CITY OF
TUCSON
DEPARTMENT
OF OPERATIONS

# Cool Roof Energy Savings Evaluation

**for**

## City of Tucson
## Thomas O. Price Service Center
## Administration Building One


**Written by**
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# PREFACE

The City of Tucson is committed to the promotion of sustainable development practices and is considered a leader in the area of energy efficiency. It has implemented numerous energy-saving projects and won several awards for its efforts. The City has established a history of promoting water and energy conservation, recycling, and participating in such programs as Green Lights, Clean Cities and Climate Wise. In 1998, the mayor and council requested City staff to develop policy options for sustainable design and construction practices for City of Tucson facilities and in 1999, Tucson was designated the Solar Capital of Arizona. The *Creating Cool Communities* project, which addresses the increasing problem of urban heat islands, is still another City effort to promote sustainability.

**Urban Heat Islands** are a recently noted phenomenon affecting large urban centers globally. They occur when urbanized areas accumulate greater amounts of heat than their rural surroundings. In cities throughout the world, on the hottest summer day, the temperature is rising by up to one degree Fahrenheit every ten years and can be six to eight degrees hotter than surrounding rural areas. Two main factors are responsible for this phenomenon: 1) a decrease of trees and native vegetation; and 2) dark, heat absorbing surfaces. This increase in temperatures causes an increase in energy usage, energy costs, air pollution, greenhouse gasses such as carbon dioxide and other indicators of global warming. The cities also retain increased temperatures throughout the night, while the surrounding rural areas cool off significantly. In 1992, the Cool Communities model was developed to help mitigate the negative effects associated with urban heat islands.

In 1998, the City of Tucson applied for, and received, a planning grant from the Public Technology, Inc.'s (PTI) Urban Consortium Energy Task Force for Phase One of a two-phase project that addressed heat island mitigation. The goal of this grant was to research and design a demonstration project that included all three components of the Cool Communities model. The project incorporated the rooftop of one office building and the two adjacent parking lots at the Thomas O. Price Service Center in Tucson, Arizona. The 24,000 square foot building is part of a larger City operations and maintenance complex. It was selected because of its general set-up and ease of

monitoring due to its ongoing participation in the Department of Energy's (DOE) Energy Star Buildings program.

The intention of Phase Two of the Cool Communities project was to measure:

- improvements in comfort in and around the building;
- reductions in energy use due to the cooler roof surface and cooler surrounding parking lot temperatures; and
- evaluate the cost effectiveness and durability of all roof, paving and landscaping materials used in the project.

Due to lack of funds, Phase II was only partially completed; a highly reflective white coating with reinforcing mesh was applied to the demonstration building's existing roof. The existing roof contains asbestos and had a temporary roof install seven years ago.

The following report by Dr. Lisa Gartland provides the results of monitoring building temperature and energy usage of the demonstration building. The reductions in energy consumption in the building due to topping the roof with a white reflective coating are quite impressive. Nearly 50% energy usage reduction was recorded from one summer week, prior to the coating, when compared to a week with similar weather conditions, after coating. The results are even more impressive when taking into consideration that this building already had modern energy efficient lighting, mechanical systems and building controls installed prior to baseline monitoring. The existing roof also contains 2.5 inches of fiberboard insulation.

Although Dr. Gartland did not provide estimates of annual avoided energy consumption due to the white topping, a reasonably accurate estimate can be calculated. Based upon the figures presented in this report, as well as measured chilled water usage during the past summer, avoided energy usage can be estimated at over 400 million Btu annually. This translates into an avoided energy cost of nearly $4,000 annually. White topping the roof cost $24,993, therefore, the simple payback period is just over six years. The rate of return is 16%. In addition to the monetary savings the reflective roof top coating eliminated several roof leaks and extended the life of the existing roof.

For more information, please contact the City's Energy Manager, Vinnie Hunt, at (520) 791-5111 extension 311, or email him at VHunt1@ci.tucson.az.us. Vinnie can also be located at the City of Tucson's Thomas O. Price Service Center, 4004 South Park Avenue, Building 1, Tucson, Arizona, 85714.

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# Cool Roof Energy Savings Evaluation for Price Service Center Administration Building One

Building One of the City of Tucson's Price Service Center has been monitored for weather conditions, energy use and temperatures since the spring of 2000. This was done in anticipation of the addition of a cool roof and cool parking lot features like lighter colored pavements and added trees and vegetation to provide shade. In the first stage of this project, a white elastomeric top coating was applied to Building One's original metal and black surfaced roof between June 18 and June 29, 2001. This report evaluates the cooling energy savings resulting from this rooftop change.

The energy savings are evaluated in two different ways. First, by looking directly at "raw" data from a week before and a week after the cool roof was applied; and second, by adjusting this raw data to account for weather and occupancy variations. This report recaps the roof construction and the instrumentation used to monitor the building, then explains the data analysis work, and finally gives roof surface temperature and energy savings results.

**Table 1**
**Roof Surface Temperature Reductions and Cooling Energy Savings due to Cool Roofing**

| | **Raw Roof Temperature Reductions** | **Adjusted Roof Temperature Reductions** | |
|---|---|---|---|
| **Peak Temperatures** - Black Roof | 70 °F | 78 °F | |
| Metal Roof | 35 °F | 46 °F | |
| **Average Temperatures** - Black Roof | 13 °F | 17 °F | |
| Metal Roof | 13 °F | 10 °F | |
| | | | |
| ***Weekdays only for one summer week*** | **Raw Energy Use (Btu)** | **Adjusted Energy Use (Btu)** July 23-29 | |
| | May 7-13 & July 23-29 | OFF at nite | ON at nite |
| **Hot roof cooling energy use** | 36,823,680 | 37,814,708 | 54,831,598 |
| **Cool roof cooling energy use** | 19,385,640 | 19,385,640 | 19,385,640 |
| **Savings** | 17,438,040 | 18,429,068 | 34,995,958 |
| **% savings** | 47.4% | 48.7% | 64.6% |

## Roof Construction & Building Instrumentation

The original roof on Building One is about 28,000 square feet in area. It is surfaced with a sturdy aluminum foil over its low-slope areas (the vast majority of the roof area), and with a copper foil that has turned black over more steeply sloped portions on the west side of the roof (furthest from S. Park Avenue).

Slightly sloped, eastern portion of the roof, surfaces with a bare metallic roofing material. Although it is somewhat reflective, metallic surfaces have low emissivities that keep them hot.

Western portion of the roof, showing flat section covered with bare metallic roofing material, and a fairly steeply sloped section in the foreground covered with a blackened copper foil. Black surfaces have very low solar reflectivities that make them hot.

Below the roof surface is a modified bitumen roof that was applied in 1993 as a repair to the building's original roof layer. The original layer consisted of a three-ply built-up roof surfaced with an asphalt capsheet material, which was applied during the building's construction in 1978. Directly below the roof layers is a 2.5 inch thickness of fiberboard, which rests on a metal roof deck. Below the roof deck is a partially enclosed air space about two feet high, containing cooling ducts, wiring and other building equipment. Suspended ceiling tiles containing fluorescent lighting fixtures are above the entire office space, with gaps between ceiling tiles where structural members support the roof.

Underside of roof, air space, and ceiling tiles shown at a gap in the ceiling around the roof support struts.

Table 2 lists the R-values of each of the roof and ceiling components for the original and new cool roof installations. Note that an air space has a fairly constant R-value of about 0.04. Note also that I'm assuming the fiberboard has an R-value-per-inch of 4.0, giving it an overall R-value of 10. Addition of the new cool surface with embedded mesh has no effect on the R-value of the entire roof assembly, so the R-value of the base roof and the new roof are the same.

**Table 2. Calculation of roof & ceiling R values in hr-ft$^{2-}$F/Btu.**

| Component | R-per-inch | Thickness (in) | Base R-value | New R-value |
|---|---|---|---|---|
| Surface coating/mesh | 0.1 | 0.020 | --- | 0.00 |
| Foil surface | 0.0 | 0.020 | 0.00 | 0.00 |
| Modified bitumen | 0.9 | 0.125 | 0.11 | 0.11 |
| Built-up roof | 0.9 | 0.125 | 0.11 | 0.11 |
| Fiberboard | 4.0 | 2.5 | 10.0 | 10.0 |
| Metal roof deck | 0.0 | 0.625 | 0.78 | 0.00 |
| Air space | 0.04 total | --- | 0.04 | 0.04 |
| Acoustic tile | 2.5 | 0.625 | 1.56 | 1.56 |
| **Total R-value** | | | **11.82** | **11.82** |

Monitoring equipment has been installed in and around the building. Table 3 lists the equipment used, what it measures, the time interval between measurements, and when it was deployed, as well as comments about data collection problems.

For the most part the data collection equipment worked smoothly. One important exception was the rooftop pyranometer, which was reading erratically for about six months before this problem was detected and fixed. This unfortunately meant that the solar radiation values during the period before the roof coating were no good. Thankfully, these values could be reliably estimated using a regression equation generated from summer 2000 data (see data analysis section for details).

The only other significant problem with data collection equipment was the relatively late installation of the chilled water BTU meter. This meter is obviously crucial to this analysis, since it is measuring the cooling energy used by Building One. Since it wasn't installed until March 28, 2001, none of the data collected last summer or this winter could be used to analyze energy savings.

**Table 3. Monitoring equipment on Building One used to evaluate cooling energy savings.**

| Equipment | Measurement | Time interval | Comments |
|---|---|---|---|
| Temperature sensors | Metal & black roof surface T's | 15 minutes | Good data |
| Temperature sensors | Metal & black roof underside T's | 15 minutes | Good data |
| Temperature sensors | Indoor air temperature | 15 minutes | Good data |
| Weather station | Roof air T, wind speed, humidity | 30 minutes | Data collection interval set up incorrectly at 30 min. instead of 15 |
| Pyranometer | Rooftop solar radiation | 15 minutes | Sensor reading erratically from December 2000 thru June 2001 |
| Temperature & humidity sensors | North & south parking lot T & H | 15 minutes | Good data |
| Photometers | North & south parking lot light level | 15 minutes | Good data |
| KW transducers | Lights & electrical energy use at panels | 1 minute | Good data |
| Utility meter | Chilled water BTU's for cooling | 1 hour | Not installed until 3-28-01 |

## Data Analysis

### Analysis Approach

To calculate the cooling energy savings due to the new cool roof, the data was analyzed two different ways. First, data from before and after the roof was coated was directly compared. This "raw" comparison was made carefully by picking before and after weeks with very similar weather and building use conditions. Second, to account for even these small variations in weather and building use, a regression equation was derived to describe the cooling energy use.

The “before” week chosen for comparison was Monday, May 7 through Sunday, May 13, 2001, and the “after” week was Monday, July 23 through Sunday July 29, 2001. (Note that the roof work was done between June 18 and 29, 2001.) These two weeks had the most similar weather characteristics found during the weeks before and after the roof was coated.

**Correcting "Before" Solar Radiation Data**

Unidentified problems with the solar radiation data collection during the "before" period meant that solar radiation values had to be regenerated. Figure 1 shows the actual "before" readings during the week of May 7 through 13, along with the "after" week data. These problems with extremely high readings and lots of data scatter began in December of 2000, and were not identified and corrected until June of 2001, unfortunately not in time to get good summer 2001 data before the cool roof was installed.

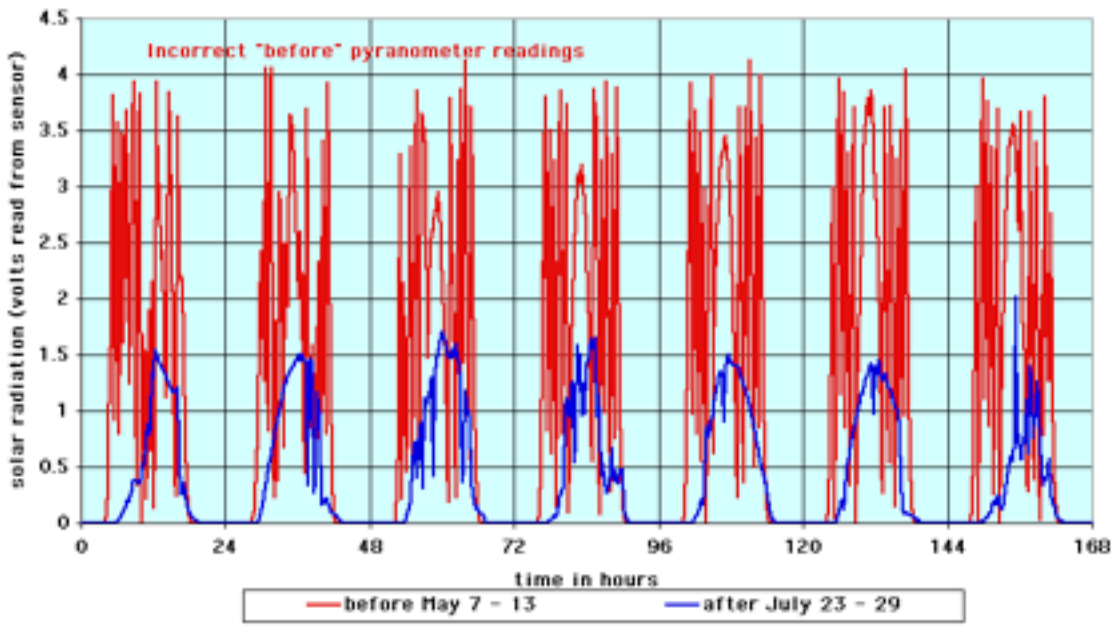



**Figure 1. Original solar radiation readings, showing problematic "before" readings**

Past work on other roof monitoring projects has found that roof surface temperatures are highly dependent on solar radiation values. Knowing this, it is possible to generate a correlation that allows us to work backwards from roof surface temperatures to estimate the solar radiation values during the May 7 through 13 "before" period.

Data from the summer of 2000, when the pyranometer was working correctly, was input to a statistical regression analysis program to find the best correlation to predict solar radiation based on rooftop surface temperature. Data from August 19 through 24, 2000, using only daytime readings with non-zero pyranometer values, was regressed to find a multiple linear equation of the form

$$\text{Solar Radiation (V)} = -1.158862 + 0.007134\ \text{Tblack} + 0.008581\ \text{Tmetal}, \quad \textbf{Equation. (1)}$$

where Tblack is the surface temperature in degrees Fahrenheit measured on the black portion of the roof and Tmetal is the surface temperature in degrees Fahrenheit measured on the metal portion of the roof. This correlation has a robust $R^2$ value of 0.805 with t-statistics of 19.3, 14.8 and 12.1 on the constant, Tblack and Tmetal coefficients, respectively.

When the correlation in Equation (1) is used to estimate/regenerate the pyranometer reading, it produces some negative values instead of zero values when the sun is supposed to be down. Therefore a further provision is made on Equation (1) that the value of solar radiation be set to zero if Equation (1) produces a negative value. Actual and regressed solar radiation values are plotted in Figure 2 for the period from August 19 through 24, 2000, to show how well the correlation fits the actual data used to derive this regression equation. The corrected solar radiation values for the week of May 7 through 13 are plotted in Figure 6.

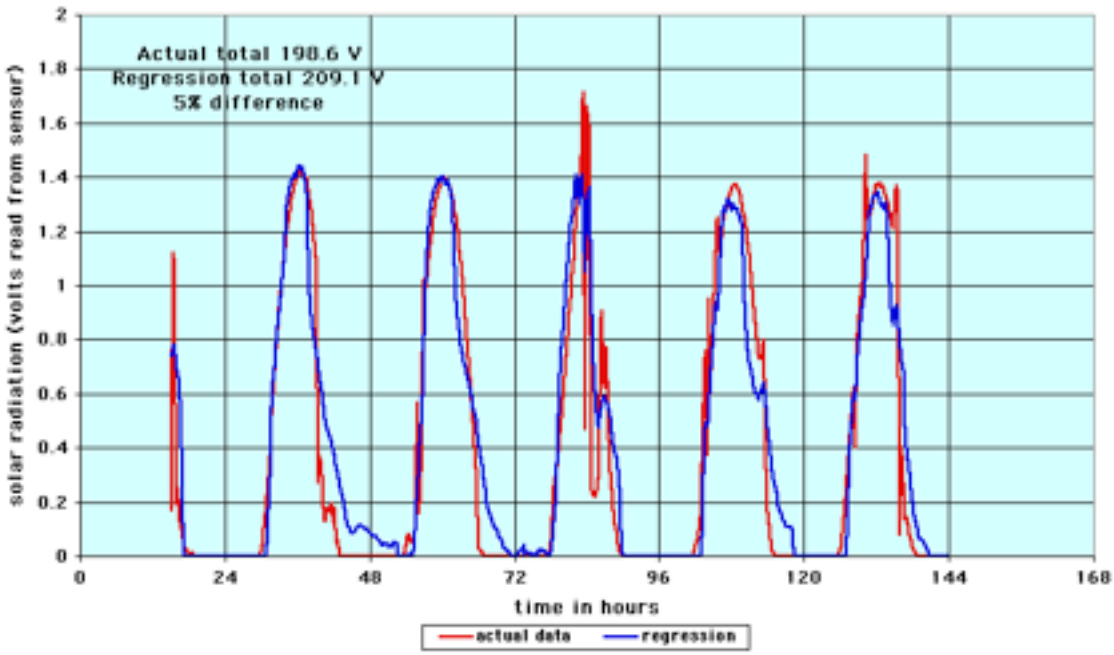



**Figure 2. Comparison of regression values and actual data for August 19-24, 2000**

**"Before" and "After" Weather and Building Data**

Figures 3 through 8 compare the outdoor temperature, outdoor humidity, wind speed, solar radiation, indoor temperature and building electrical use during the "before" and "after" weeks. These are the weather and operating conditions that most strongly influence the cooling energy use of the building.

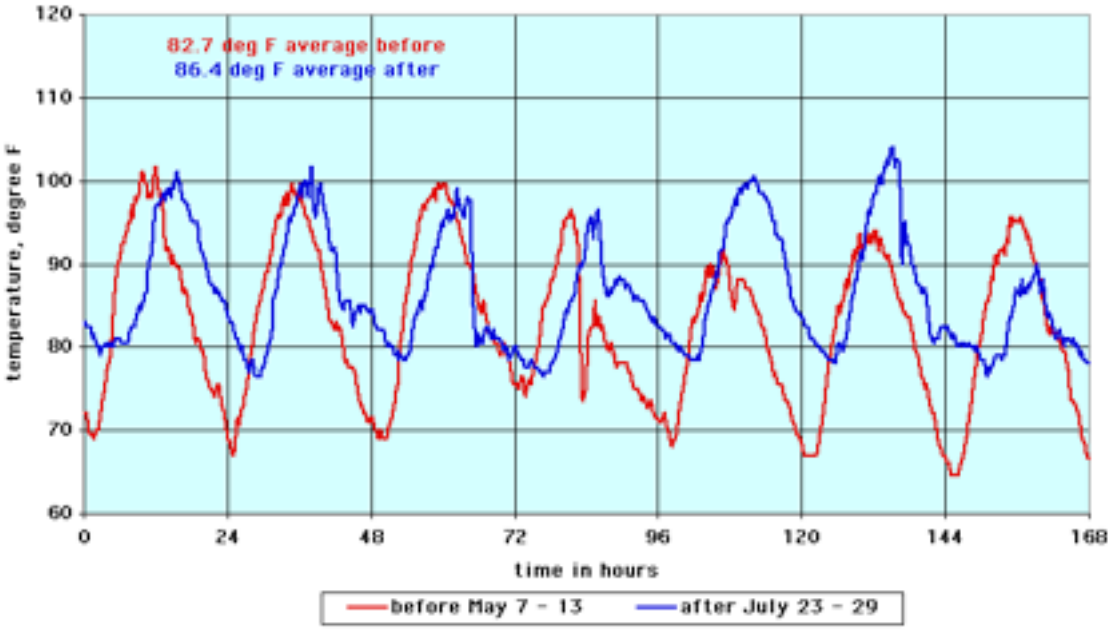



**Figure 3. Outdoor temperature before and after cool roof installation**

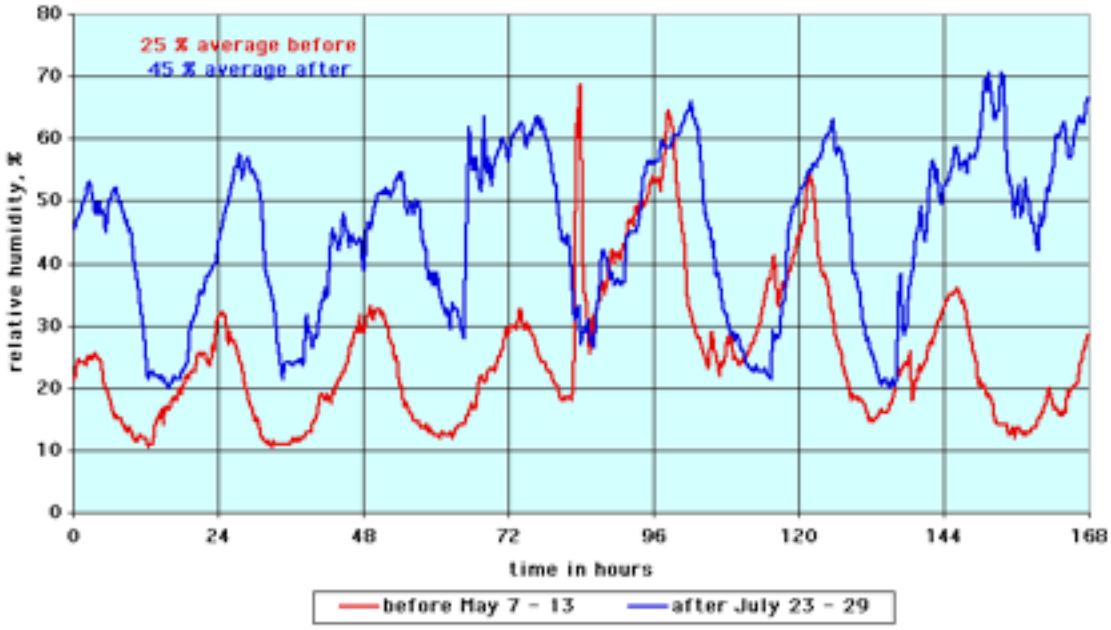



**Figure 4. Outdoor relative humidity before and after cool roof installation**

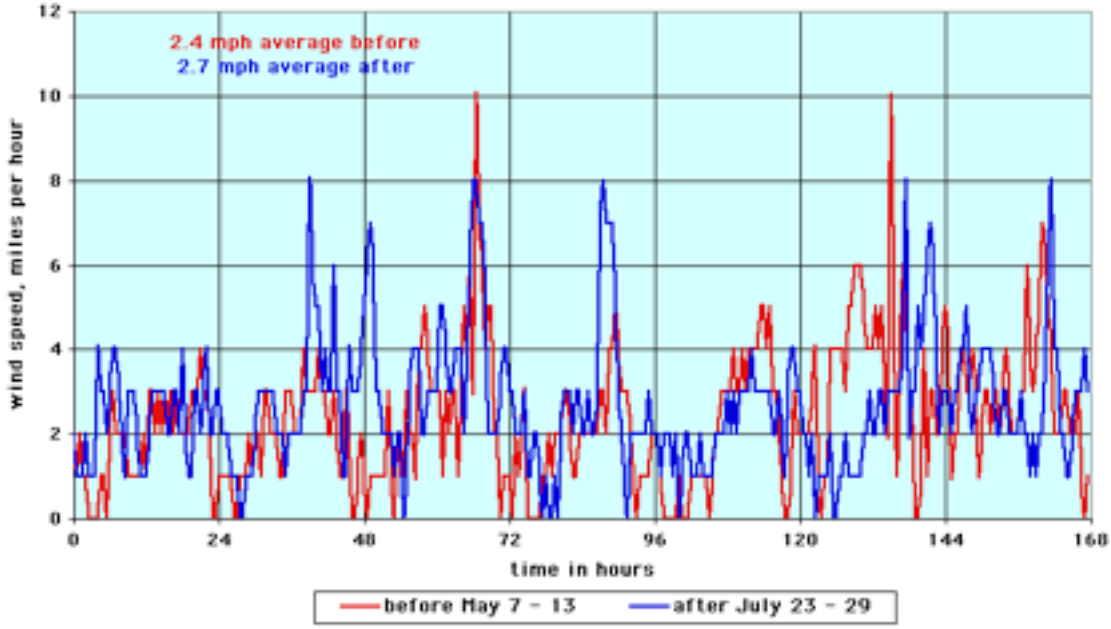



**Figure 5. Wind speed before and after cool roof installation**

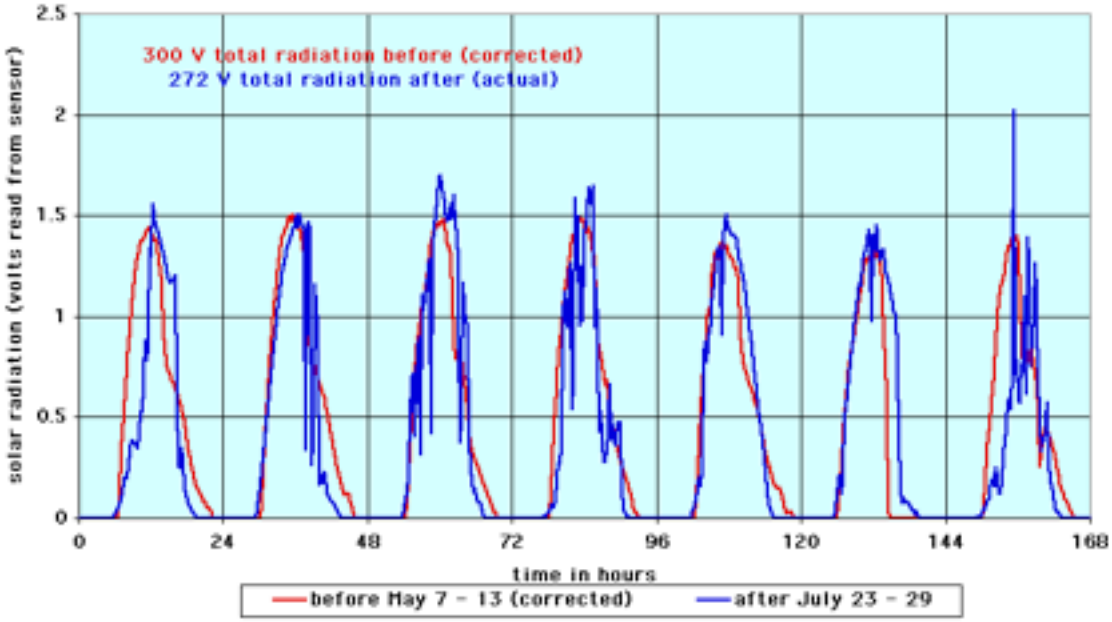



**Figure 6. Solar radiation before and after cool roof installation**

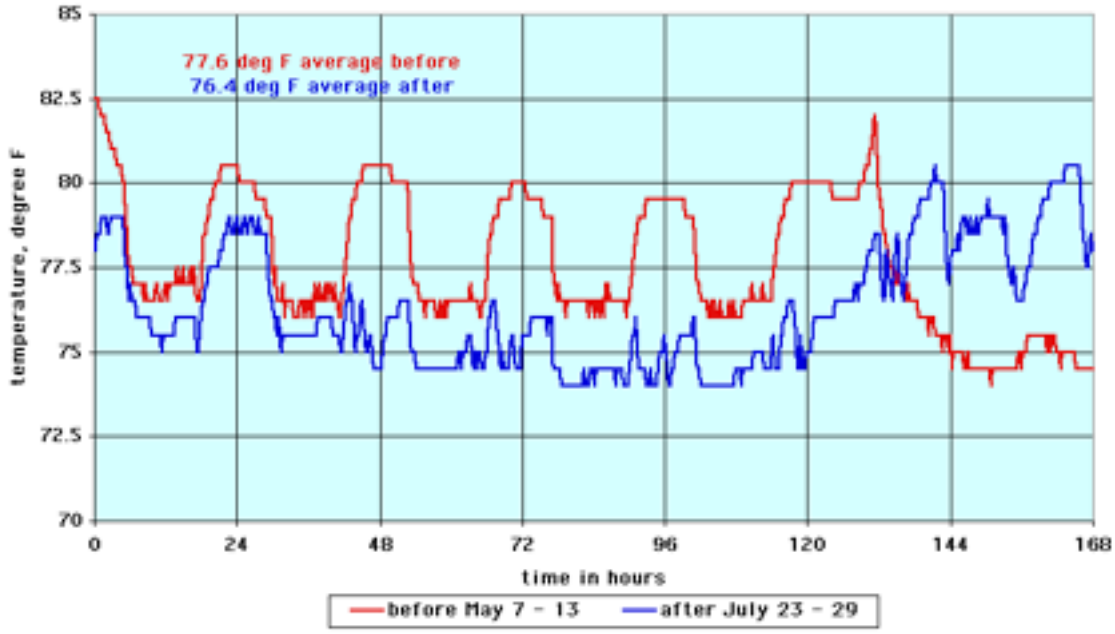



**Figure 7. Indoor air temperatures before and after cool roof installation, measured in an office cubicle**

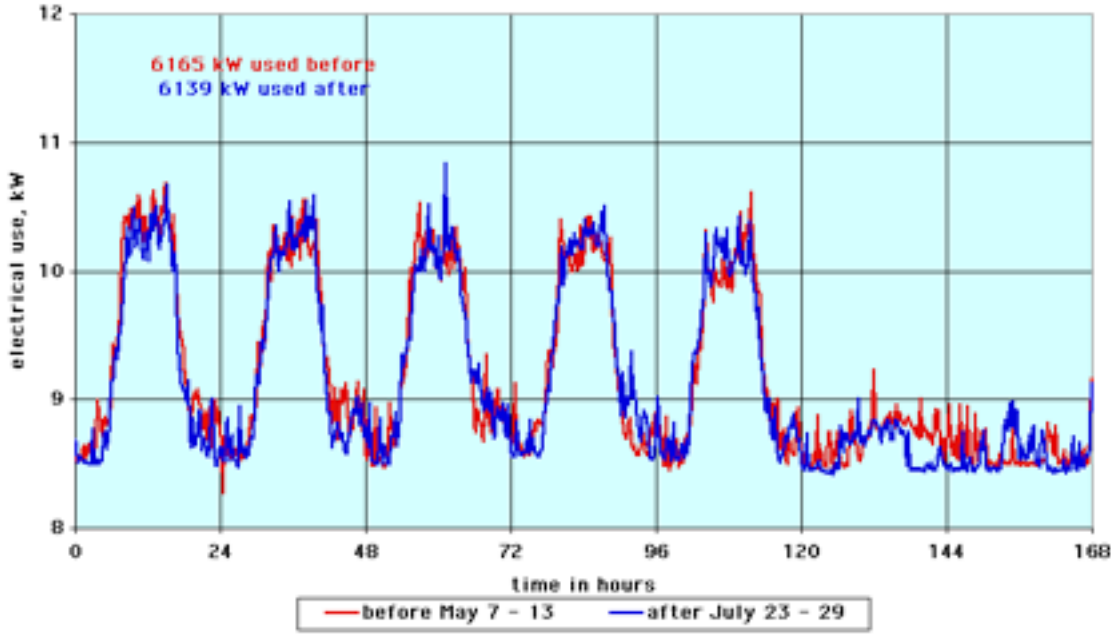



**Figure 8. Building electrical use before and after cool roof installation**

**(does not include HVAC energy use).**

Note that the building electrical use plotted in Figure 8 represents only the electrical energy drawn by three electrical panels that serve the lights and outlets in the building. All cooling energy use for the building was supplied via chilled water pipes running from a chiller in an adjacent building.

Table 3 summarizes the average weather and building conditions during the "before" and "after" weeks studied for this analysis.

**Table 3. Average weather & building conditions before and after cool roof installation**

| Variable | Before – May 7-13 | After – July 23-29 |
|---|---|---|
| Outdoor Temperature | 82.7 °F | 86.4 °F |
| Outdoor Relative Humidity | 25% | 45% |
| Wind Speed | 2.4 mph | 2.7 mph |
| Solar Radiation | 300 V * (corrected) | 272 V * (actual) |
| Indoor Temperature | 77.6 °F | 76.4 °F |
| Building Electrical Use | 6165 kW | 6139 kW |

* Units of total volts read by the pyranometer, not converted into an energy flux.

The weather conditions in the "after" week are somewhat more severe than the "before" conditions, with average outdoor temperature almost 4 °F hotter, 20% higher relative humidity, and 0.3 mph faster wind speed. Indoor conditions are over 1 °F cooler after the cool roof is added, while "after" building electrical use remains within 0.5% of its "before" value. More severe weather conditions and cooler indoor temperatures during the "after" period mean that the energy savings due to the cool roof will be under-predicted if based on a raw data analysis alone. To get a true energy savings, unbiased by varying weather or building use conditions, it is necessary to correct for these variations using correlations for roof surface temperature and energy use.

**"Before" Roof Surface Temperature Correlations**

In order to eliminate variations due to weather conditions and get a true temperature reduction due to the cool roof, a regression of surface temperature is derived. The "before" period data from May 7 through 13 is statistically analyzed. The resulting multiple linear regression equation for the surface temperature on the portion of the roof is:

$$Tmetal = 75.202 - 0.122556Tout + 58.761399Qsolar + 0.020878RH + 2.110335Wspeed,$$

**Equation (2)**

where Tmetal is in degrees Fahrenheit, Tout is the outdoor temperature in degrees Fahrenheit, Qsolar is the solar radiation in units of Volts measured directly by the pyranometer, RH is the outdoor relative humidity in percent, and Wspeed is the wind speed in miles per hour. The overall $R^2$ value for this correlation is 0.916, with t-statistics of 4.8, 0.7, 24.5, 0.2 and 4.2 on the constant, Tout, Qsolar, RH and Wspeed coefficients, respectively. Usually variables with

t-statistics below 1.0 are dropped from a regression equation as insignificant variables. They are kept here for consistency with the regression equation for the black roof surface (derived next), where the outdoor temperature and relative humidity variables are significant.

The multiple linear regression for the surface temperature on the black portion of the roof found from May 7 through 13 "before" data is:

$$Tblack = 18.125 + 0.509743Tout + 78.171259Qsolar + 0.146907RH + 0.509349Wspeed,$$

**Equation (3)**

where Tblack is in degrees Fahrenheit and all other variables are in the same units as in Equation (2). The $R^2$ value of this correlation is 0.950, and t- statistics for the variables are 1.0, 2.6, 29.6, 1.3 and 0.9 for the constant, Tout, Qsolar, RH and Wspeed, respectively. Figure 9 shows how well this regression correlation matches the actual "before" black and metal roof temperatures measured during the week of May 7through 13.

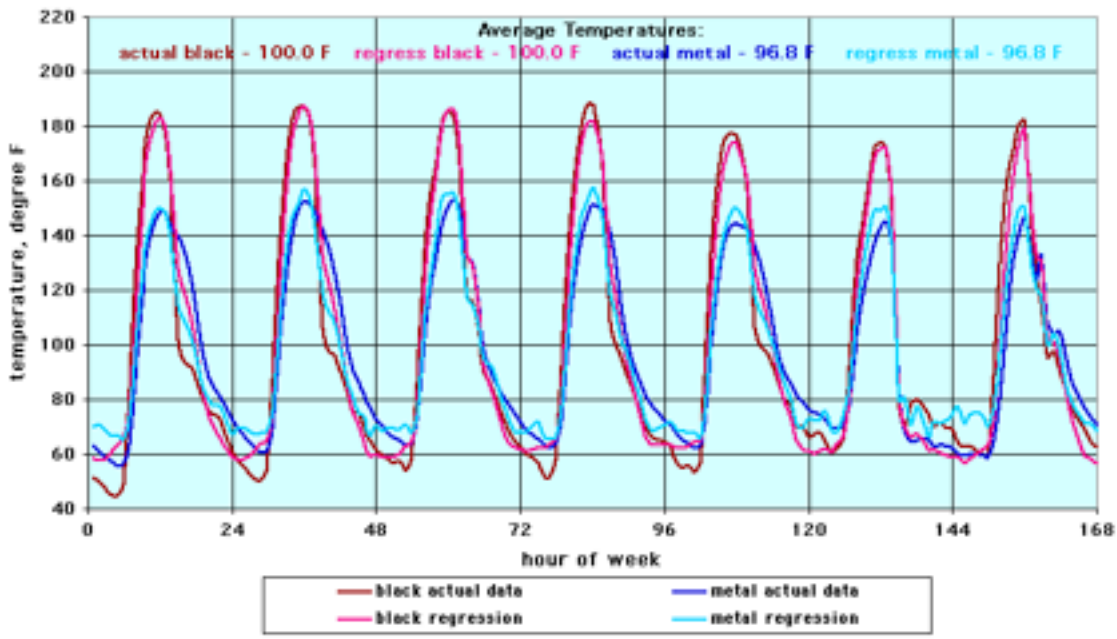



**Figure 9. Comparison of actual roof temperatures with regression results for "before" data during May 7 through 13, 2001.**

The correlations in Equations (2) and (3) are applied to the July 23 through 29 "after" data to find true, roof surface temperatures that would have existed during this period if the original roof were still in place.

**"Before" Cooling Energy Use Correlation**

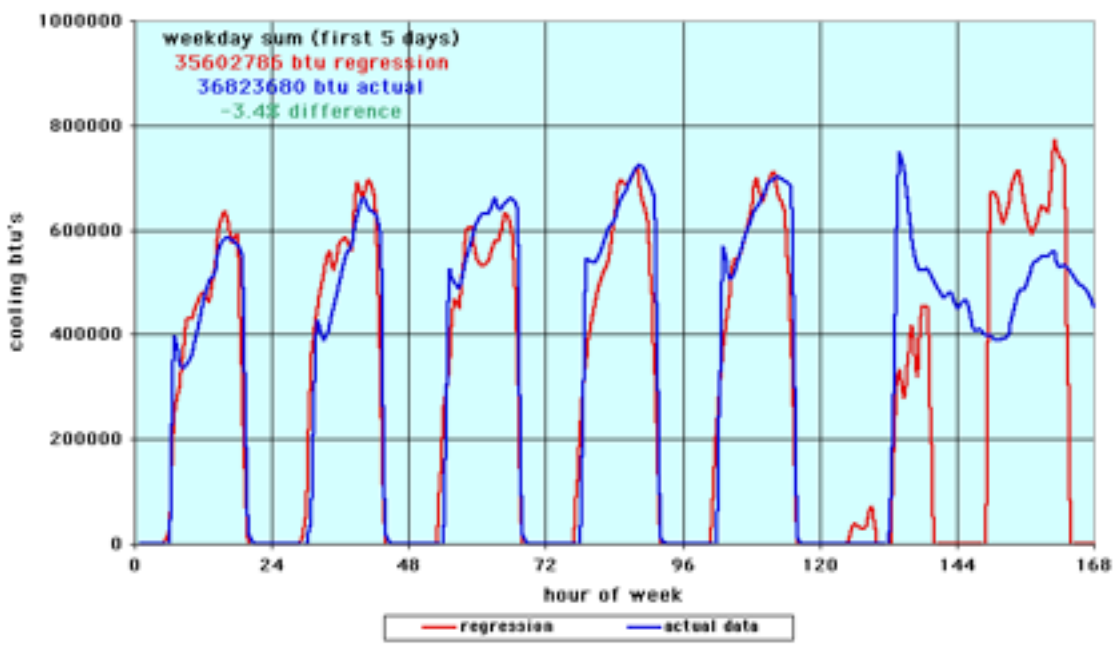
The May 7 through 13 "before" data was statistically analyzed to produce a multiple regression of the cooling energy use versus weather and building use variables. Since the cooling energy use data was only collected hourly, the rest of the data was first condensed into hourly values by

either averaging 15 minute readings (most variables) or 30 minute readings (wind speed). The weekend cooling energy use seemed to be on a different schedule from the weekday use, so the regression analysis only used weekday data. The resulting equation to estimate "before" cooling energy use characteristics is:

$$\text{Cooling} = 10705562 - 15115\ \text{Tout} - 4756\ \text{RH} - 157262\ \text{Qsolar} + 28671\ \text{Wspeed} - 131724\ \text{Tin} + 87828\ \text{Welec} + 4960\ \text{Tmetal} - 3048\ \text{Hour}, \quad \textbf{Equation (4)}$$

where Cooling is the cooling energy use in BTU, Tout is the outdoor temperature in degrees Fahrenheit, RH is the outdoor relative humidity in percent, Qsolar is the solar radiation in Volts measured by the pyranometer, Wspeed is the wind speed in miles per hour, Tin is the indoor temperature in degrees Fahrenheit, Welec is the building electricity use in kW, Tmetal is the surface temperature of the metal portion of the roof in degrees Fahrenheit, and Hour is an integer from 1 to 24 representing the hour of the day. The $R^2$ value of this correlation is 0.864, and the t-statistics of each variable are 6.6, 3.7, 2.6, 1.5, 2.8, 8.5, 1.5, 2.4 and 1.4 for the constant, Tout, RH, Qsolar, Wspeed, Tin, Welec, Tmetal and Hour, respectively. An additional assumption is made that the cooling system is turned off between the hours of 7 pm and 6 am. Figure 10 shows how well this regression correlation fits the actual "before" cooling energy use measured during May 7 through 13. Note that the correlation does not do such a great job of predicting the weekend energy use. This seems to be mostly due to this particular weekend's cooling energy use being on a different schedule than the weekday use, with the system turning on at around noon on Saturday and staying on for the rest of the weekend.

**Figure 10. Comparison of actual cooling energy use with regression results for**




**"before" data during May 7 through 13, 2001**

Equation (4) is used later with the July 23 through 29 data to estimate the cooling energy the original roof would have used under "after" weather and building conditions.

## Roof Surface Temperature and Energy Savings Results

### Raw Data Results

Figure 11 plots the actual measured roof temperatures during the "before" week of May 7 through 13, 2001 and the "after" week of July 23 through 29, 2001. Table 4 lists the peak and average roof surface temperatures measured during these weeks. Without correcting for any weather variations between these weeks, the surface temperatures show drops in temperatures of 70 °F and 35 °F at peak times and 13 °F averaged over the entire week.

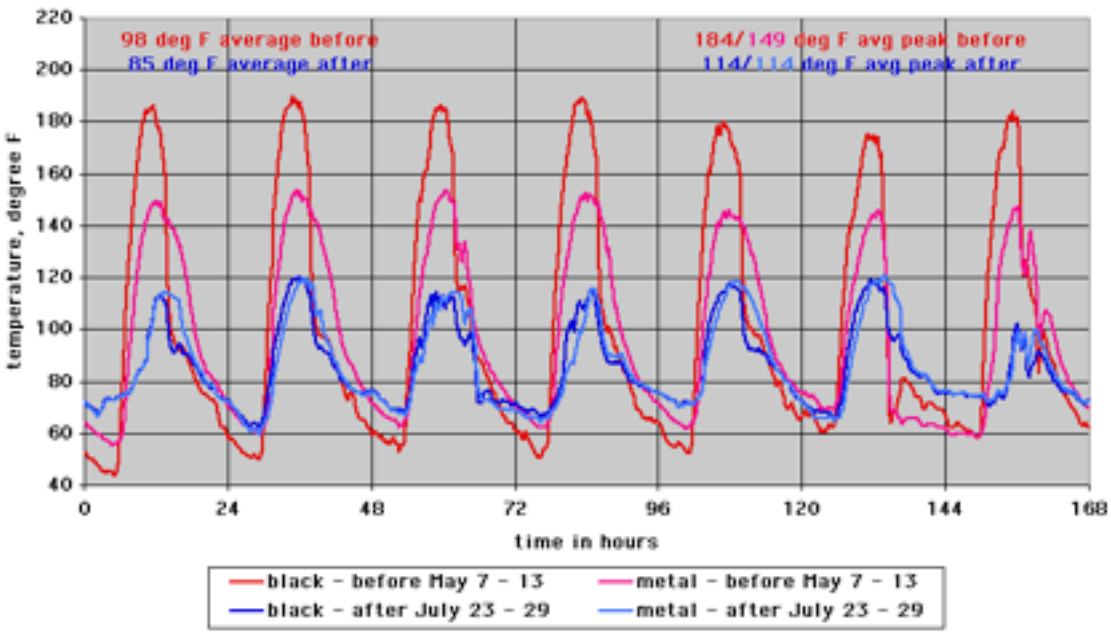



**Figure 11. Comparison of "raw" data roof surface temperatures measured during the "before" week of May 7-13, 2001 and the "after" week of July 23-29, 2001**

**Table 4. Hot and cool roof raw data roof surface temperature comparison**

| | Hot Roof Surface May 7-13, 2001 | Cool Roof Surface July 23-29, 2001 | Temperature Reduction |
|---|---|---|---|
| **Peak Temperatures** | | | |
| Black Roof | 184 °F | 114 °F | 70 °F |
| Metal Roof | 149 °F | 114 °F | 35 °F |
| **Avg. Temperatures** | | | |
| Black Roof | 98 °F | 85 °F | 13 °F |
| Metal Roof | 98 °F | 85 °F | 13 °F |

Figure 12 plots the raw data measurements of cooling energy use during the "before" week of May 7 through 13, 2001 and the "after" week of July 23 through 29, 2001, and Table 5 lists the actual cooling energy use and savings during these weeks. Without correcting for weather or operational variations, the actual savings over the weekdays was 48%, and over the entire week it was 61%.

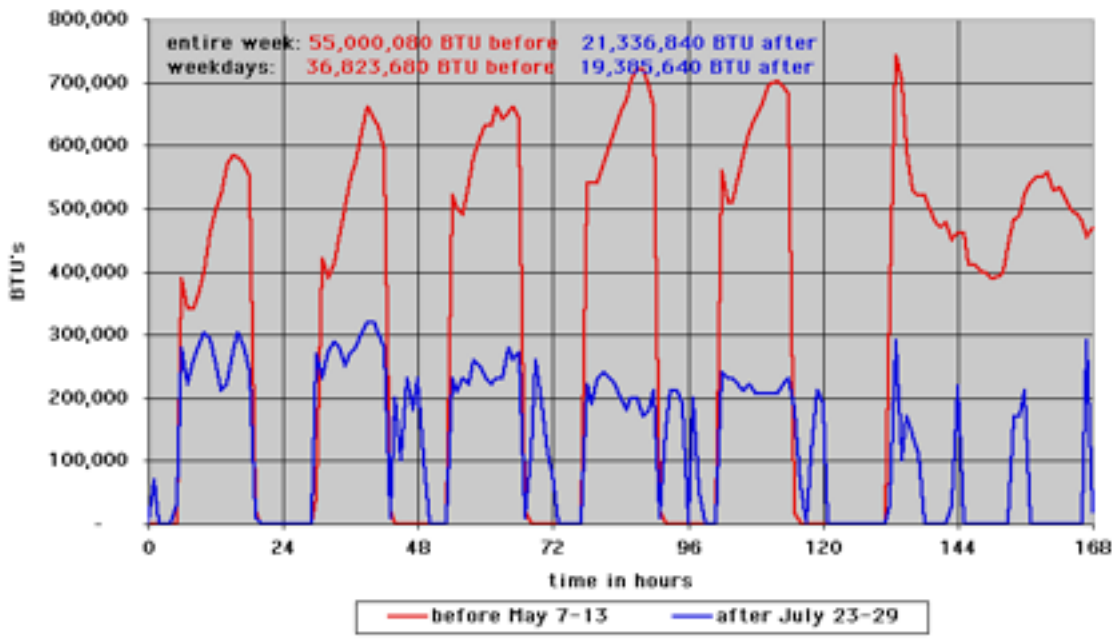



**Figure 12. Comparison of actual measured cooling energy use during the "before" week of May 7-13, 2001 and the "after" week of July 23-39, 2001**

**Table 5. Cooling energy use & savings during "before" week of May 7-13, 2001 and the "after" week of July 23-29, 2001**

| | **Entire week** | **Weekdays only** |
|---|---|---|
| **May 7-13, 2001** | 55,000,080 Btu | 36,823,680 Btu |
| **July 23-29, 2001** | 21,336,840 Btu | 19,385,640 Btu |
| **Savings** | 33,663,240 Btu | 17,438,040 Btu |
| **% savings** | 61.2% | 47.4% |

## Weather-Corrected Results

Figure 13 plots the actual measured surface temperatures on the cool roof together with the estimated hot roof temperatures based on the regression correlations of Equations (2) and (3) for the "after" week of July 23 through 29, 2001. Both the black and metal portions of the roof

showed significantly lower surface temperatures during daylight hours. Table 6 summarizes the peak and average temperatures during this week. The cool roof installation reduces the black portion of the roof's peak temperature by more than 70 degrees Fahrenheit, and the metal portion's temperature is reduced by over 40 degrees Fahrenheit.

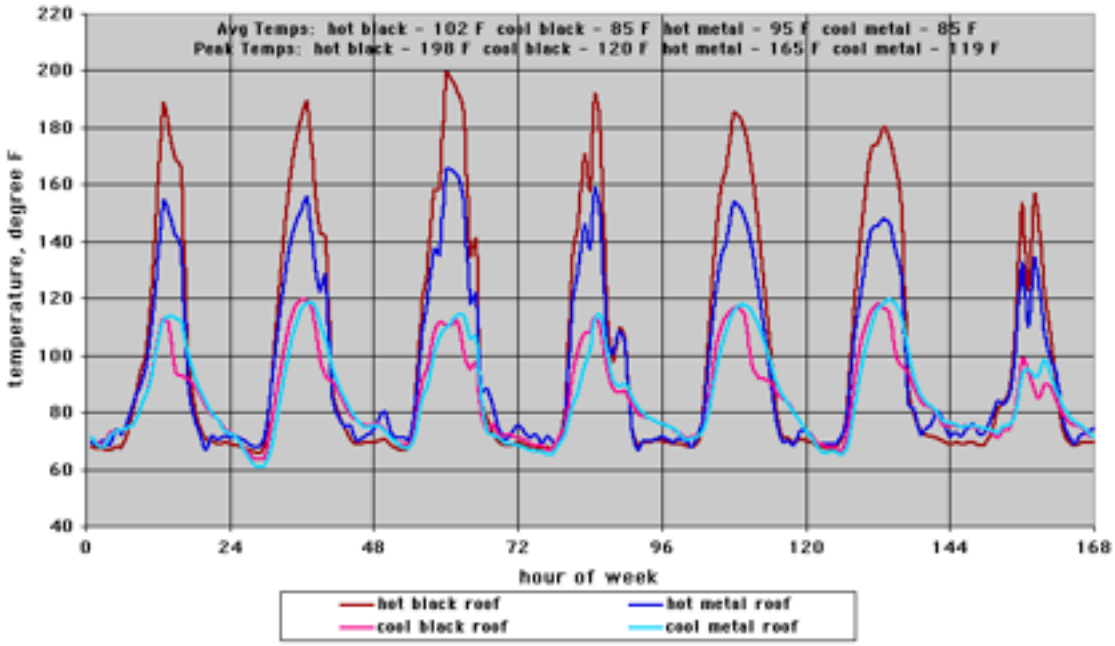



**Figure 13. Comparison of hot regressed & cool actual roof temperatures during the "after" week of July 23-29, 2001**

**Table 6. Hot & cool roof temperature comparison during "after" week of July 23-29, 2001**

| | Hot Roof Surface (Regressed values) | Cool Roof Surface (Actual values) | Temperature Reduction |
|---|---|---|---|
| **Peak Temperatures** | | | |
| Black Roof | 198 °F | 120 °F | 78 °F |
| Metal Roof | 165 °F | 119 °F | 46 °F |
| **Avg. Temperatures** | | | |
| Black Roof | 102 °F | 85 °F | 17 °F |
| Metal Roof | 95 °F | 85 °F | 10 °F |

Figure 14 compares the actual cool roof cooling energy use to the energy use predicted by the regression correlation of Equation (4) for the hot roof. Figure 14 sets the hot roof regression correlation to zero between the hours of 7 pm and 6 am, assuming that the cooling system was turned off at night.

The hot roof correlation of Equation (4) is not very accurate for weekend comparisons, so only the weekdays are compared (Monday through Friday are the first five days plotted in Figure 14). Table 7 lists the weekday cooling energy use and energy savings in the "after" week for

weekdays only. An impressive savings of 50% to 65% are realized during this week, assuming the cooling system is turned off at night.

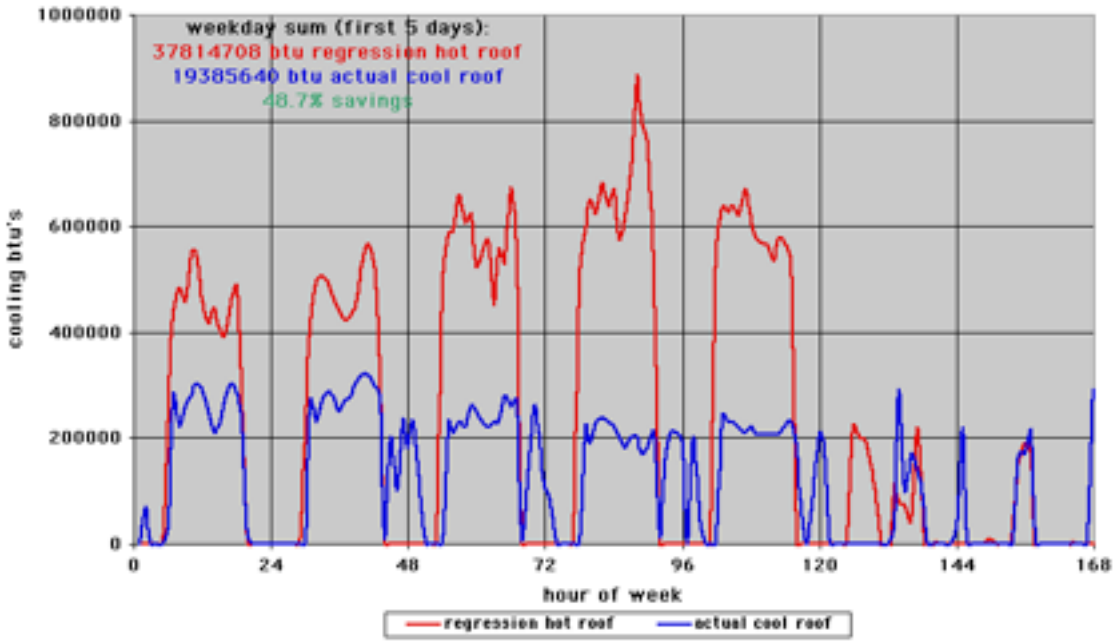



**Figure 14. Comparison of hot roof & cool roof cooling energy use, assuming cooling is turned OFF at night, during the "after" week of July 23-29, 2001**

**Table 7. Cool roof cooling energy use & savings during "after" week of July 23-29, 2001**

| *Weekdays only* | **OFF at night** | **ON at night** |
|---|---|---|
| **Hot roof cooling energy use (Regressed values)** | 37,814,708 Btu | 54,831,598 Btu |
| **Cool roof cooling energy use (Actual values)** | 19,385,640 Btu | 19,385,640 Btu |
| **Savings** | 18,429,068 Btu | 34,995,958 Btu |
| **% savings** | 48.7% | 64.6% |

**Effects of Insulation Versus the Cool Surface**

One questions that is frequently asked is how effective is a cool roof compared to roof insulation. The roof in this study already had a moderate R-11 level of insulation. How much energy would a cool roof have saved without this insulation, or with higher insulation levels? Some quick calculations are used to estimate these effects. The effective cooling load on the roof can be estimated by using the equation:

$$Q = (T_{roof\ surface} - T_{inside}) / \text{R-value} \qquad \textbf{Equation (5)}$$

The values of roof surface and inside temperatures from the "after" week of July 23 through 29, 2001, are used to estimate roof cooling loads with the actual ~R-11 insulation level and with higher levels, all both with and without a cool surface. Table 8 shows these calculations at both peak conditions and average conditions. Surface temperatures in Table 8 were estimated by assuming that 1/8 of the total roof surface is covered black roof material and 7/8 is covered with metallic surface material. At peak conditions the average roof temperature is then (198)(1/8) + (165)(7/8) = 170 °F, and at average conditions the roof temperature is (102)(1/8) + (95)(7/8) = 96 °F.

From examination of Table 8, it is clear that adding a cool surface is on par with adding more insulation in the roof. Further reductions in cooling load could have been made by adding more insulation to the building, although an analysis should first be done to justify costs.

**Table 8. Calculation of roof cooling loads and savings due to adding insulation and a cool surface, for July 23 through 39, 2001 conditions**

| | **Surface T** °F | **Inside T** °F | **R-value** hr-ft$^2$-F/Btu | **Q** | **% reduction from base** |
|---|---|---|---|---|---|
| **Peak Conditions** | | | | | |
| Original roof | 170 | 76.4 | 11 | 8.5 | --- |
| More insulation | 170 | 76.4 | 19 / 30 | 4.9 / 3.1 | 42 / 64% |
| Cool surface | 119 | 76.4 | 11 | 3.8 | 55% |
| Both | 119 | 76.4 | 19 / 30 | 2.2 / 1.4 | 74 / 83% |
| **Avg Conditions** | | | | | |
| Original roof | 96 | 76.4 | 11 | 1.8 | --- |
| More insulation | 96 | 76.4 | 19 / 30 | 1.0 / 0.65 | 44 / 64% |
| Cool surface | 85 | 76.4 | 11 | 0.78 | 57% |
| Both | 85 | 76.4 | 19 / 30 | 0.45 / 0.29 | 75 / 84% |

## Conclusions

The cool roof installation has been a very successful energy savings measure, with savings of between 50 and 65% of the building cooling energy depending on how the building is operated after normal working hours. These savings are even more impressive when realizing that this roof has a moderate level of insulation (around R-11).

It is clear that this building's cooling energy use was previously dominated by the heat being absorbed by the roof. The reasons for this can be found by examining the building. The roof comprises 75 to 80% of the building's surface area and is not shaded by any surrounding trees or buildings. The outside walls and windows are protected from solar radiation by wide overhangs. So the external cooling loads on this building are clearly dominated by the roof. Internal cooling loads appear to have already been minimized with efficient lighting systems and good energy management practices.

It is highly recommended that other buildings owned and operated by the City of Tucson also have cool roofs installed during their next roof overhaul. Consideration should also be given to the cost effectiveness of adding some type of insulation under the cool roof material (either a spray polyurethane foam or some type of rigid insulation) to uninsulated roofs. This would provide the combined benefits of reducing both the energy absorbed from the sun and the heat conducted through the roof.