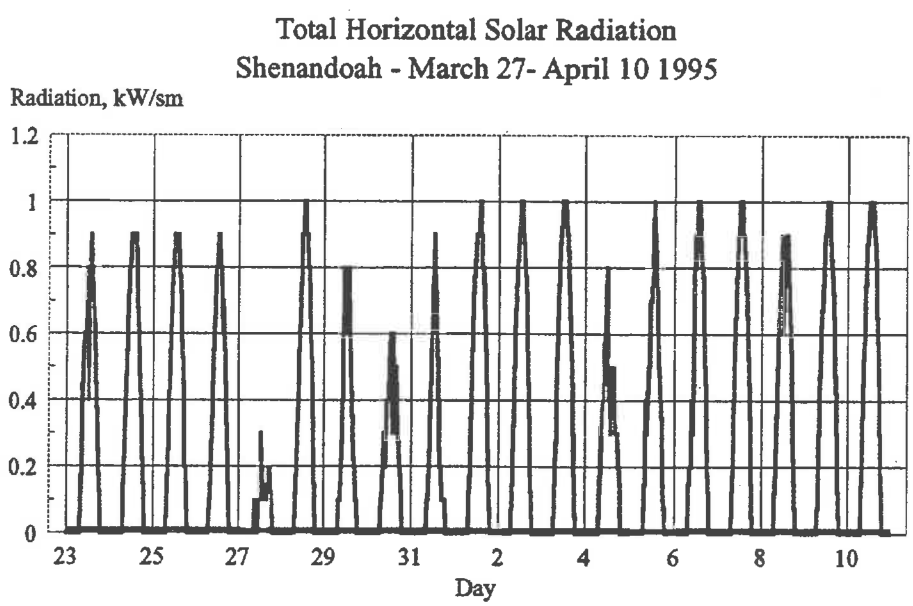

Figure 6 Total Horizontal Solar Radiation - March 27 - April 10, 1995

Figures 5 through 7 show that the ambient conditions in the days and months following coating were more severe than comparable days and months before coating. This means that the decreases shown in this report were the result of the roof coating and not due to less severe ambient conditions.

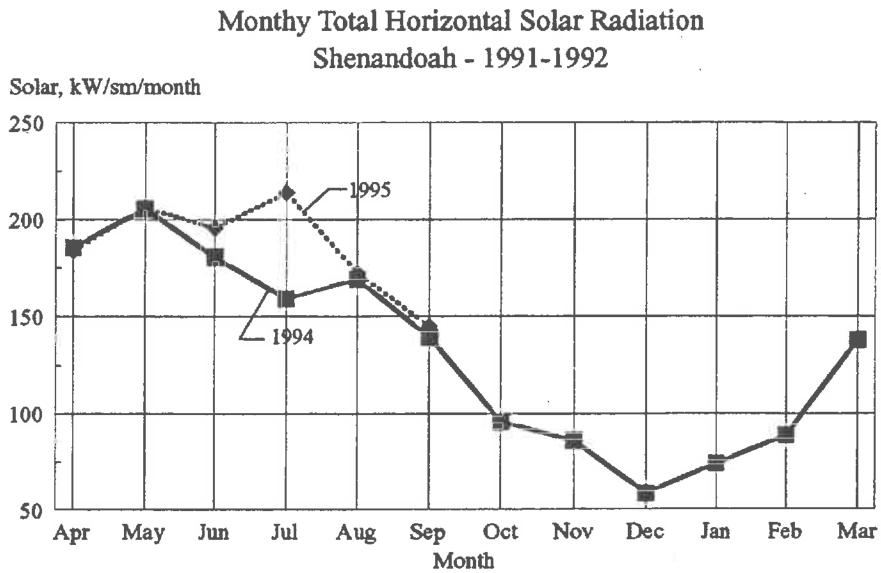

Figure 7 Comparison of Monthly Total Horizontal Solar Radiation - 1994 - 1995

Figure 8 gives the heat flux through the roof in the days immediately before and immediately following the roof being coated. Figure 8 shows just how effective the coating is in reducing the energy flow through the roof. Notice that the peak heat flux before coating varied from 25 to above 40 Btu/hr/sf. This is energy that got through the roof and insulation and eventually had to be removed by the HVAC system. Energy flux following coating reached a peak of 5 Btu/hr/sf and over most twenty-four hour periods averaged less than zero. This means that over a twenty-four hour period the roof had a net cooling effect on the building. The low heat flux on March 27, before coating, was the result of a rainy day.

Figure 9 gives the roof hourly heat flux extremes for twelve months before coating and six months following coating. Notice that there was a sharp drop in maximum hourly heat flux for the months following the roof being coated. There is also a modest decrease in the average hourly heat flux for the months following coating. The decrease in magnitude of the minimum hourly heat flux following coating was at first surprising. It apparently results from there being less energy conducted into the attic during the daylight hours following coating. This results in less energy in the attic and less being conducted out of the attic through the roof at night.

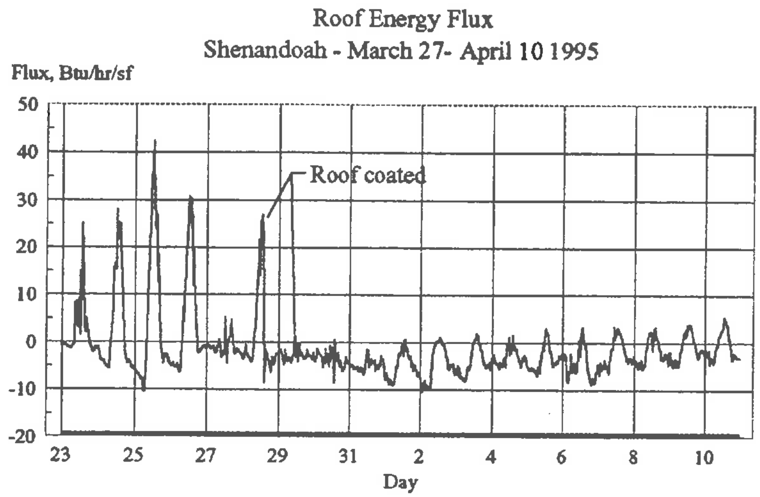

Figure 8 Roof Energy Flux - March 27 - April 10, 1995

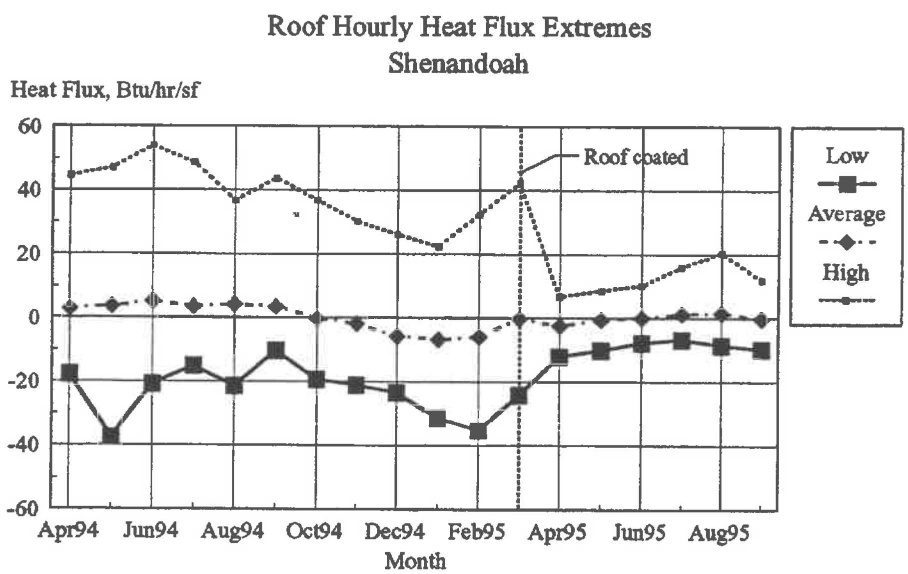

Figure 9 Roof Hourly Heat Flux Extremes

Figure 10 compares the maximum hourly roof heat flux before and after coating for comparable months. This figure really tells the story relative to the energy arriving in the attic during the daylight hours when the HVAC is operating at peak loads. Had the HVAC returns not been ducted and an open plenum been used, this energy would have translated directly into a HVAC load. With insulated ducted returns the energy must still conduct through the duct insulation. While light colored roofs are very important on those building with open plenum returns, they are also important on those building with insulated ducted returns.

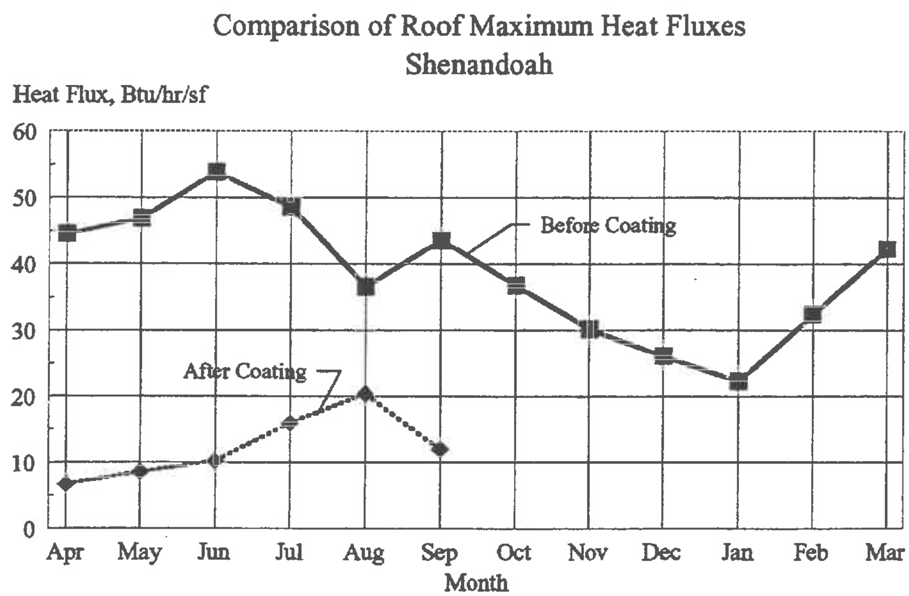

Figure 10 Comparison of Roof Maximum Monthly Heat Fluxes

Figure 11 gives the attic temperature distribution for the days immediately prior and immediately following the roof being coated. Notice that peak attic temperature before coating reached levels above 90°F. There was a sharp drop in attic temperatures following the roof being coated, with peak attic temperatures reaching only about 75°F. Attic temperatures slowly began to increase as April progressed because the ambient temperature began to increase. Attic temperature decreases of this magnitude were at first surprising because of the three inches (R-11) of insulation between the roof and the attic. When one examines the roof temperature curves and the roof heat flux curves it becomes apparent that one should not have been surprised. The temperature differential across the roof insulation decreased significantly. Attic temperature decreases of this magnitude should result in a significant decrease in the HVAC load. Also notice the minimum attic temperature decreased although not to the degree the peak temperature decreased.

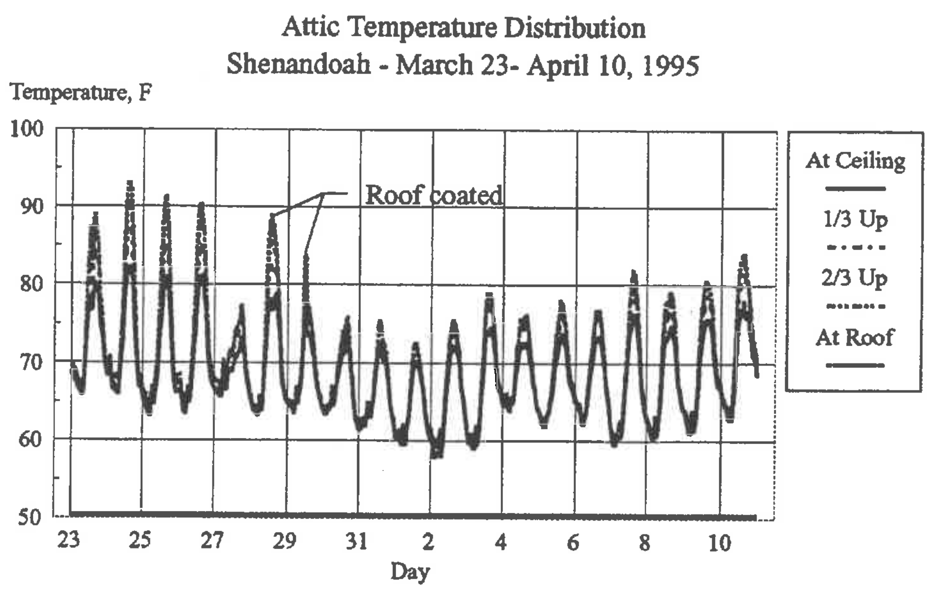

Figure 11 Attic Temperature Distribution - March 27 - April 10, 1995

Figure 12 compares the average attic temperature for the months before the roof coating and for six months following the roof coating. The longer term data given in Figure 12 show that the drops depicted in Figure 11 were realized in monthly average temperatures. When one considers that the ambient temperatures and solar radiation were greater in 1995 than in 1994, the decreases shown in Figure 12 are more impressive. Decreases of 3-8°F in average attic temperature decrease the driving force through both the ceiling and duct insulation. It should be noted that the attic temperature is driven to some extent by the energy produced by the fluorescent lights located in the suspended ceiling.

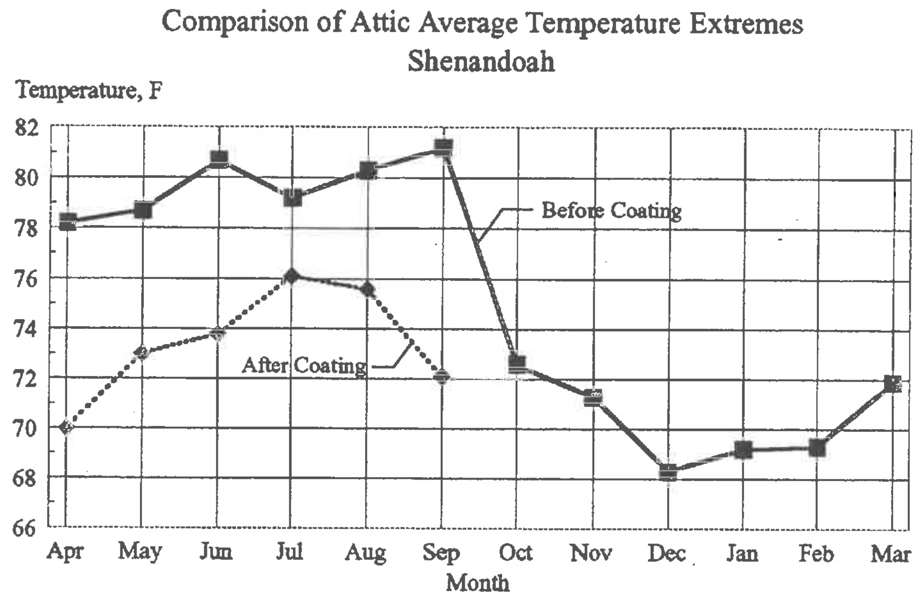

Figure 12 Comparison of Attic Average Temperature Extremes

Figure 13 compares the maximum attic temperature before and after coating. We see from this figure that coating the roof resulted in decreases in peak attic temperature of 13-19°F. Comparison of Figure 13 with Figure 2 shows that the maximum attic temperature before roof coating was well above the ambient temperature. Surprisingly maximum attic temperature following roof coating was below ambient temperature. This suggest that although the HVAC returns have been ducted with insulated ducts, there is still some cooling of the attic by the HVAC system. It is not known whether this results from conduction through the ceiling and duct insulation, leakage from the ducts, or from infiltration between the conditioned space and the attic. One suspects that it is a combination of these.

Considerable effort was directed to establishing some reasonable estimate of the savings in HVAC input energy due to the roof coating. It was found that correlation between energy used in 1994 and in 1995 was difficult because things that we had no control of or even were aware of changed. People present in the building obviously have an important impact on the energy used by the HVAC systems. We don't have records available that tell how many people are in the building during each period. The building also has had a significant increase in the number of computers and miscellaneous equipment. These all have an impact on the energy required to condition the building.

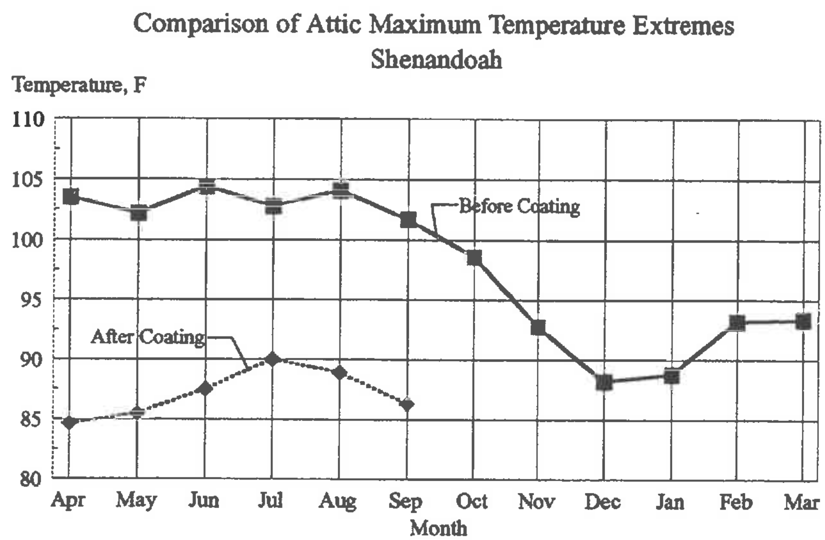

Figure 13 Comparison of Attic Maximum Temperature Extremes

The best correlation was obtained by correlating the energy used in March 1995 before the roof being coated to the energy used in April 1995 after the roof was coated. Regression analyses were conducted on both these sets of data. Best correlation were obtained by correlating energy use to solar radiation, cooling degree days, heating degree days, lighting input, dew-point temperature and miscellaneous energy input. Correlation coefficient of .80 was obtained for the March data and .81 for the April data.

Figure 14 compares the predicted compressor input before coating with the compressor input following coating. Compressor input was used because some zones used a little strip heat in early March, thus increasing the total HVAC input for March compared to April. Heating degree days, Cooling degree days, dew-point, lighting input, and miscellaneous input were held constant at values that would be typical for summer months. Only the solar radiation at the site was varied because it is the driving force for the energy coming through the roof. Figure 14 shows that there was a saving of 8.7% at zero solar and 21.6% at 9 kWh/sm/day. Zero solar would be slightly worse that a very overcast day, while 9 kWh/sm/day would be typical of a very sunny day. Figure 14 is for a cooling degree day level of 15. This would be typical of a hot day in July or August. One might question why there is a benefit to the roof coating on days when there is no solar load. It is important to remember that the building has a relatively high internal load and is in a cooling mode much of the time. One suspects that the high emissivity of the coated roof helps cool the attic and thus helps reduce the load even on days when there in no solar load. Figure 8 showed that the energy flux on the roof following coating was negative much of the time. Having said this, one can't rule out a difference in people load in the building in March and April or another load that hasn't been included in the regression analysis having contributed to the decrease.

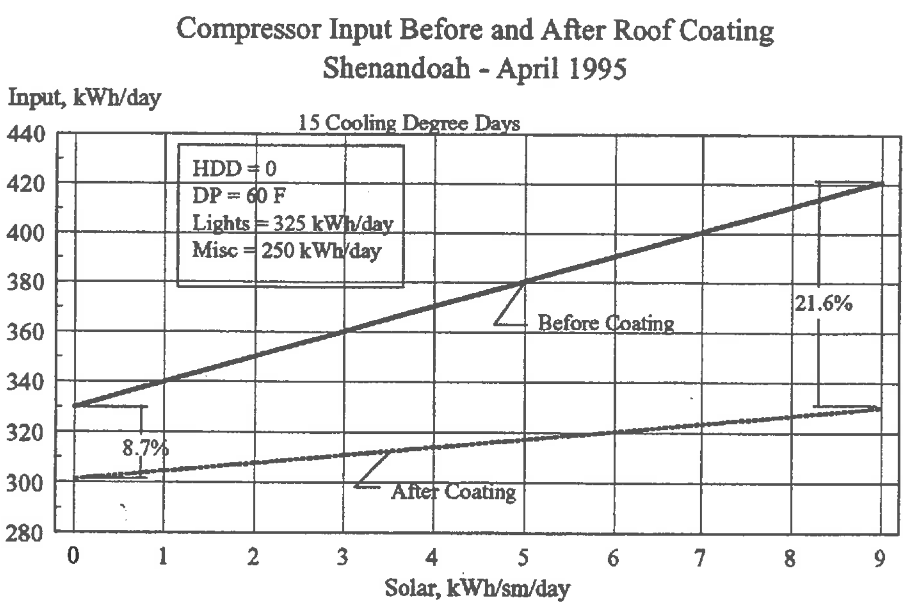

Figure 14 Predicted Compressor Input Before and After Roof Coating - 15 CDD

Figure 15 compares the predicted compressor load for a day with five cooling degree days. Everything else in the correlation was held constant. Notice that the percentage savings at zero solar increased to 10.7%. The savings predicted to be due to the roof coating at 9 kWh/sm/day also increased to 27.5%. Since there is less driving force due to ambient temperature as shown by the lower cooling degree days, the solar load became a larger percentage of the lower total. One still suspects that some factor not measured also contributed to the savings.

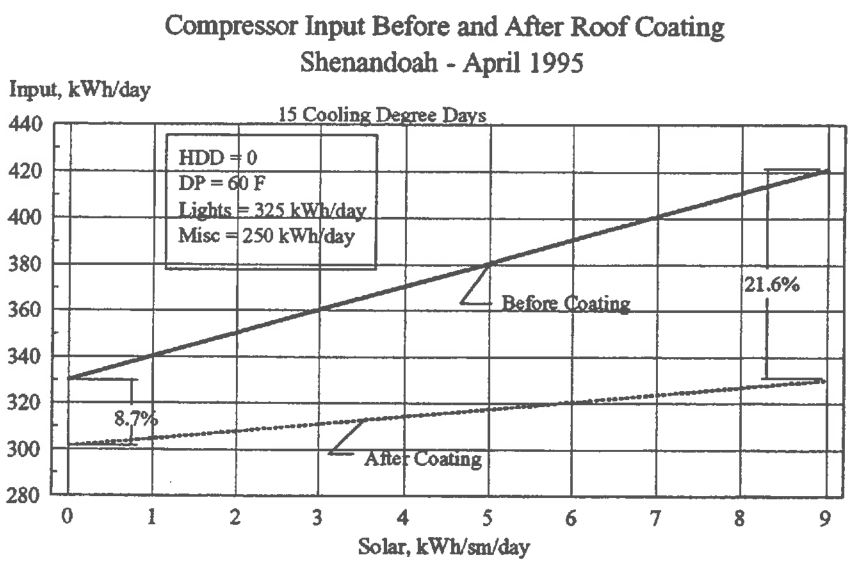

Figure 15 Predicted Compressor Input Before and After Roof Coating - 5 CDD

Figure 16 gives the compressor load as a function of solar radiation for several different cooling degree days. Figure 16 gives the load before the roof was coated. Notice that the compressor load is highly dependent on both solar radiation and on cooling degree days. The lower curve is for zero cooling degree days, i.e., the average daily temperature is 65°F. Notice that there is still a significant load when both the cooling degree days and the solar radiation are zero. This shows that the building has a cooling load due to lights, people and miscellaneous factors when two of the primary driving forces are absent.

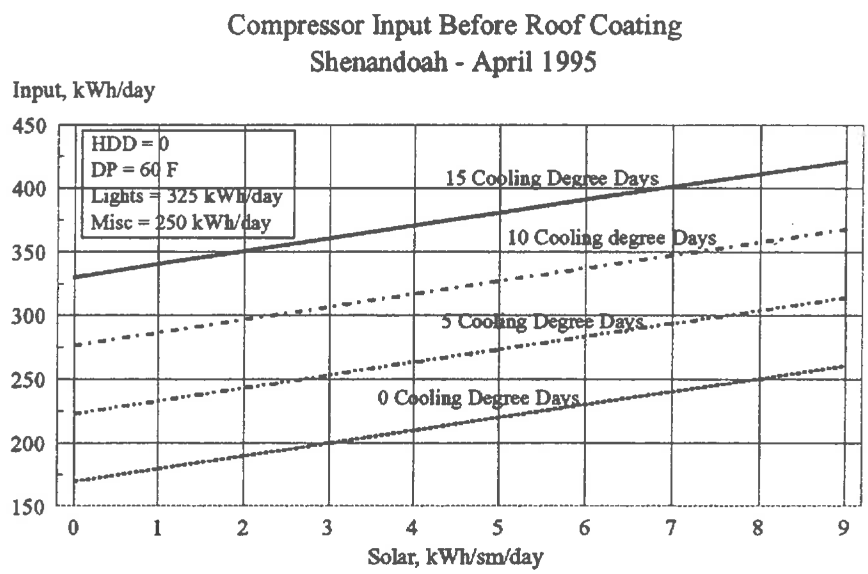

Figure 16 Predicted Compressor Input - Before Roof Coating

Figure 17 gives similar data following the roof being coated. Notice that the slope of the curves as a function of solar radiation is much less than they were before coating. This reduced slope is directly a product of the roof coating. Figure 17 shows that there is still a load on the building when both cooling degree days and solar radiation are zero. This remaining load is less than it was before coating, yet is still a significant load.

Summary

These tests show that relatively inexpensive commercially available roof coatings have the capability to significantly reduce roof temperatures and energy flux. This translates in very significant energy savings. For buildings with plenum return the energy savings would be greater than those measured here. The hot-humid Southeast is noted for mold and mildew on roofs. This study hasn't determined how long the roof coating will be effective. Although the coating is guaranteed for ten years, it is unlikely that the coating will be as effective as measured here for the ten year period.

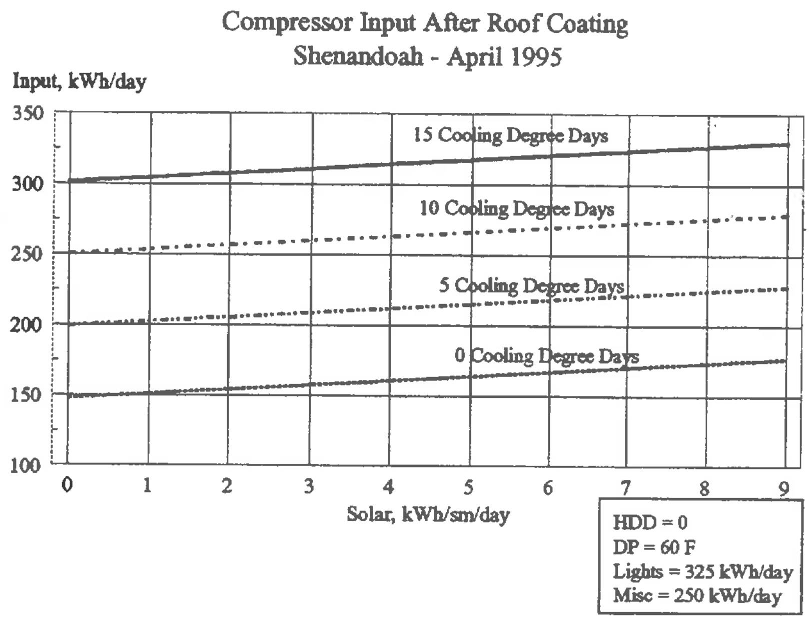

Figure 17 Predicted Compressor Input - After Coating