Measured Energy Savings of Light-colored Roofs: Results from Three California Demonstration Sites

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ABSTRACT

Measured data and computer simulations have demonstrated the impact of roof albedo in reducing cooling energy use in buildings. Savings are a function of both climate and the amount of roof insulation. The cooling energy savings for reflective roofs are highest in hot climates. A reflective roof may also lead to higher heating energy use. Reflective coatings are also used in commercial buildings to protect the roofing membrane, and hence, maintain and prolong the useful life of the roof. Reflectivity of coatings changes with weathering and aging which in turn could have an effect on building cooling-energy savings. For that reason, reflective roof coatings are not primarily marketed for their energy savings potential.

To monitor the field performance of reflective coatings, we initiated a demonstration project where three commercial buildings in California were painted with light-colored roof coatings. The buildings are two medical care centers and one drug store. At all sites, the roof reflectance, both fresh and aged, and cooling energy use were monitored. In addition, we measured temperature throughout the roof systems and inside the conditioned space.

In the monitored buildings, increasing the roof reflectance from an initial value of about 20% to 60%, dropped the roof temperature on hot summer afternoons by about 45°F. Summertime standard-weekday average daily air-conditioning savings were 18% (198 kWh) in the first medical office building, 13% (86 kWh) in the second medical office building, and 2% (13 kWh) in the drug store. The overall u-value of the roofs had dictated the impact of roof reflectance.

Introduction

The use of dark roofs affects energy use in buildings and the urban climate. At the building scale, dark roofs are heated by the summer sun and thus raise the summertime cooling demand. For highly-absorptive (low-albedo[1]) roofs the difference between the surface and ambient air temperatures may be as high as 50°C (90°F). For less-absorptive (high-albedo) surfaces with similar insulative properties, such as roofs covered with a white coating, the difference is only about 10°C (18°F) (Berdahl and Bretz 1995). For this reason, "cool" roofs (which absorb little sunlight) can be effective in reducing cooling-energy use. Earlier studies have suggested that cool roofs incur no additional cost if color changes are incorporated into routine re-roofing and resurfacing schedules (Bretz *et al.* 1997 and Rosenfeld *et al.* 1995).

There is a sizable body of measured data (primarily collected for the residential sector) documenting energy-saving effects of light-colored roofs. Akbari *et al.* (1993), in the summers of 1991 and 1992, monitored peak power and cooling-energy savings from high-albedo coatings at one house and two school bungalows in Sacramento, California. Applying a high-albedo coating to one house resulted in seasonal savings of 2.2 kWh/day (80% of base case use) and peak demand reductions of 0.6 kW (about 25% of base case demand). In the school bungalows, cooling-energy use was reduced by 3.1 kWh/day (35% of base case use) and peak demand by 0.6 kW (about 20% of base case demand).

[1] When sunlight hits an opaque surface, some of the energy is reflected (this fraction is called the albedo = a) and the rest is absorbed (the absorbed fraction is 1-a). Low-a surfaces of course become much hotter than high-a surfaces.

Parker *et al.* (1998) report on monitored energy savings in nine homes in Florida before and after applying high-albedo coatings to their roofs. Daily air-conditioning energy use was reduced by 2 - 43%, with an average savings of 7.4 kWh/day (19% of low-albedo use). Peak demand between 5 and 6 pm was reduced by 0.2 - 1.0 kW, with an average reduction of 0.4 kW (22% of low-albedo demand). The amount of energy savings were in general inversely correlated with the amount of ceiling insulation and duct system location: large savings in poorly insulated homes and those with the duct systems in the attic space and smaller savings in well-insulated homes. In a more recent study, Parker *et al.* (1997) have monitored seven retail stores with R-11 ceiling insulation within a strip mall in Florida before and after applying high-albedo coatings to the roof. Average daily summer space cooling energy dropped 25% (25.5 to 34.1 kWh/day) in the seven shops.

Konopacki *et al.* (1997) have made quantitative estimates of peak demand and annual cooling-electricity use and savings that would result from increasing the reflectivity of the roofs. The study estimates that, nationally, light-colored roofing could produce savings of about 10 TWh/yr (about 3% of the national cooling electricity use in residential and commercial buildings) and a decrease in net annual energy bills for the rate-payers of $750 Million.

Both measured data (mostly for the residential sector) and simulations clearly demonstrate that increasing the albedo of roofs is an attractive and cost-effective way of reducing the net radiative heat gains through the roof and hence, reducing building cooling loads. To change the albedo, the rooftops of buildings may be painted with reflective coatings or covered with a new material. It is most economical to increase the roof albedo at the time when the roof is scheduled for maintenance. In that condition, the cost would be limited to the incremental cost associated with the change in albedo.

This study was designed to address some of the questions regarding the actual implementation of reflective roofs in a few commercial buildings. The objective of the project was to work with developers, industry, businesses, and utilities to develop and carry out up to three demonstration cases, in commercial buildings, to show effectively the impact of cool materials on building energy use. The demonstration project included three commercial buildings in California (two medical care centers and one drug store) that their roofs were painted with light-colored coatings. This paper summarizes the experience gathered throughout various phases of application of roof coatings and data collection for these demonstration sites.

Methodology

Description of Buildings

The three selected commercial buildings were Kaiser Permanente medical office buildings in Gilroy and Davis, and Longs Drug Store in San Jose. All three buildings are single-story, with flat/low-slope (less than 3°) roofs, and use asphalt based capsheet[2] as their roofing material.

The Davis building is 31,700 ft^2 with a reciprocating air-cooled chiller and a gas boiler. It has four variable volume air-handling units with hot water reheat, which use a minimum of 20% outside air. The roof is built-up with light-gray granules. The solar reflectance of the roof was 0.24. The roof was coated on April 12, 1997 and the solar reflectance after coating was applied was 0.60. There is R-8 rigid insulation and an unvented return plenum located underneath.

The Gilroy building is 23,800 ft^2 with seven roof-mounted packaged-single-zone air-conditioners. They are variable-air-volume units with gas heating. The roof is built-up with light-gray granules of 25% solar reflectance. There is R-19 fiberglass insulation and an unvented plenum with ducts located underneath. The rooftop of the Gilroy building was given two coats of a elastomeric roof

[2] Capsheet roofing is similar to residential asphalt roofing tiles, with surface granules pressed into asphalt-saturated felt fibers, but capsheet roofing comes in large sections of about 4 feet by 10 feet.

coating on August 5, 1996. The reflectance of this type of bright white coating product has a laboratory-measured solar reflectance on a smooth surface of 70% or higher. The capsheet roof is fairly rough, which tends to absorb more of the reflected sunlight and thus lower reflectances. The field-measured value of Gilroy's post-coated rooftop was 60%.

The San Jose building is 33,000 ft^2 with a constant-volume roof-mounted packaged-single-zone air-conditioner, where a sales zone accounts for 26,000 ft^2 and a mezzanine for 7,000 ft^2. It operates with a two-stage compressor and electric reheat. There is a five-ton heat pump servicing the pharmacy. The roof is built-up with tan granules of 16% solar reflectance (60% post-coating). There is a radiant barrier and a well-ventilated plenum with ducts located underneath. There is a dropped ceiling in place above the sales zone of "loose" construction. It provides a low-resistive path for evacuation of air from the sales space to the plenum above, which is then exhausted outdoors. The solar reflectance of the roof was 0.16. The roof was coated on March 24, 1997 and the solar reflectance after coating was applied was 0.60.

Instrumentation and Data Acquisition Systems

At each site, we measured weather variables (wind speed, wind direction, outdoor temperature, outdoor relative humidity, and horizontal insolation), electricity use (whole-building and cooling), roof surface heat flux, and temperatures (roof surface, roof underside, plenum air, inside air, and return air). The weather variables were all measured on a ten-foot weather tower located at the approximate center of each rooftop. Multiple sets of roof/plenum measurements were made on each building, with the roof surface, roof underside, plenum, and inside temperatures stacked at the same locations.

In each building, instrumentation is wired into a data logger, which is in turn connected to a personal computer with an internal modem connecting to a phone line. The PC uses ProComm Plus for Windows software. Every 15 minutes the data logger sends data to the PC. The ProComm Plus software sends these data to 2 files: an archive file and a file containing all data collected for the previous 168 hours (the weekly file). ProComm Plus also maintains a bulletin board in the background, which allows the archive file to be downloaded remotely by calling into the PC. A detailed list of the instrumentation and equipment used, including its manufacturer and cost, is in (Konopacki *et al.* 1998).

In addition to the values which are measured by the data logging system, the rooftop solar reflectance was measured before and after the rooftops were coated. The measurements were made accordance to ASTM Standard 1918-97 (ASTM 1998).

Data Collection

At all buildings, data were collected on a 15-minute intervals. These data were plotted weekly for inspection. Questionable or missing data, holidays, and days with abnormal operation were identified in this manner. Also visible was the weekday versus weekend variation in air-conditioning electricity use. Davis and Gilroy typically were not operating during the weekends and holidays, while San Jose was operating on weekends but not on holidays.

Before the analysis could begin the final data base was prepared. Days with questionable or missing data were identified and removed from the analysis. Holidays and weekends were not included in the data analyses either. At this point the data were considered "clean" and consisted of only "standard weekdays".

For all buildings, we collected and analyzed data from June 1, 1996 through September 30, 1997.[3] The hourly data clearly show strong seasonal and daily dependency of some of the monitored

[3] Data collection at the Gilroy building did not begin until June 12, 1996, and the San Jose site had missing data from March 5 through 24, 1997.

data such as the cooling-energy use and air and surface temperature. The cooling energy-use data in the Davis and Gilroy buildings show the difference between the weekday and weekend schedules in the building operation. In the analysis presented here, we used only data for standard weekdays excluding weekend days and holidays.

Data Analysis Technique

The first step in the analysis was to convert the validated 15-minute data into hourly data by summing the cooling and total electricity use and averaging the remainder of the variables. From these data average daily profiles were derived for cooling electricity use and outdoor, indoor, and roof surface temperatures by month. Also, scatter plots showing the dependence of cooling electricity use on outdoor temperature were created on a monthly basis.

Second, we converted the hourly data into daily data by summing the cooling electricity use and averaging the outdoor air temperature. At this point, multi-variate regressions performed on the seasonal data with daily cooling electricity use as the dependent variable and average daily outdoor air temperature as the independent variable generated a single slope and eight y-intercepts (one for each month) or a single slope and two intercepts (one for the pre-coating period and one for the post).

The third and final step was to normalize the monitored average daily cooling electricity use for variation in outdoor temperature during pre- and post-retrofit.

Data Analysis and Results

Temperatures and Heat Flux Through the Roof System

Figure 1 shows pre- and post-coating monitored hourly data for the period when the coating was applied at the Gilroy building. There were noticeable drops in roof surface temperatures and heat fluxes at the time the roofs were coated at all three sites. At Gilroy the roof temperature dropped from 160°F to 100°F. The maximum roof surface temperature of the building at Davis dropped from 140°F to 100°F immediately after the light-colored coating was applied. At San Jose, the roof temperature dropped from 130°F to 85°F.

Fig. 1 also shows the underside roof and plenum temperature, the heat flux through the roof, and cooling electricity use. As expected, the impact of roof coating is less pronounced on the temperatures of layers below the roof. But in all the buildings the reduction in temperatures in all layers and reductions in heat flux can be observed.

In reviewing typical hourly data a hot summer day at the Gilroy site before and after coating the roof, the pre-coated roof surface temperature peaked at 170°F on July 29, 1996. On a comparable day (July 3, 1997) the post-coated roof surface temperature peaked at 120°F. The outdoor temperature peaked at about 95°F both of these days; therefore the temperature difference between the roof surface and the outdoor air decreased from 75°F to 25°F. The heat flux decreased by a factor of three and the air-conditioning demand was noticeably affected. From 7 am to 4 pm the demand profile decreased substantially from pre- to post-coating conditions.

In Davis, the pre-coated roof surface temperature peaked at about 175°F on July 1, 1996. On a comparable day (July 8, 1997) the post-coated roof surface temperature peaked at about 120°F. The outdoor temperature peaked at just under 105°F both of these days; therefore the temperature difference between the roof surface and the outdoor air decreased from 70°F to 15°F. The heat flux was essentially cut in half and the air-conditioning demand was noticeably affected. From 8 am to 4 pm the demand profile decreased substantially from pre- to post-coating conditions.

For the San Jose building, the pre-coated roof surface temperature peaked at 165°F on August 9, 1996. On a comparable day (August 5, 1997) the post-coated roof surface temperature peaked at

135°F. (On other comparable days the post-coated roof surface temperature peaked at 120°F). The outdoor temperature peaked at about 95°F both of these days; therefore the temperature difference between the roof surface and the outdoor air decreased from 70°F to 40°F. The heat flux decreased by 50%. But the air-conditioning demand was not noticeably affected. This is probably due to a well ventilated plenum installed over the ceiling in this building.

Impact of "Cool" Coatings on Air-Conditioning Electricity Use

The effect of cool-roof coatings on air-conditioning electricity use was examined during the summer months of June, July, August, and September for 1996 and 1997. The pre-coating period for Davis and San Jose were those summer months in 1996, and the post-coating were those in 1997. However, in Gilroy the months of June and July 1996 were grouped into the pre-coating period with the balance of the months into the post-coating period.

Figure 2 shows the 24-hourly roof surface temperature averaged for summer standard weekdays at the Gilroy building. The average peak roof surface temperature was 155°F (before coating) in the month of July 1996 and 115°F (after coating) in July 1997, decreasing by 40°F. In Davis and San Jose the average peak roof surface temperature was 160°F in the month of July 1996 (before coating) and 120°F (after coating) in the same month in 1997, decreasing by 40°F.

Average daily air-conditioning electricity use and average indoor and outdoor temperature. Fig. 2 also shows average air-conditioning electricity use and indoor and outdoor temperatures for summer standard weekdays (summer 1996 and 1997) at Gilroy. The figure also provides an overview of the daily air-conditioning energy use and indoor air temperature in these buildings, as well as some relevant information regarding the schedules of operations. The average hourly data for June show a slight increase in average cooling electricity use, and average indoor and outdoor temperatures, from 1996 to 1997. In July the cooling electricity demand decreased as did the outdoor and indoor air temperatures.

At the Davis building, the average air-conditioning electricity use in June 1996 and June 1997 differ only during the late evening hours. The average outdoor temperatures are also very close. But the average indoor air temperature was 1.5°F lower in June of 1997 than in 1996, the major benefit from the cool roof. In July there was a significant reduction in air-conditioning electricity use during each hour of operation, with the outdoor temperature less in July 1997 than in 1996, and nearly identical indoor temperatures. Thus, there is a strong suggestion that the cool roof influenced cooling electricity use. The average air-conditioning use for August and September differ significantly only in the early morning and late evening hours and the indoor air temperatures are actually slightly higher (1°F) in 1997 than 1996. In August 1996 the outdoor temperature is higher during peak operating hours than 1997 and the reverse is true for September. From examining the average air-conditioning electricity use, outdoor temperature, and indoor temperatures, for the Davis site, it can be concluded that further analysis is necessary to understand the effect of the light-colored roof on cooling electricity savings.

At the San Jose building, the indoor air temperature remained stable during operating hours for each month (June and July show a 0.5 - 1°F differential). During June and July cooling electricity demand during peak hours 12 noon through 5 pm was reduced from 1996 to 1997. Both cooling use and average outdoor temperature were higher in September of 1997.

Daily air-conditioning electricity use versus average outdoor temperature scatter plots. Scatter plots were prepared to show the dependence of daily cooling electricity use on outdoor temperature and to isolate clusters of data for each month. **Figure 3** shows monitored daily air-conditioning electricity use versus outdoor temperature for summer standard weekdays for all three buildings. For the Davis and Gilroy buildings, two groups of data are easily identifiable, pre- and post-coating cooling electricity use, with the pre-coating cluster shifted higher than the post-coating cluster in both. But in the San Jose building, we did not detect significant change in cooling electricity use after coating the roof. We will later discuss the cooling electricity savings in the San Jose building.

Statistical Analysis of Cooling Electricity Use. Our statistical analyses primarily focused on daily cooling electricity use and average daily outdoor temperature. The outdoor temperature captures the variations in solar flux (cloud cover), wind speed, and air moisture content that influence the heating and cooling loads on a building; therefore, it was used as a representative climatological indicator.[4] The statistical analysis was performed in two steps. First, we used a single-variate regression model with the daily cooling electricity use regressed against the average daily temperature for each month. The equation used was of the form

$$\mathrm{Elec}_{AC}(i,T) \;=\; \sum_{j=1}^{j=8} C_0(j)\delta_{ij} \;+\; C_1T \qquad (1)$$

where, $\delta_{ij} = 1$ for $i = j$ and $= 0$ for $i \neq j$, $\mathrm{Elec}_{AC}(i,T)$ is daily cooling-electricity use during the month of i at temperature T, and T is the average daily outdoor temperature.

The parameter estimates from these regressions are discussed in Konopacki (1998). Most of the months from each site did have similar slopes and high correlations, confirming that the temperature dependency of the cooling electricity use should be fairly constant during all summer months and for both pre- and post-retrofit conditions. In the second step of the analysis, we utilized a multi-variate model and repeated the regressions for each building assuming a single slope for pre- and post-retrofit data with: (a) 8 intercepts (one for each summer month) and (b) 2 intercepts (one for pre- and one for post-retrofit data). These intercepts and slopes are shown in the third and fourth (a) and fifth and sixth (b) columns of **Table 1** for each site.

Table 1. Parameter estimates from regression analyses of daily air-conditioning electricity use vs average daily outdoor temperature for summer standard weekdays. The slope is in kWh/day/°F and the intercept is in kWh/day, calculated at 55°F.

Building	1996				1997				All	
	June	July	Aug.	Sep.	June	July	Aug.	Sep.		
Davis	Pre				Post				Pre	Post
Intercept	247	336	241	210	211	32	137	-118	248	54
Slope	<---------------------- 45.6 ---------------------->								<-- 46.6 -->	
Gilroy	Pre		Post							
Intercept	278	357	155	136	233	262	256	241	290	173
Slope	<---------------------- 29.8 ---------------------->								<-- 33.1 -->	
San Jose	Pre				Post					
Intercept	341	366	349	327	298	333	373	337	320	307
Slope	<---------------------- 28.2 ---------------------->								<-- 29.9 -->	

[4] Through a series of single-variable regressions with several independent variables (daily average outdoor air temperature, daytime average outdoor air temperature, daily peak outdoor air temperature, daily average outdoor air enthalpy, and daytime average outdoor air enthalpy), it was determined that the daily average outdoor air temperature provided the best correlation with daily cooling-electricity use. We also concluded the daily average outdoor air temperature captures the variations in cloud cover and outdoor air moisture that influence the cooling loads on these buildings.

The estimated average daily air-conditioning electricity uses for summer standard weekdays for pre- and post-retrofit conditions were compared, using the single-slope regression model. The data for the Davis building shows, month by month, the pre-coating periods with a higher cooling electricity demand than the post-coating period and the same is true for Gilroy. In San Jose the 1996 months of June and July had higher cooling electricity demand than the respective months in 1997. However, the opposite was true for August and September. The month of July 1996 had the greatest demand in Davis and Gilroy and was a very close second to August 1997 in San Jose. We used the coefficient of the single-slope model to normalize the monitored cooling electricity use for variation in the outdoor temperature during the monitoring period.

Estimated Savings in Cooling Electricity Use. The monitored average daily cooling-electricity use for the post-retrofit period was normalized for differences in the average daily outdoor temperature between the pre- and post-retrofit periods. **Table 2** shows the monthly monitored cooling electricity use data for 1996 and 1997, and the 1997 cooling electricity use data normalized for the temperature difference between 1996 and 1997. The slopes from the 8-intercept multi-variate regression model were used to normalize the 1997 cooling electricity use. The table also lists the estimated savings in cooling electricity use for each month. When comparing 1996 to 1997, the Davis building experiences monthly cooling electricity savings ranging from 3 to 39%. The month-by-month comparison for Gilroy is limited to June and July and show savings of 9 and 12% respectively. In San Jose the month-by-month comparison shows some savings during June and July (7 and 4%) and a similarly small deficit in August and September (-3 and -2%).

Table 2 also shows the summertime monitored cooling electricity use data for pre- and post-retrofit conditions, and the post cooling electricity use data normalized for the temperature difference between pre- and post-periods. The slopes from the 2-intercept multi-variate regression model were used to normalize the post-retrofit cooling electricity use. The table also lists the estimated savings in cooling electricity use for each period. When comparing 1996 to 1997, the normalized pre-to-post-retrofit summer periods the standard-weekday average daily air-conditioning electricity use was reduced by 18% (198 kWh) in the Davis building, 13% (86 kWh) in the Gilroy building, and 2% (13 kWh) in the San Jose store.

In the Gilroy building, the pre-coating period consisted of the 1996 months of June and July, as the roof was coated early in August of that year. We extrapolated the cooling electricity use in the post-coating months of August and September 1996 to estimate pre-coating use to obtain the value of 675 kWh in column A of the table.

The most savings were seen in the Davis building since of the three buildings it roof system was least resistant to heat transfer (i.e. primarily R-8 rigid insulation). The Gilroy building has R-19 fiberglass insulation as the roof system's primary resistive element and was found to have less average daily cooling kWh savings during the months of June through September than Davis. The air-conditioning electricity use in the San Jose retail store is dominated by internal load, and the roof system plays a relatively small role in the whole-building load, and thus the savings were least in this building (even though Δa was higher than in the Kaiser buildings). It has a well ventilated plenum, which efficiently exhausts to the outdoors any heat that is transferred through a radiant barrier attached under the roof.

Discussion

In this project the cost of the coating was to be paid by the facility itself, and the coating was applied by a roofing contractor instead of by project personnel. There were many unexpected difficulties in completing high-reflectance rooftop coatings.

One of the difficulties was selling the coating based on its cost-effectiveness. Based on the projected energy savings of these coatings alone (2-5¢/ft^2 per year) a roof coating is not cost-effective. If

Table 2. Monitored and normalized average daily air-conditioning (AC) electricity use and estimated savings for summer standard weekdays by month and for the entire summer season.

month	monitored AC kWh/day		normalized 1997 AC kWh/day for 1996 T_{out}	estimated AC savings	
	1996	1997		Δ kWh/day	%
	A	B	$C=B+m(T_A-T_B)$	D=A-C	E=(D/A)*100
Davis					
June	1006	991	973 ± 22	33 ± 22	3 ± 2
July	1320	895	1018 ± 22	302 ± 22	23 ± 2
August	1168	1026	1063 ± 22	105 ± 22	9 ± 2
September	853	750	522 ± 22	331 ± 22	39 ± 2
Gilroy[a]					
June	511	565	467 ± 12	44 ± 12	9 ± 2
July	774	641	680 ± 12	94 ± 12	12 ± 2
-					
San Jose					
June	645	618	601 ± 11	44 ± 11	7 ± 2
July	814	736	781 ± 11	33 ± 11	4 ± 1
August	772	798	795 ± 11	-23 ± 11	-3 ± 1
September	605	766	617 ± 11	-12 ± 11	-2 ± 2

Summer	monitored AC kWh/day		normalized post AC kWh/day for pre T_{out}	estimated AC savings	
	pre	post		Δ kWh/day	%
Davis	1094	915	896 ± 15	198 ± 15	18 ± 1
Gilroy	675[b]	658	589 ± 7	86 ± 7	13 ± 1
San Jose	713	730	700 ± 6	13 ± 6	2 ± 1

a The roof was coated August 5, 1996; therefore, a direct month-to-month comparison for August and September could not be made.

b The pre-coating monitoring period was June through July 1996. We extrapolated June and July data to estimate air-conditioning energy use for August and September 1996 and the entire summer of 1996.

the coating can be used to lengthen the life of the roof and avoid replacement costs, it becomes much more economically attractive.

Other difficulties arose in working with facility managers and roofing contractors. Neither group has much experience with or knowledge of high-reflectance coatings, leading to a hesitance to adopt this new technology. These people are also extremely busy, so scheduling meetings and work can be challenging. A set of information to collect and guidelines for coating costs were developed to help streamline the process of coating rooftops.

Conclusions

In this study, we monitored air-conditioning electricity use, indoor and outdoor temperatures, roof surface temperature, heat flux through the roof, incoming solar radiation, and some other environmental variables in three buildings. The following is the summary of findings.

In the Davis building, coating the roof with a reflective coating increased the roof albedo from 0.24 to 0.60. The roof surface temperature on hot sunny summer days before coating was applied reached 175°F but only 120°F after coating. In the Gilroy building, coating the roof increased the roof albedo from 0.25 to 0.60; the "hot day" roof surface temperature was reduced from about 170°F to about 120°F. In the San Jose building, coating the roof increased albedo from 0.16 to 0.60 and the "hot day" roof surface temperature decreased from 165°F to about 120°F.

Summertime standard-weekday average daily air-conditioning savings were 18% (198 kWh) in the Davis medical office building, 13% (86 kWh) in the Gilroy medical office building, and 2% (13 kWh) in the San Jose retail store. The Davis building, having the lowest overall roof U-value among the three buildings, had the highest cooling electricity savings of the three. In the Gilroy building, with R-19 roof insulation, cooling electricity savings of about 13% were measured. In the San Jose retail store, which was dominated by internal load and a well ventilated plenum with a radiant barrier attached under the roof, the measured cooling electricity savings were only 2%.

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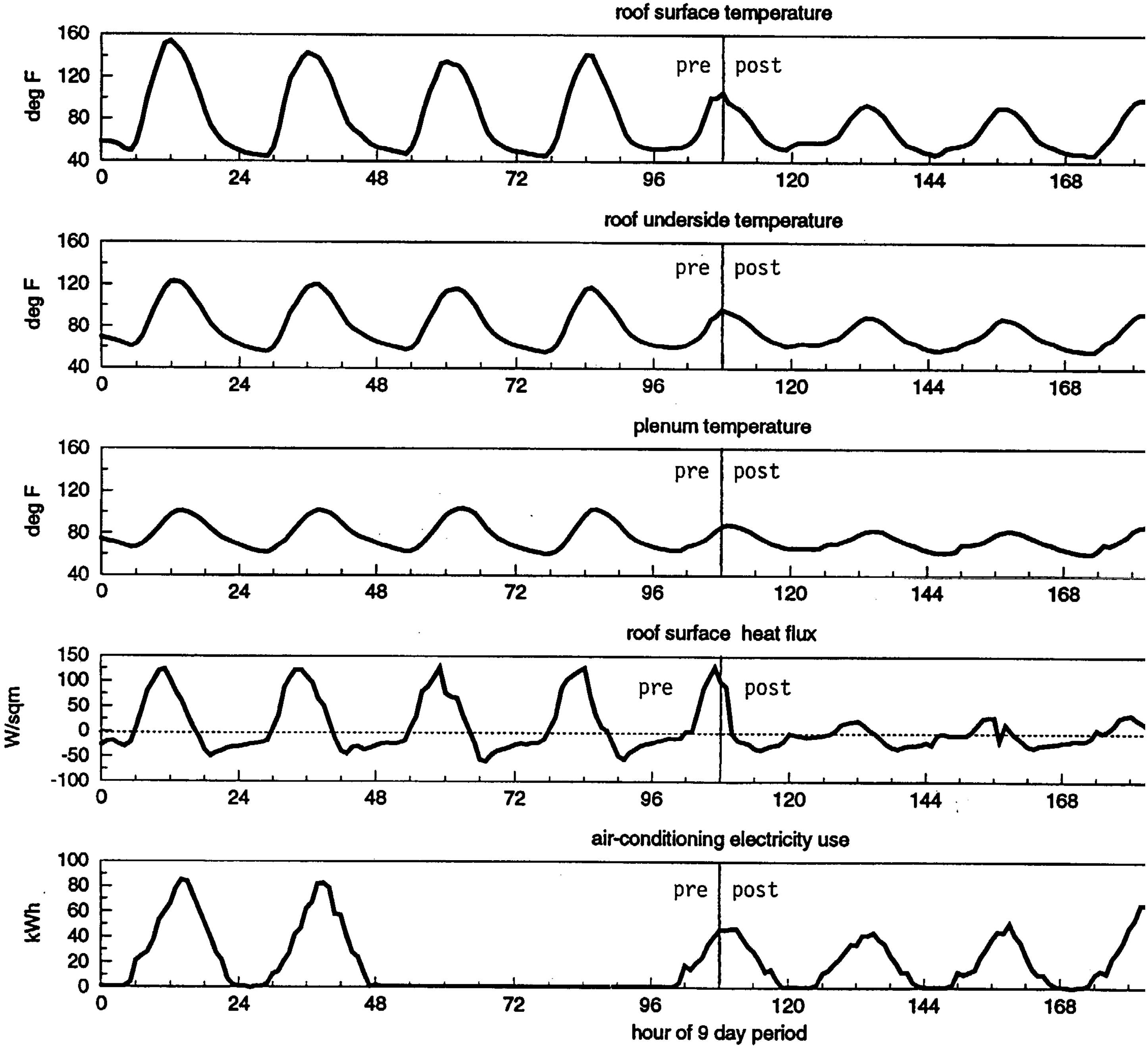

Figure 1. Gilroy monitored hourly data: 8/1-8/9/96.

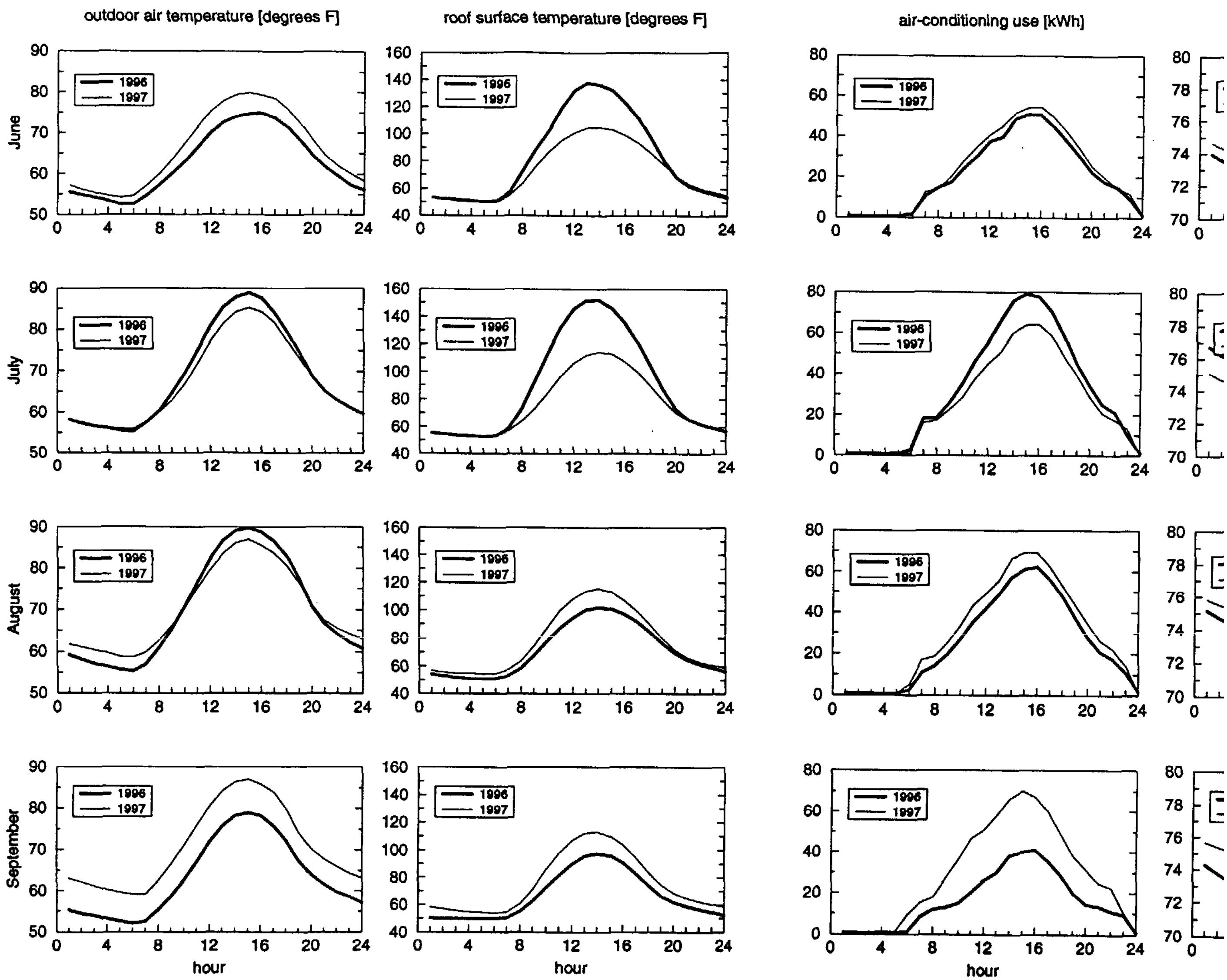

Figure 2. Gilroy average standard weekday profiles of outdoor air, indoor air, and roof surface temperatures, for June, July, August, and September 1996 and 1997.

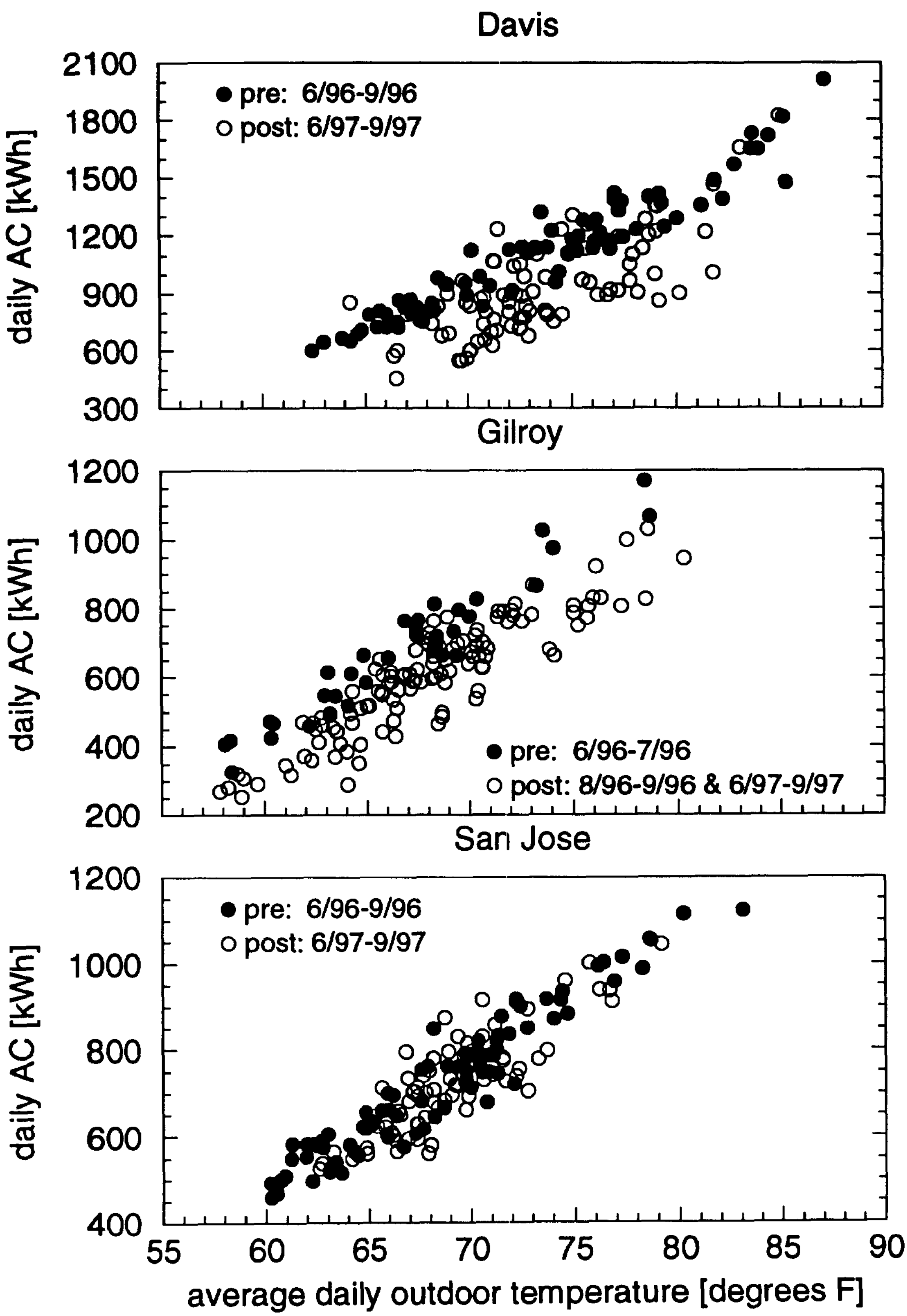

Figure 3. Monitored daily a/c electricity use versus average daily outdoor temperature.