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ABSTRACT

A 2-year Florida study attempted to quantify air conditioning cost savings when buildings have a white reflective roof. A 10,000 square foot elementary school with a gray modified bitumen roof over plywood decking that had a solar reflectance of 23 percent was monitored for an entire year. After one year of building thermal conditions and electrical demand monitoring, the roof was covered with an acrylic white elastomeric coating that achieved a solar reflectance of 68 percent. Data show that classroom air temperatures were significantly lower during the second year of the study compared to the first. Additionally, chiller electric power use was reduced by an average of 10 percent, totaling 13,000 kWh in annual savings. However, peak electrical demand was much more strongly impacted than energy. Daily average annual demand reductions of 1.5 kW were observed during school hours. Confining the analysis to weekdays and during the summer greatly magnified differences. School staff also noted interior comfort conditions were noticeably improved by the white roofing system. (Contains 16 references, 7 figures, and 2 tables.) (GR)

DEMONSTRATION OF COOLING SAVINGS OF LIGHT COLORED ROOF SURFACING IN FLORIDA COMMERCIAL BUILDINGS: OUR SAVIOR'S SCHOOL

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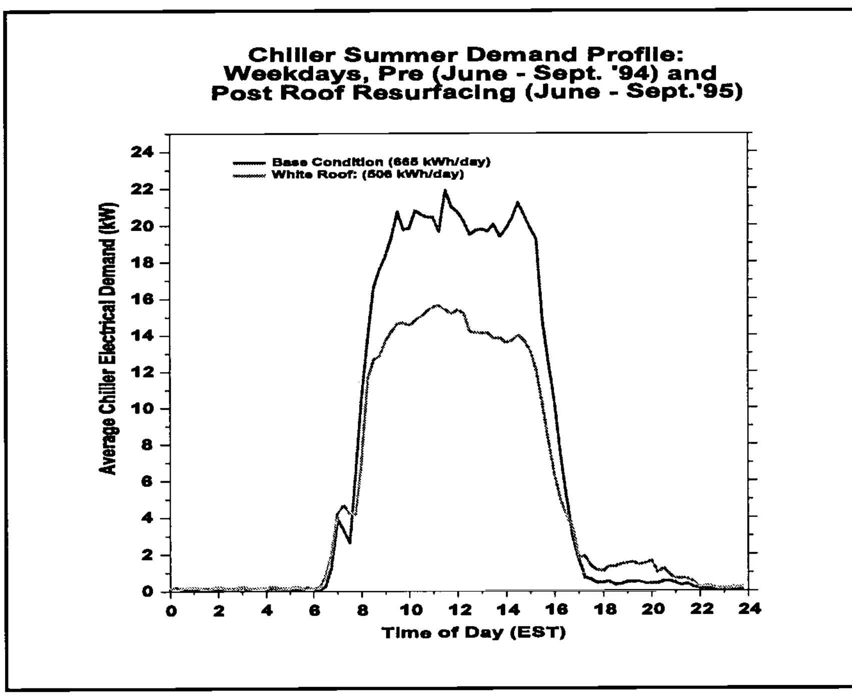
Executive Summary

Architects and designers have long known that light-colored building roofs can reduce cooling needs. Recently, monitoring studies in Florida have made an effort to quantify these savings. Experiments in existing residences have shown that a white reflective roof can reduce cooling requirements by an average of 20%. However, until now there has been no investigation in Florida's climate to examine the potential in commercial scale buildings.

To remedy this need, a two year study was performed on a private elementary school building in Cocoa Beach, Florida. *Our Savior's Elementary School* was monitored for an entire year in a base line condition beginning in May 1994. Detailed 15-minute data was obtained on building thermal conditions, weather and chiller and air handler electrical demand.

The 10,000 square foot facility had a gray modified bitumen roof over plywood decking with a measured solar reflectance of 23%. The dropped ceiling above the classrooms was insulated with R-19 fiberglass batts, although the insulated chilled water lines were located in the hot roof plenum space. In May, of 1995 the roof of the facility was covered with an acrylic white elastomeric coating. The measured solar reflectance after the third application was 68%; measured after one year of exposure the solar reflectance had only diminished to 63%.



Data analysis of the year pre and post the roof resurfacing revealed that the roof sur-face, roof plenum and class-room air temperatures were significantly lower during the second year of moni-toring. In addition, chiller electric power use was re-duced by an average of 10% from one year to the next, totaling 13,000 kWh in annual savings. However, peak electrical demand was much more strongly impacted than energy. Daily average annual demand re-ductions of 1.5 kW were observed between 9 AM and 4 PM on an annual basis. Confining the analysis to weekdays and during the summer greatly magnified observed differences (see E-1 above). Summer weekday utility peak coincident electrical demand of the cooling system between June and September from 3 - 4 PM EST was lowered by 5.6 kW -- a 35% reduction over the previous year.

Beyond the cooling energy and demand savings, the school staff noted that interior comfort conditions were noticeably improved by the white roofing system. Based on these initial results, we conclude that reflective roofing shows considerable promise for peak demand and energy savings in Florida's school buildings.

DEMONSTRATION OF COOLING SAVINGS OF LIGHT COLORED ROOF SURFACING IN FLORIDA COMMERCIAL BUILDINGS: OUR SAVIOR'S SCHOOL

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1. Introduction

Traditionally architects in hot climates have recognized that reflective roof colors can reduce building cooling loads (Lee, 1963; Givoni, 1976). Experimentation spanning nearly three decades has shown that white roofing surfaces can signicantly reduce surface temperatures and cooling loads (Givoni and Hoffmann, 1968; Reagan and Acklam, 1979; Griggs and Shipp, 1988; Anderson, 1989; Anderson et al., 1991 and Bansal et al., 1992). A recent report by the U.S. Environmental Protection Agency (EPA) has suggested that reflective surfaces and landscaping has significant potential to reduce building cooling energy needs (Akbari et al., 1992). Most importantly, measured cooling energy savings of white surfaces have been significant in California's climate (Akbari, 1992b).

In Florida, field research by the Florida Solar Energy Center (FSEC) over the last three years has quantified the impact of reflective roof coatings on sub-metered air conditioning (AC) consumption in tests in nine occupied homes (Parker et al., 1993; 1994; 1995). The coatings were applied to the roofs of each home in mid-summer after a month-long period of monitoring during which meteorological conditions, building temperatures and AC energy use were recorded every 15 minutes.

Data analysis revealed significant reductions in space cooling energy at all sites. Using weather periods with similar temperatures and solar insolation, air conditioning energy use was reduced by 2% - 43% in the homes. The average drop in space cooling energy use was about 7.4 kWh/day or 19% of the pre-application air conditioning consumption. Utility coincident peak electrical demand reduction between 5 and 6 PM varied between 201 and 988 W (12% - 38%), averaging 427 W or 22%. The recorded load profiles showed that the energy use reduction occurred primarily during daytime hours between 10 AM and 8 PM. Recorded temperatures and infrared thermography revealed very large changes to the roof-attic thermal performance in each building.

Unfortunately, there has been no objective testing of the impact of roof whitening on the AC load of commercial buildings in Florida. This has remained a gap in knowledge of the technology's potential. With the sponsorship of the U.S. Environmental Protection Agency and Florida utilities this study has begun to examine the magnitude of energy savings in Florida commercial buildings.

2. Description of Test Site

The building chosen for the first demonstration was a elementary school (Figure 1). *Our Savior's* is a private Catholic school built in the 1960's consisting of grades one through eight, with a student body of approximately 160 and faculty of 15. The building is a rectangular 10,000 ft^2 structure (63.5 x 158 ft) with four identical classrooms on the north and south separated by a 12 foot central hallway. The building's major axis runs east-west; a wide six foot overhang protect the classroom windows from direct sun. Each of the eight identical classrooms has a set of controls for the chilled water cooling system. However, the influence of the central hallway (see Figure 2) was judged potentially significant at the outset of the project due to several reasons:

- The roof/ceiling of the hallway is uninsulated
- During the school day the conditioned classrooms are typically open to the unconditioned hallway
- The unconditioned hallway is often left open to the outdoors from double glass doors on the west side of the building

The 12,000 square feet pitched roof has a gray modified bitumen roll roofing. The building initially contained no insulation, but was retrofitted with a dropped ceiling and R-19 when a cooling system was added in 1982.

As shown in Figure 3, the building has two 20-ton air-cooled *Carrier 30GB040510* liquid chillers which are mounted in tandem on the west side of the building. The full load EER of the unit is 10.5 Btu/w; the seasonal IPLV value is 13.1 Btu/w. The chilled water is circulated by a 1.5 horsepower electric pump (*Marathon NVF 145TTDR7029ED*, 1745 rpm, 4.8 amps at full load). On inspection, typical operating conditions showed a chiller leaving water temperature of 52°F with a return water temperature of 66°F. The chilled water lines are insulated with approximately R-5 insulation, but pass through the building roof plenum prior to dropping down to individual ceiling mounted air handlers in the classrooms (See Figure 4). One anticipated result of the roof whitening was that loads attributable to heat transfer to the chilled water lines in the attic space might be significantly reduced.

The energy consumption of the facility reflects its annual schedule. School is in session from the last week in August through the first week in June. However, teacher in-service days fill much of the calendar in August and although the cooling system is not normally used during the summer period, it is often activated for cleaning or other maintenance related activities. The school week is a typical Monday - Friday schedule, although some weekend activities occur during the school year. There are 182 school days per year although there are approximately eight teacher workdays in which the building is conditioned and a similar number of evenings in which PTO meetings are held. Also, there are another six days in which weekend functions are prominent.

3. Monitoring Protocol and Instrumentation

Instrumentation was installed in the school to collect data pertaining to the potential energy savings from the reflective roofing system. Instrumentation for this site was completed in April 1994. Figure 5 shows the current transducers being installed on the cooling system chiller; Figure 6 shows the project data logger being wired to collect the necessary data.

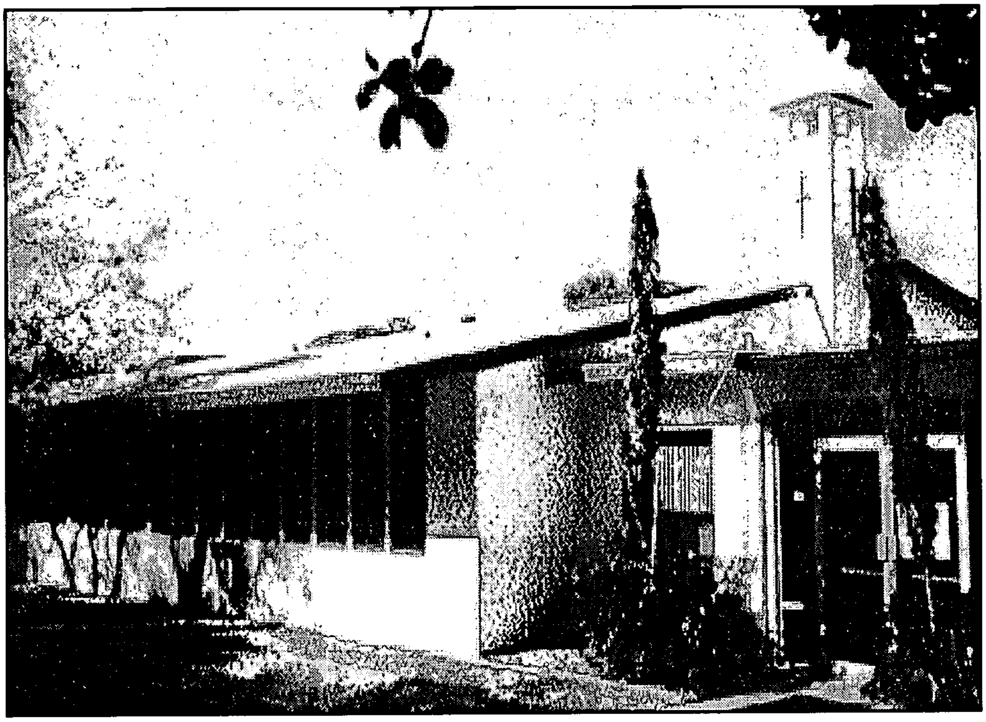

Figure 1. Our Savior's Elementary School in Cocoa Beach, Florida.

Figure 2. Central unconditioned hallway.

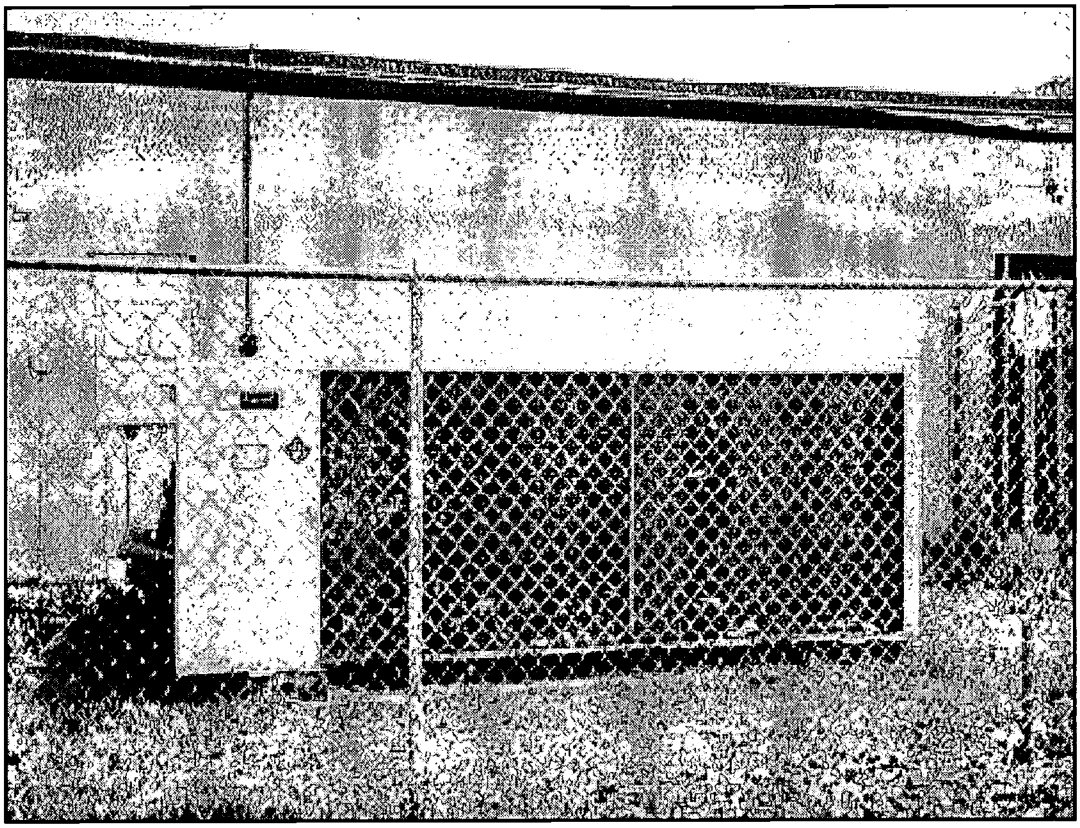

Figure 3. Forty-ton air cooled liquid chiller.

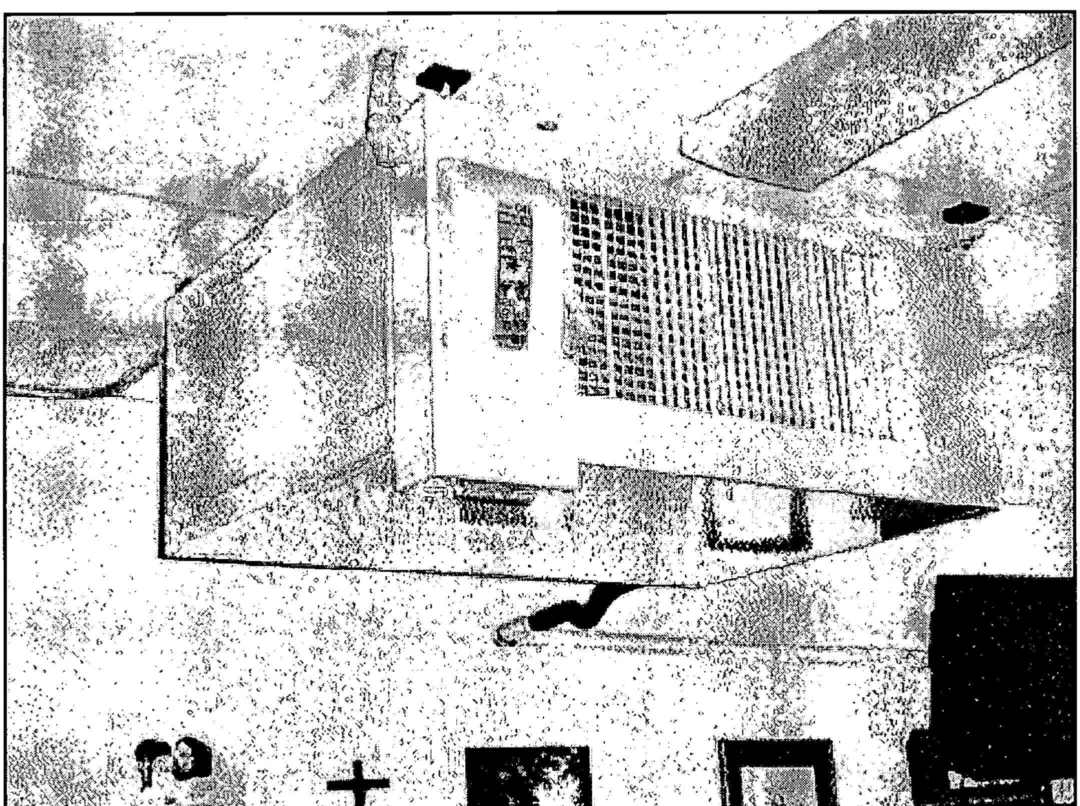

Figure 4. Ceiling mounted classroom air handler. Above acoustic tiles is R-19 insulation. Chilled water lines are located in roof plenum above insulation.

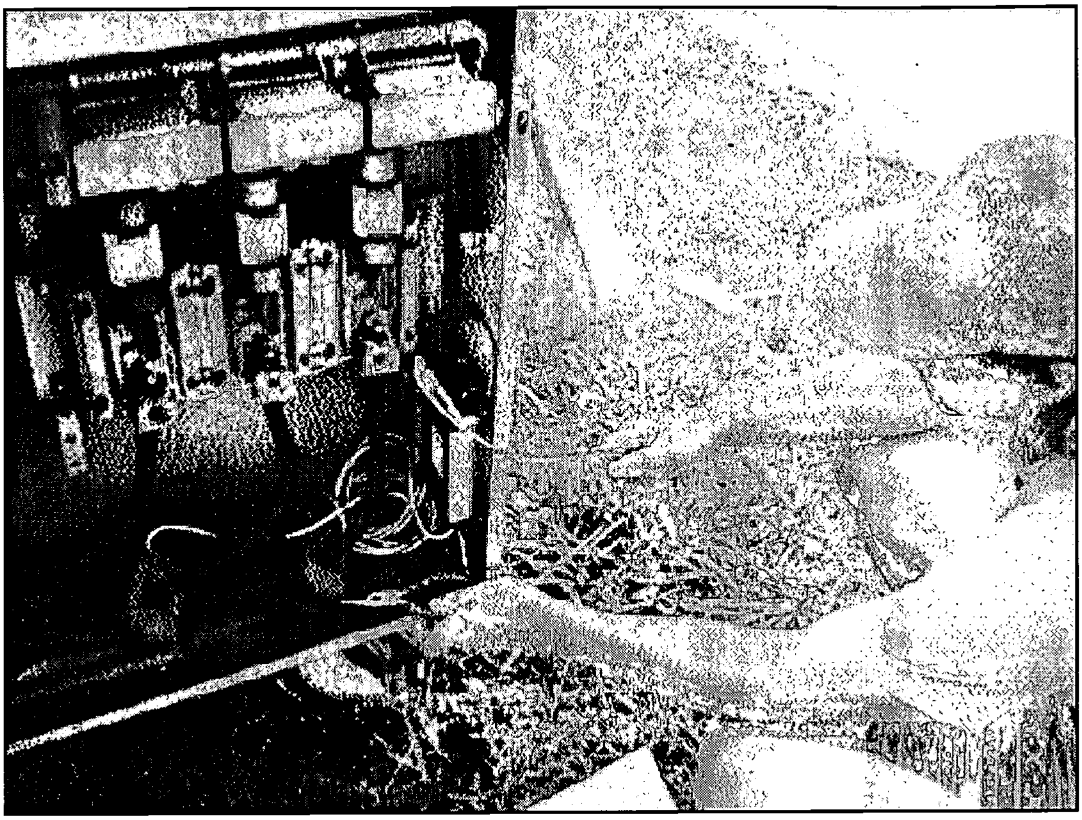

Figure 5. Stephen Barkaszi installs watt-hour transducers on the facility chiller to record electrical consumption.

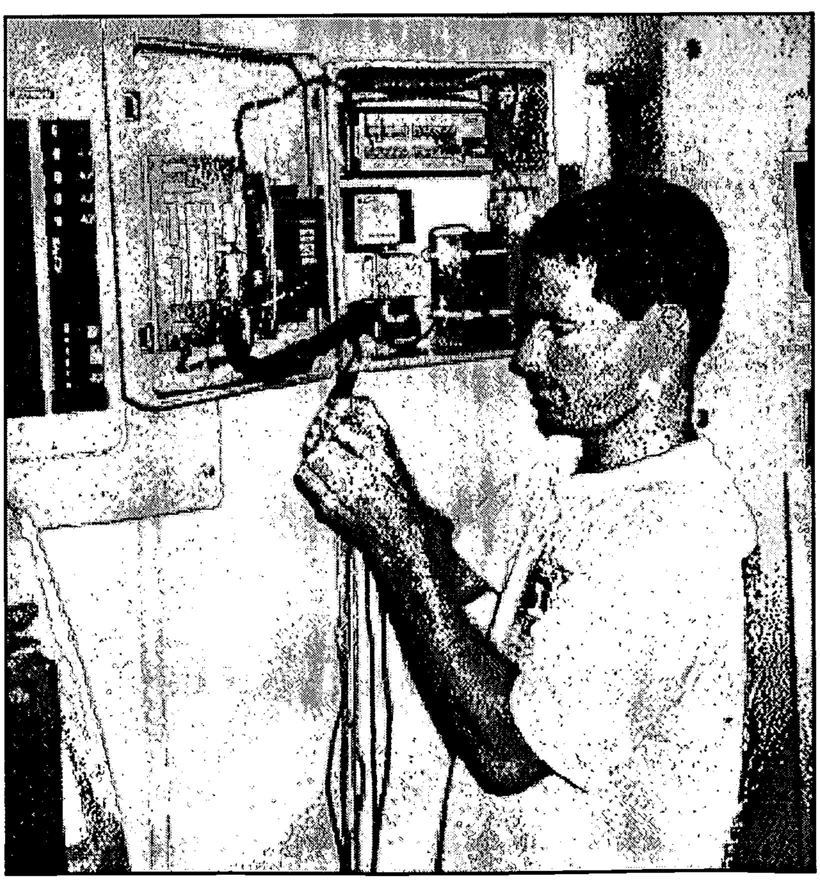

Figure 6. John Sherwin wires in data logger to collect 15-minute data on weather, building thermal conditions, and cooling system electric power.

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Meteorological conditions monitored at each site were: ambient temperature, relative humidity, and insolation. Temperature readings were obtained for the roof surface, decking underside surface, attic air, and interior air. Interior relative humidity was measured to investigate the effects of sensible heat reduction on measured classroom relative humidity. The amount of power consumed by the air conditioning chiller and various classroom air handlers was monitored to determine the electrical demand. Table 1 lists the measurements taken:

Table 1
Site Data Collection Parameters

Parameter	Units
Meteorological Conditions	
Ambient air temperature	°F
Relative humidity	%
Insolation	W/m^2
Building Conditions	
Roof surface temperature (North/South)	°F
Roof decking underside temperature	°F
Attic air temperature	°F
Unconditioned hallway air temperature	°F
Conditioned air temperature (Eight classrooms)	°F
Interior relative humidity (North/South)	%
Cooling System Power Consumption	
Chiller electrical demand	W-hrs
Air handler electrical demand (8 air handlers)	W-hrs

Temperature measurements were obtained using calibrated, type-T, copper-constantan thermocouple wire installed at various points in the building. The ambient air and roof surface temperature measurement is illustrated in Figure 7 and Figure 8. The ambient air sensor was shielded from direct radiation by a vented enclosure. Capacitive-type humidity transmitters provided temperature compensated RH readings. Insolation was measured using a horizontally mounted silicon-cell pyranometer located on the rooftop. Electrical power consumption was assessed by 50 and 200-amp pulse-initiating power transducers.

The instruments were calibrated in accordance with procedures established by Hurley (1986). Thermocouples were calibrated against NIST traceable thermometers and the humidity transmitters against a *General Eastern Hygro-M1* chilled-mirror hygrometer. Insolation values obtained using the pyranometer were compared to those of a *Eppley Precision Spectral Pyranometer* (PSP). The power meters were factory calibrated and checked against a *Magtrol 4260 Power Analyzer.*

A *Campbell Scientific Model CR10* data logger was used to convert the analog and pulse instrument outputs to digital format. Instrument data were read at 10 second intervals and integrated or totalized values were recorded by the data logger every 15 minutes. Data were transferred from the data loggers via telephone modems to the mainframe computer each evening. The data are then automatically plotted to summarize the daily performance parameters measured at each site. Such plots are then examined by the project engineer the

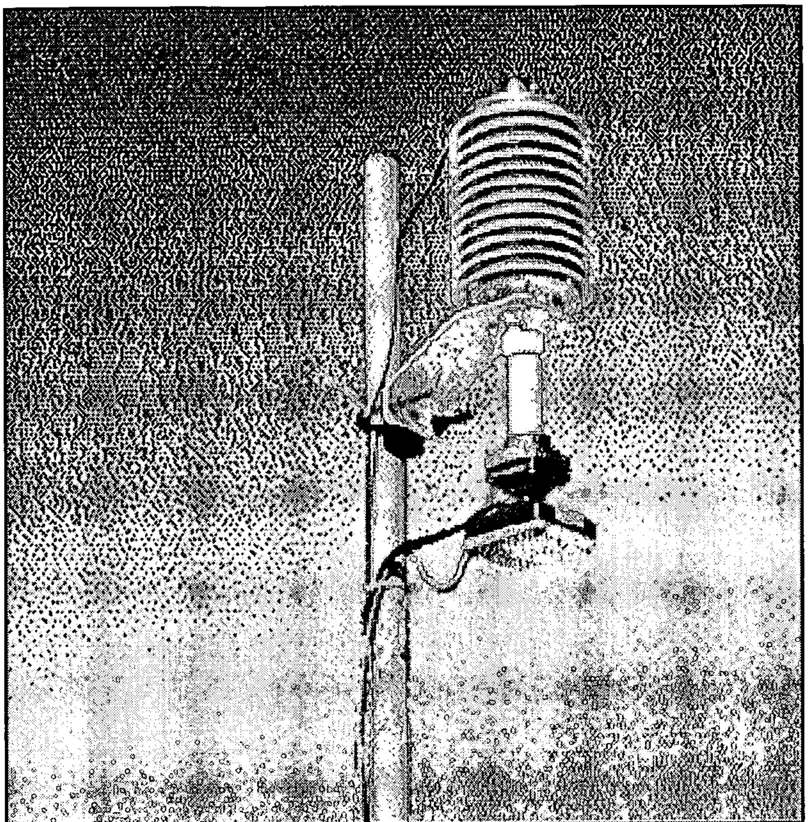

Figure 7. Ambient and relative humidity air temperature measurement configuration; silicon cell pyranometer is mounted on top.

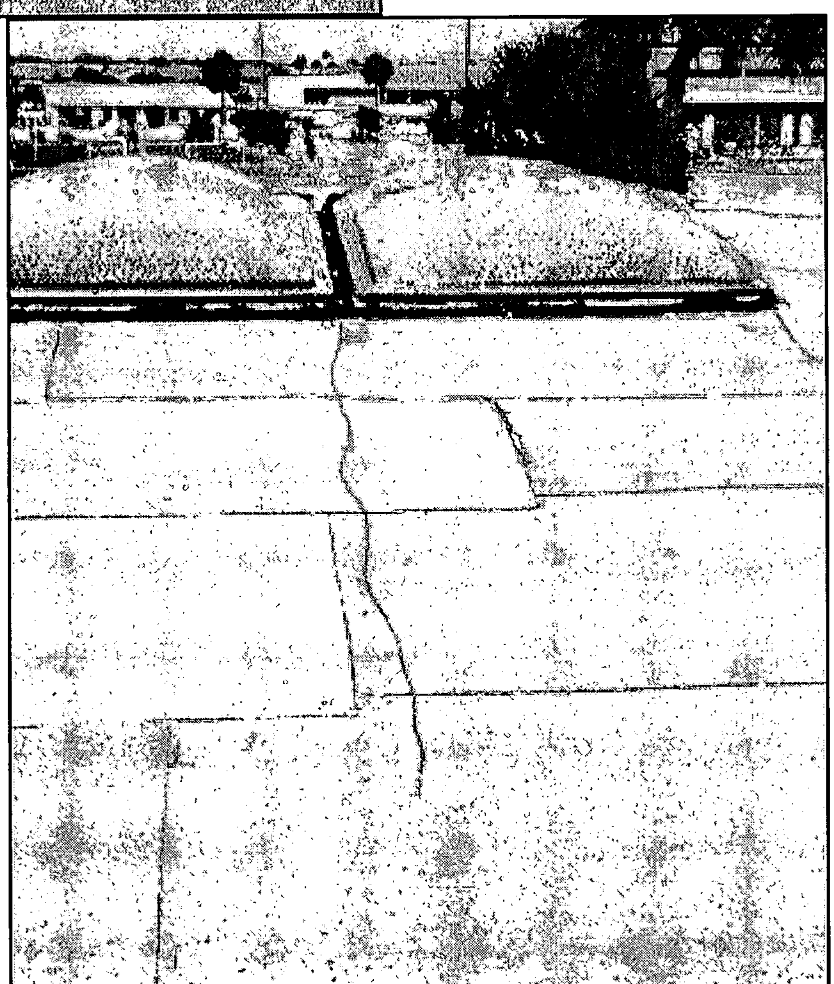

Figure 8. Roof surface temperature thermocouple on modified bitumen surface. Other thermocouples below measure decking and roof plenum space temperatures.

following morning to insure reliable data collection. An example of daily plots is shown in Figures 9 and 10 during the period before and after the roof coating was installed. A single plot summarizes the daily weather conditions, another plot describes the air conditioning demand and interior comfort conditions and a third graphic illustrates the roof-attic temperature profiles. The two plots show that the cooling system often operates at full load and that very high temperature levels are experienced above the ceiling.

4. Albedo Measurements

Roof reflectivity measurements used methods developed by previous investigators (Reagan and Aklam, 1979 and Taha et al., 1992). The measurements were made with an *Eppley Precision Spectral Pyranometer* (PSP) that is sensitive to radiant energy in the 0.28-2.8 nanometer range. The pyranometer has an out output of 8.65 x 10^{-6} volts per W/m^2. The double-dome design of the PSP mitigates the effects of internal convection resulting from tilting the pyranometer at different angles. The PSP is alternately faced up and down to gauge the amount of radiation being reflected from the roof surface. The output of the PSP was recorded on a *Fluke 77 Multimeter* over a period of approximately 30 seconds. The ratio of the reflected flux measurement to that of the incident solar reading was taken as the reflectivity of the surface.

To perform the tests, the PSP was extended on a six foot boom and held above the measured roof section as shown by the apparatus depicted in Figure 11. Theoretically, the resulting shadows from the apparatus will somewhat bias the measured albedo. However, based on other research (Lapujade, 1994), we expected these effects to be minimal. In accordance with the LBL work, we chose a 1.5 foot height for the flux measurements so that the PSP's view factor of the roof was maximized, while minimizing the impact of shadowing. The test points were taken within one hour of noon under clear sky conditions in which the pyranometer was alternately faced upward toward the sun, and downwards towards the roof surface. Six measurement locations were tested on the roof of each of the sites with three repetitions made at each measurement point. The resulting data were then averaged into a single calculated albedo for the roof surface.

Measured roof reflectivity at the school was changed from 0.229 ($\pm$0.004) to 0.668 ($\pm$0.054) as measured before and after the coating. These values represent the averages of 12 repetitions of these measurements across the surface of the roof. The results were very uniform, with a fairly homogenous roof albedo across the entire surface; the albedo measurements before the roof was coated only varied from 0.227 to 0.231 over the range of the repeated measurements. The roof reflectivity was reassessed after one year of exposure on June 20th. The reflectivity was found to be 0.627 ($\pm$0.052) -- a decrease in reflectivity of 4.4%. This level of degradation is consistent with previous studies (Bretz and Akbari, 1993; Byerley and Christian, 1994; Parker et. al., 1995).

5. Roof Resurfacing

The roof coating was applied after a full year of pre-coating data had been collected. The first coat was applied on May 9, 1995 with second and third coats being administered on May 10th and May 30th. Figure 12 shows the first coat of the material in application. A commercially available acrylic elastomeric product (*Kool Seal Acrylic Elastomeric*) was used for the coating.

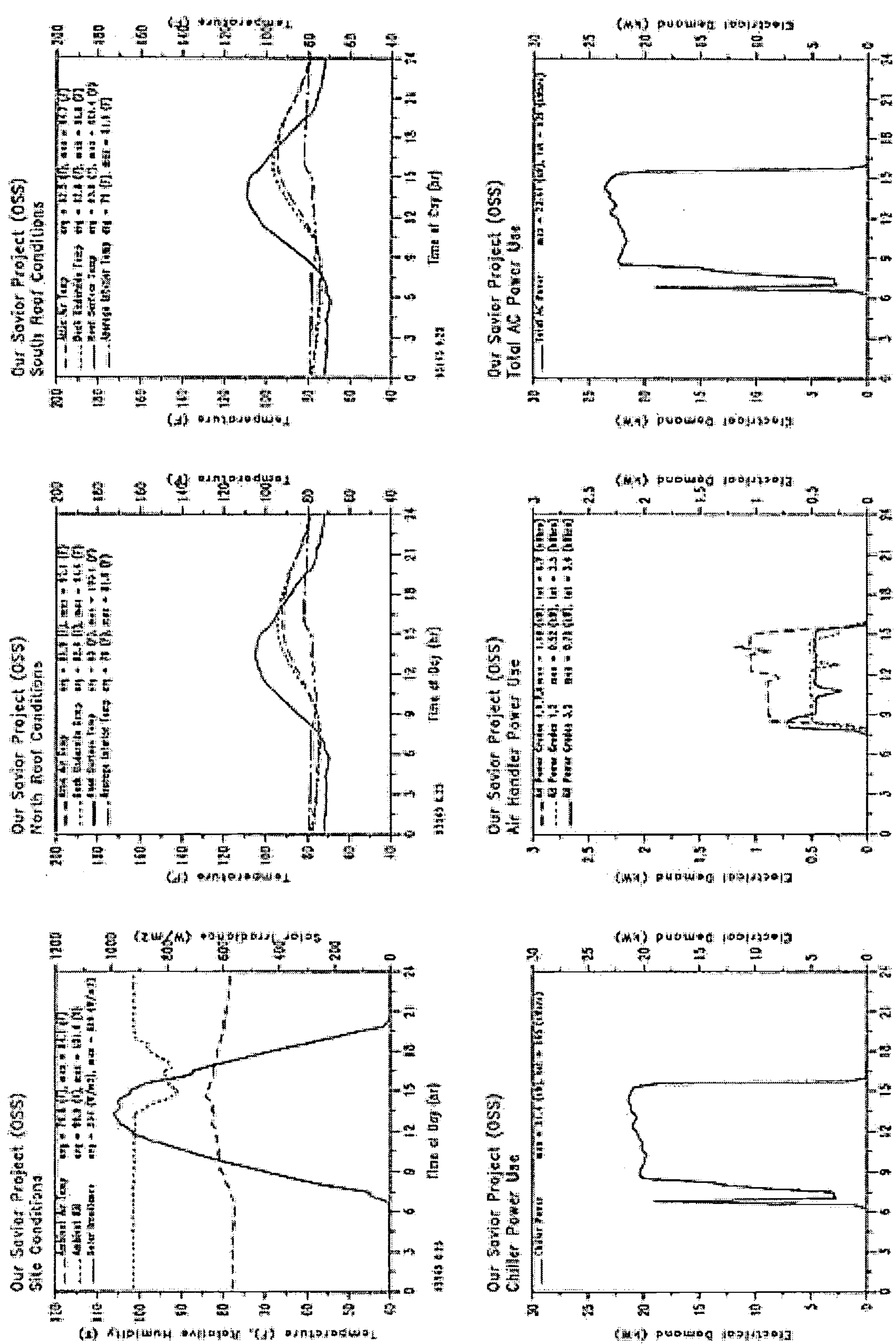

Figure 9. Measured thermal conditions and energy use at school prior to roof whitening – May 27, 1994.

Figure 10. Measured thermal conditions and energy use at school after roof resurfacing – May 25, 1995.

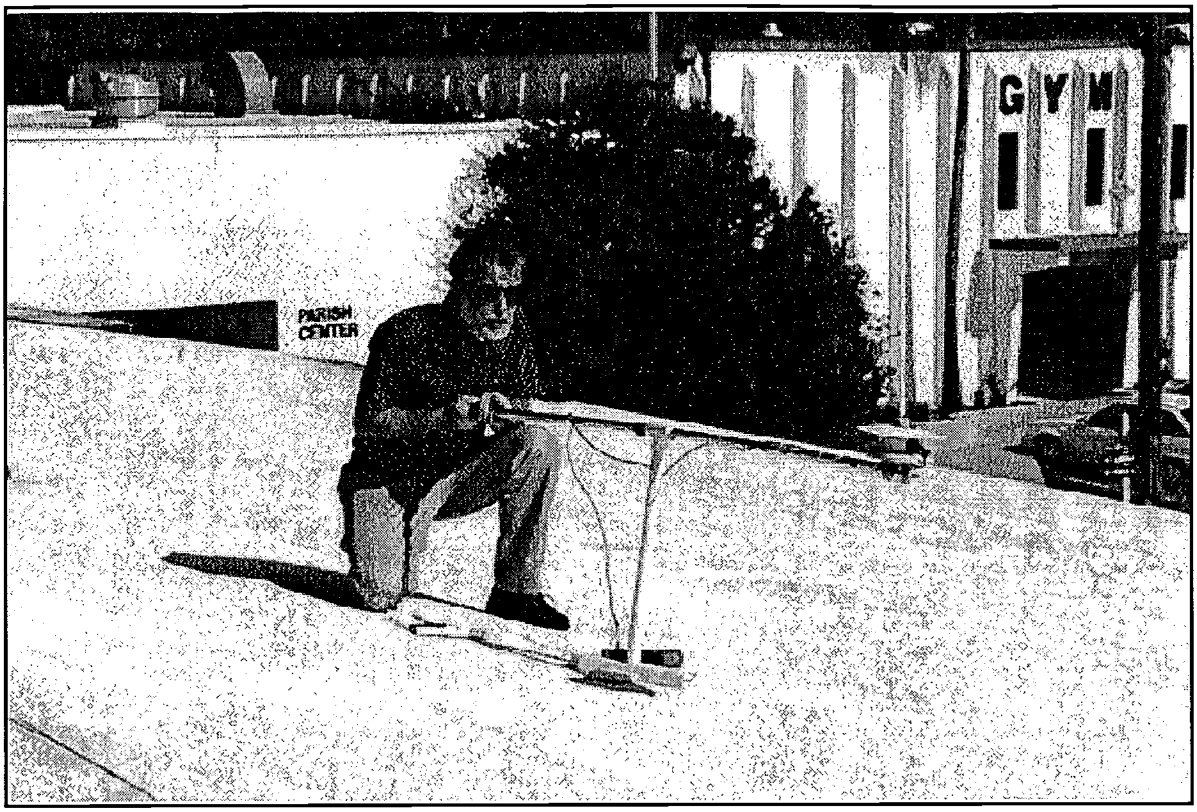

Figure 11. Pyranometer is used to measure roof reflectance one year after initial treatment.

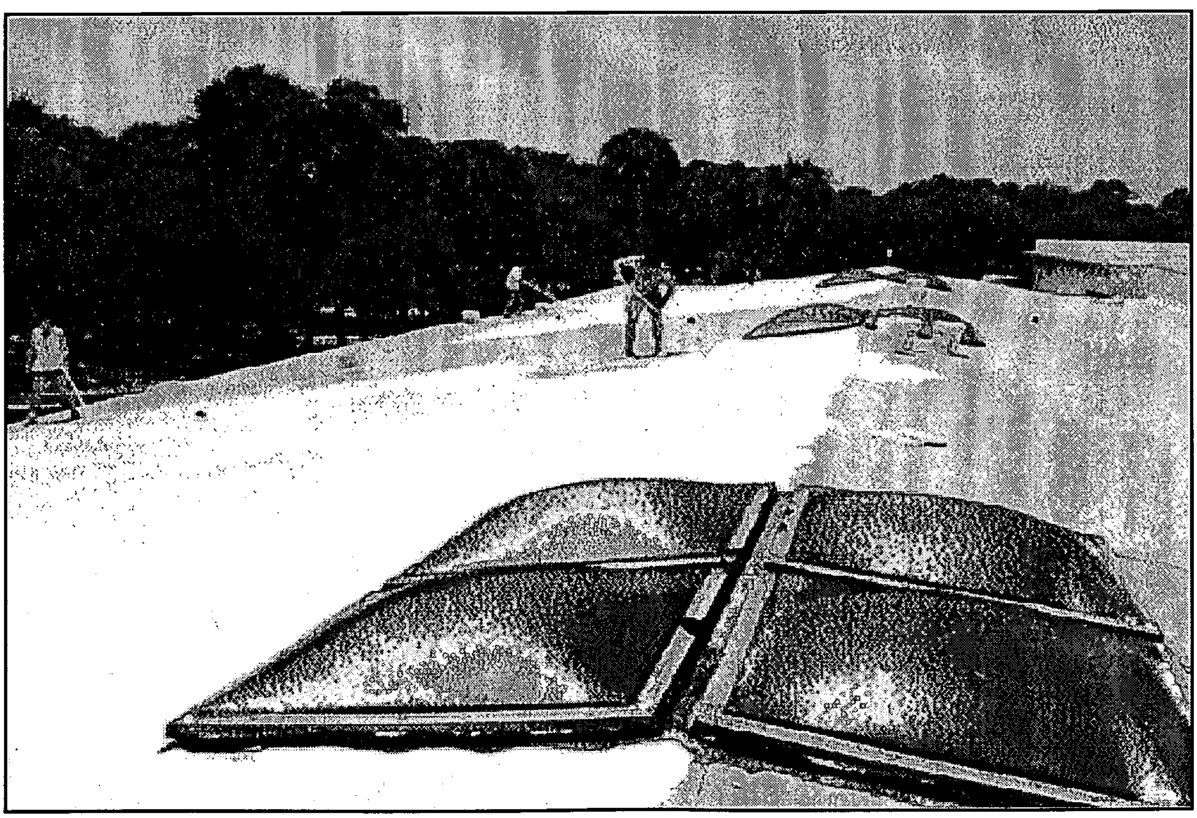
Figure 12. First of three coats of white acrylic elastomeric is applied to school roof on May 9, 1995.

However, due to previous experience with microbial growth on light colored surfaces a microbicide (*Skane M-8*) and an additional 25 G of zinc oxide per gallon were added to the product prior to application. The coating was applied by rollers; each application took approximately 5 hours. A total of 88 five gallon containers were used for all three coats.

6. Experimental Results

Initial examination of the 15-minute data suggested substantially lower roof, attic and hallway temperatures. Sample daily data plots for the site before and after the coating for similar days in late May are presented as Figures 9 and 10. Even though weather conditions were similar, the roof-attic temperatures evidence significantly improved thermal performance post application. The required cooling energy is 16% lower after the coating's application in spite of lower interior temperatures being maintained.

A graphic comparison of the performance of the building over the two year period, pre and post are contained in Figures 13 - 15. Figure 13 compares the change in the roof surface and roof plenum temperatures before and after the treatment. Similarly, Figure 14 shows how the unconditioned hallway temperature was reduced closer to ambient air temperature after the roof was whitened. Finally, Figure 15 shows how both the chiller power and roof plenum temperatures were reduced after the roof treatment. Particularly large differences in electrical demand were observed in August and September.

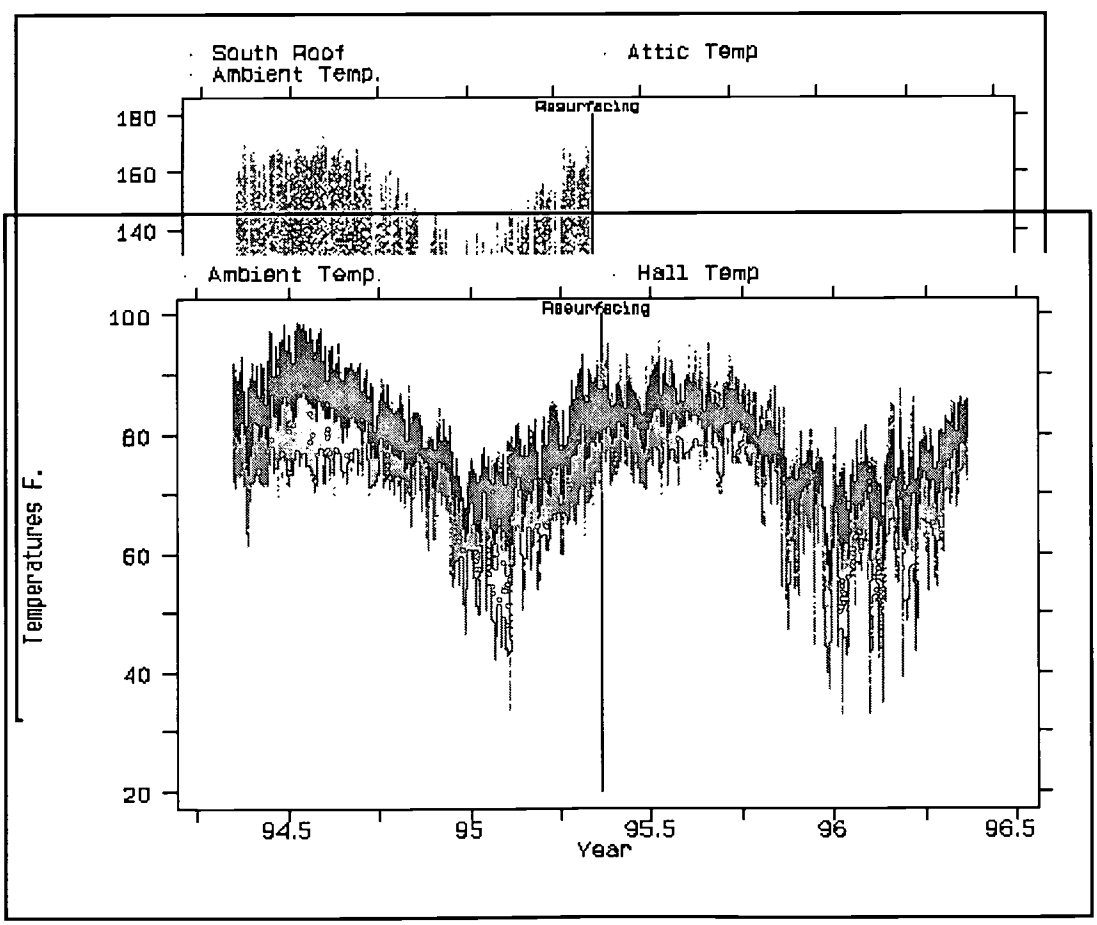

Figure 14. Data over the two year period showing how the unconditioned hallway temperature was reduced relative to the ambient air temperature.

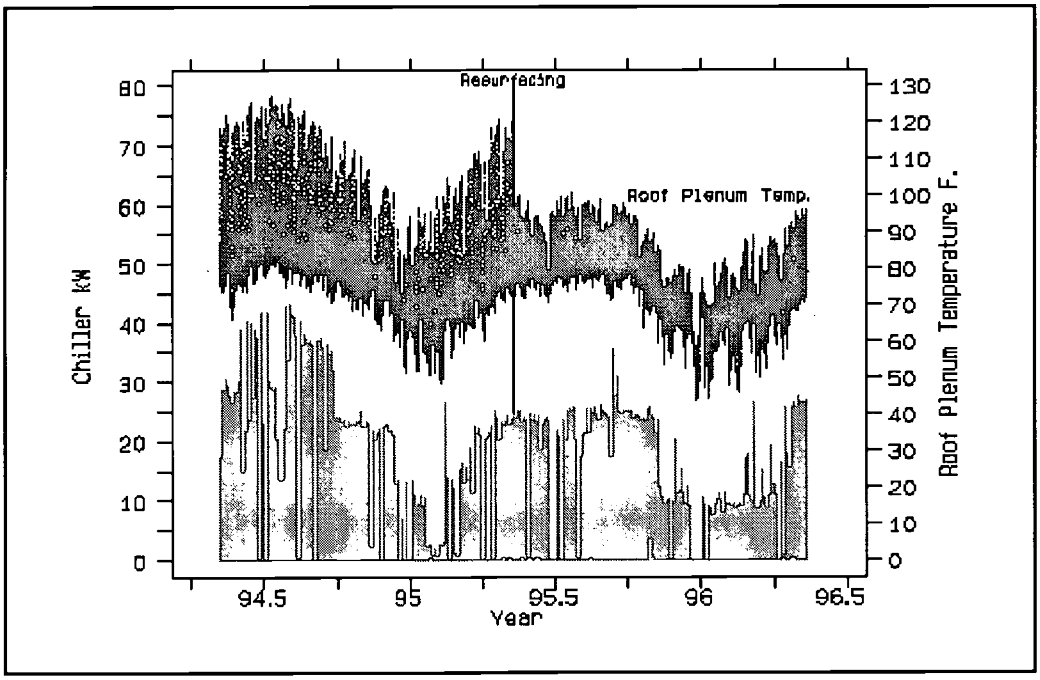

Figure 15. Data for two year period showing change in roof plenum thermal performance against 15-minute chiller electrical demand.

Table 2 describes key statistics for comparison of the year of pre and post data for the project:

Table 2

Comparative Average Performance Pre- and Post-Roof Whitening
Before: May 8, 1994 - May 7, 1995 / After: May 9,1995 - May 8, 1996

Parameter		Before	After	Difference
Roof Surface (^{o}F)	Avg.	86.2	73.8	12.4
	Std.D	29.8	17.2	
	Min.	28.8	26.0	2.8
	Max.	172.6	120.6	52.0
Roof Plenum (^{o}F)	Avg.	83.1	74.7	8.4
	Std.D	15.2	10.9	
	Min.	48.2	43.7	4.5
	Max.	127.3	104.4	22.9
Hallway (^{o}F)	Avg.	79.5	76.8	2.7
	Std.D	7.4	7.5	
	Min.	58.1	54.8	3.3
	Max.	98.7	92.6	6.1
Interior (^{o}F)	Avg.	77.7	75.5	2.2
	Std.D	5.9	6.3	
	Min.	59.6	55.2	4.4
	Max.	94.0	90.6	3.4
Tamb (^{o}F)	Avg.	73.1	72.7	0.4
	Std.D	9.0	10.7	
	Min.	33.6	32.9	0.7
	Max.	94.2	95.4	-1.2
Insolation (W/m^2)	Avg.	194.6	208.2	-13.6
	Std.D	284.7	295.1	
	Min.	0.0	0.0	0.0
	Max.	1143.5	1078.1	
Chiller (kW)	Avg.	3.73	3.36	0.37
	Std.D	8.27	6.76	
	Min.	0.0	0.0	0.0
	Max.	43.1	35.5	7.60

We also examined how the savings of the roof resurfacing varied on a seasonal basis. Not surprisingly, the largest absolute savings accrued in the hot and humid month of September when savings of 144 kWh/day (10.3%) were demonstrated. Although smaller in absolute terms, percentage reductions in cooling energy use were greatest during the "shoulder months." Chiller energy use was 28% less in March after the roof coating and 35% less in November. Also, as expected, we observed *increases* to space conditioning energy use during the two coldest months; consumption was elevated by 59 kWh/day during January and by 84 kWh/day in February. Regardless, these increases were readily offset by the much larger saved energy during the cooling season.

Figure 16 and 17 show the average measured performance over the daily cycle for a full year, showing the change in building temperatures and chiller energy use. The data indicate that all

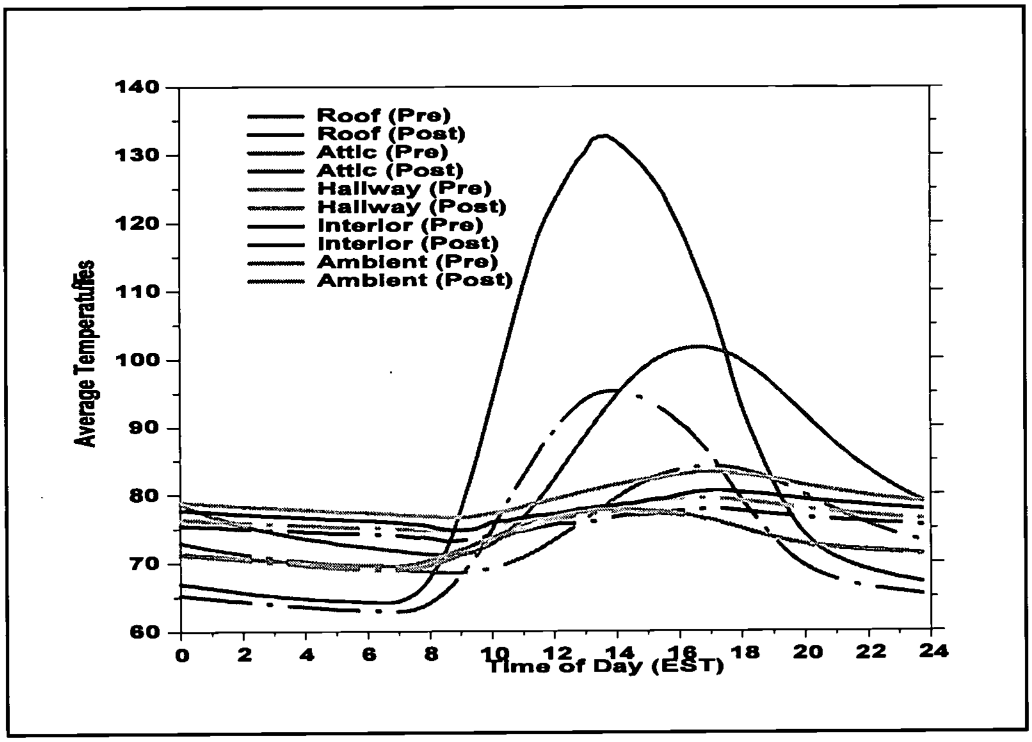

Figure 16. Measured average building thermal conditions in year before and after roof resurfacing. Dotted lines are for post period.

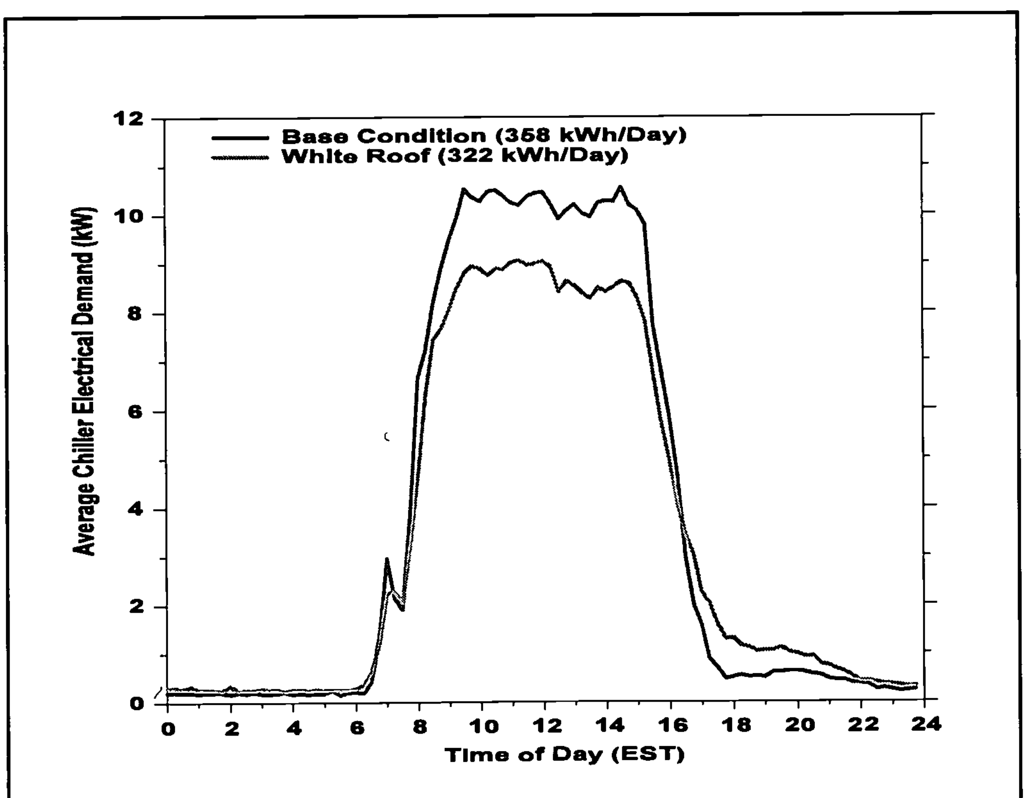

Figure 17. Measured average cooling system demand profile over the daily cycle for the year before and after the roof resurfacing.

building temperatures were significantly reduced by the treatment. Subsequent to the roof re-surfacing the roof plenum temperature on the typical day did not exceed the average ambient air temperature until 1 PM. Notably, the interior air temperatures in the classroom were reduced by an average of two degrees and the unconditioned hallway by over 2.5 degrees. This observation of increased comfort -- frequently made by the school's teachers and principal -- was verified by the field measurement.

In spite of the increased comfort levels, the electrical consumption was 35.7 kWh less per day or 10% average reduction in chiller and air handler power requirements. This equates to an annual reduction in cooling energy use in the facility of approximately 13,000 kWh. When confined to weekdays only, the savings were approximately 69 kWh/day or 14.7 %.

Average reductions in daily electrical demand over the entire year of approximately 1.5 kW (15%) were observed between 9 AM and 4 PM. However, confining the analysis to weekdays and using the critical summer utility system peak hour of 4 - 5 PM (3 - 4 PM EST), between June and September the chiller electrical demand was dropped by 35% from 16.2 kW to 10.6 kW. The slightly higher elevated consumption in nighttime hours in the post treatmen period reflects the increased use of the building during evenings during the second year of monitoring.

7. Conclusions

A monitoring study was performed in Cocoa Beach, Florida in an 10,000 square foot school building to examine how making a roof reflective could reduce cooling energy use in a commercial facility. Our Savior's Elementary School was monitored for an entire year from May, 1994 in a base line condition. In May, 1995, the modified bitumen roof surface (with a measured solar reflectance of 0.23) was coated with a white elastomeric coating which greatly increased its solar reflectance. A year of post retrofit energy use and thermal performance data were taken.

Data analysis revealed that roof surface, roof plenum and classroom temperatures were all significantly lower in the second year of monitoring. In addition chiller electric power consumption was reduced by an average of 10% from one year to the next, representing an energy savings of 13,000 kWh per year. However, peak demand was much more strongly affected than energy. Summer weekday utility peak coincident electrical demand of the cooling system was lowered by 5.6 kW -- a 35% reduction over the previous year. Beyond the cooling energy savings, the school staff had indicated that interior comfort has been noticeably improved by the white roofing system.

8. Acknowledgments

This project was supported by the Florida Energy Office; data analysis was supported by the Lawrence Berkeley Laboratory and the U.S. Department of Energy under a sub-contract from the U.S. Environmental Protection Agency. Additional support came from the Florida Electric Coordinating Group coordinated through the Florida Power and Light Company. The combined support of these agencies is gratefully acknowledged. The *Kool Seal Corporation* provided the elastomeric coating material for the project. Assistance with creation of a microbial resistant

top-coat was provided by Mr. Bill Kirn with the *Rohm & Haas Corporation*. FSEC staff assisted in the actual application of the material; thanks to Jon Klongerbo and David Floyd for lending a hand in this task. And last, but not least, the staff at *Our Savior's School* were particularly cooperative. Special thanks to Mr. Dan Fiori, the facilities administrator and Ms. Marianne Brown, the school principal.

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