Carpeteria Retail Store

Building Description

The Carpeteria retail store, located in Sacramento, has been selected as the Northern California retail monitoring site (see Figure 1). The building is a 19,000 ft^2 single story concrete tilt-up building. The interior area consists of 13,000 ft^2 of sales floor, 1,500 ft^2 of office, and 5,000 ft^2 of warehouse. (LEO: Where is the other 500 ft2?) The Sales floor is mostly open with 16' high ceilings, with a portion of dropped 10' t-bar ceiling. The office is all t-bar or sheetrock ceiling and the warehouse is all open. The open areas are insulated with multi-layer radiant barrier. The t-bar ceiling has 10" of fiberglass batt on top of the ceiling tiles and nothing at the roof. The roof is covered with a grey mineral cap sheet in very poor shape (it was installed in 1989) with a reflectivity of 21%. All spaces except the warehouse section are conditioned with roof top gas packs (five 5-ton and one 3-ton). Two of the RTUs have exposed duct work on the roof.

Figure 1: Carpeteria Store

Instrumentation and Data Acquisition Systems

Monitoring data were collected for approximately one month before and after installation of the reflective roof. Parameters that were measured to assess cool roof performance include:

- Roof surface temperatures
- Roof underside temperatures
- Indoor and plenum air temperatures
- Weather conditions
- Building energy use.

Table 1 summarizes the monitoring points and Figure 2 shows their locations.

Table 1: Building Monitoring Points

No.	Name	Location	Purpose
1	TRS-A	Roof surface above Office	Roof surface temperature
2	TRS-B	Roof surface above Sales	Roof surface temperature
3	TRS-C	Roof surface above Warehouse	Roof surface temperature
4	TRU-A	Roof underside in Office	Roof underside temperature
5	TRU-B	Insulation underside in Sales	Insulation underside temperature
6	TRU-C	Insulation underside in Warehouse	Insulation underside temperature
7	TAP-A	Plenum in Office	Plenum air temperature
8	TAI-A	Office	Interior air temperature
9	TAI-B	Sales	Interior air temperature
10	TAI-C	Warehouse	Interior air temperature
11	TAO	Weather tower	Outdoor dry bulb temperature
12	RHO	Weather tower	Outdoor relative humidity
13	HSOL	Weather tower	Horizontal solar radiation
14	WAC1	Panel AC1	Total A/C electricity use for RTU1-RTU5
15	WAC2	Panel AC2	A/C electricity use for RTU6 (office)
16	WOTH	Panel A	Other building electricity use

In addition to the continuously monitored data the following one-time measurements and observations were recorded:

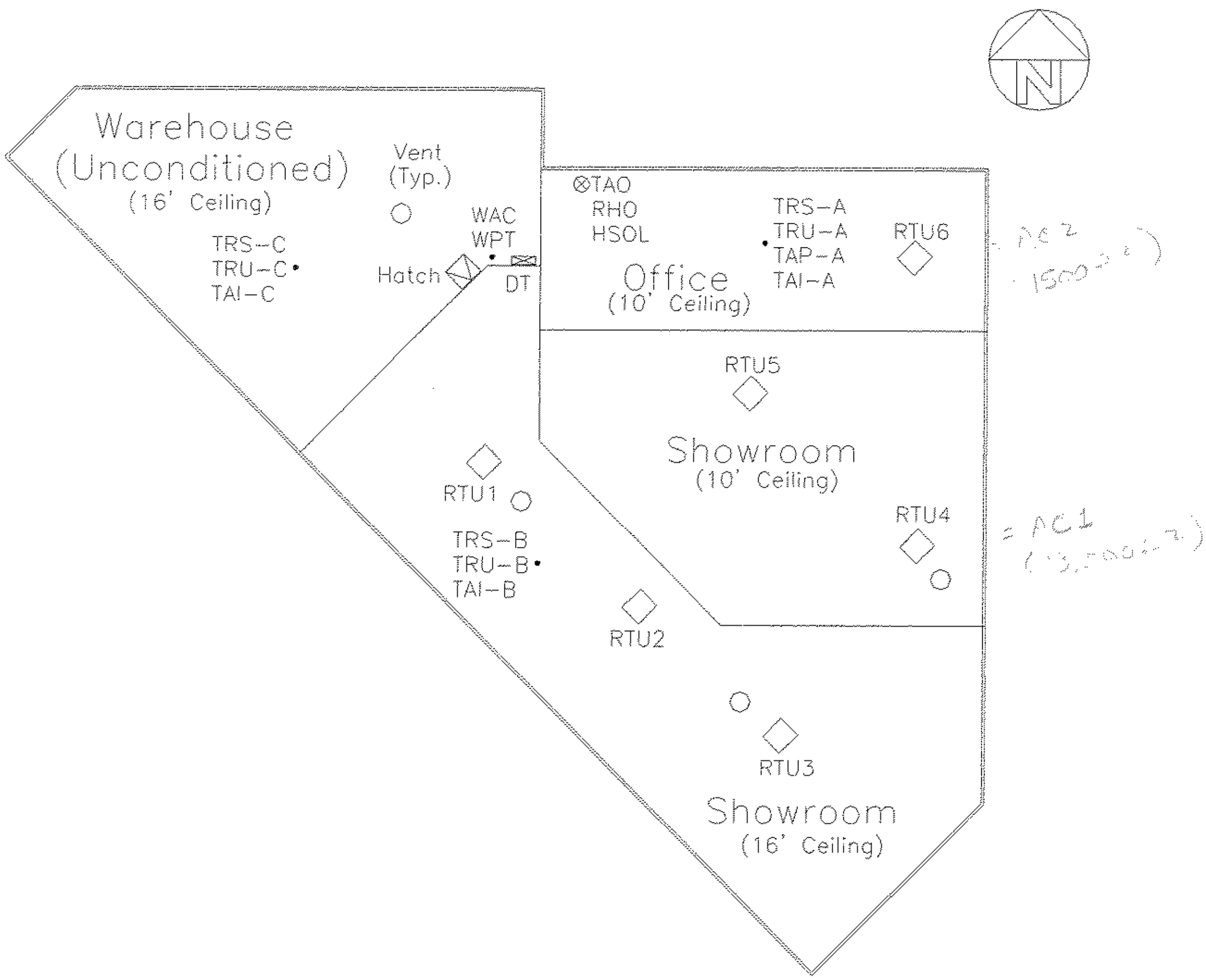
- Roof albedo before and after re-roofing.
- Wall and roof insulation levels.
- A/C nameplate and power.
- Fenestration
- External shading

LEO: Will you please give me your notes on the above items?

All sensors were calibrated using the following equipment:

Air temperatures:	Visala HMI41 thermohygrometer
Relative humidity	Visala HMI41 thermohygrometer
Surface temperature	Raytek ST20 infrared thermometer
Electric power	Tif 2000A Wattprobe

Figure 2: Building Monitoring Point Locations



Air Conditioning Systems and Building operating Schedules

Leo: will you please provide details?

Data Acquisition Approach

All sensors were continuously scanned and will be summed or averaged in datalogger memory every 15 minutes. The datalogger had battery backup to protect against data loss during power outages. Data were downloaded nightly and all data ranges were reviewed the next day. Out-of-range data were reported and investigated to determine whether a sensor or monitoring error exists or equipment has failed. Data were collected by Davis Energy Group and files were transferred to LBNL weekly during the monitoring period.

Datalogger and Sensor Specifications

Datalogger

A Data Electronics DT50 datalogger mounted in a NEMA 1 box were installed next to the power distribution panels in the warehouse section. The datalogger was provided with an RS232 communications interface, modem, and battery backup. A Teltone M392-B-01 telephone line-sharing switch were used to share the current fax line.

Surface Temperatures

All surface temperatures were measured with Minco RTD thermal ribbon sensors connected to the data logger with 4-20ma current transducers. Roof surface sensors were placed just under the roofing felt. Roof underside temperature were measured in the office. Insulation underside temperature were measured in the sales and warehouse.

Air Temperatures

Plenum air temperature above the office were measured in the middle of the plenum with a shielded AD592 semiconductor air sensor. Building interior temperatures were measured with a wall mounted AD592 semiconductor sensor placed next to the room Thermostat.

Weather Tower

Three sensors were mounted to a weather tower mast attached to the roof parapet wall. Outdoor dry bulb and relative humidity were measured with an R.M. Young RH/temperature probe mounted in a Gill multi-plate radiation shield. Total horizontal solar isolation were measured with a Li-Cor LI-200SZ silicon photodetector.

Power

Air-conditioner and total building power were measured with Continental Control Systems 3P-208 WattNode power transducers mounted inside the building electrical panels. Current were measured with 100 amp Magnelab split-core current transformers.

Cable

All cables were shielded twisted-pair. Exterior cable runs were brought into the building through a unit heater exhaust vent in the warehouse. All interior wire runs run above the ceiling tiles to the extent possible. Any exposed wires run vertically along door jams and securely attached.

Monitoring Period

The instrumentation was installed on August 3-4, 2002. The system was debugged and data were calibrated during the period August 4-8, 2002. The pre-retrofit (Pre) data cover the period of August 8, 2002 to September 9, 2002 (32 days). The roof was coated during September 9 and 10. The post-retrofit (post) data cover the period of September 11 to September 30, 2002 (20 days).

Data Analysis and Results

The first step in the analysis was to aggregate the validated 15-minute data into hourly and daily data. This was done for solar intensity, cooling electricity use, and total building electricity use. The temperature data were averaged to yield hourly and daily variables. In this process, questionable and missing data were identified and excluded from the analysis.

The parameters that can affect air-conditioning electricity use include outside temperature, inside temperature, solar heat gain, internal loads, relative humidity, and wind speed. A systematic regression analysis was performed in order to determine the sensitivity of the air-conditioning electricity use to these environmental parameters. The analysis was performed for the initial conditions before the roof was coated with a reflective white coating (defined as Pre period) and for the conditions after the roof was coated (defined as Post period). These regressions allowed normalizing the Pre and Post conditions for all parameters before making an attempt to estimate savings from the application of white coating.

Temperature Data

Figure 1 shows hourly temperature data for a period of two weeks before and two weeks after the roof was coated on September 11, 2002. Figure 2 shows the corresponding hourly temperatures averaged over the "Pre" (August 8 to September 9) and "Post" periods (September 11 to September 30). As Figure 2 shows the average outdoor hourly temperatures for the "Pre" and "Post" periods are remarkably similar. The maximum surface temperature in the "Pre" period is about 65°F higher than the ambient air temperature. For the "Post" period, the maximum surface temperature is only a few degrees higher than the ambient temperature. Hence, the maximum surface temperature was reduced by about 60-65°F after coating the roof. The minimum nighttime surface temperature for the "Pre" and "Post" periods can get about 20°F cooler than ambient air temperature. This is mostly because of radiative nighttime cooling to the Sacramento clear sky.

The under-roof temperature in the conditioned area "A" (area with a plenum) is about 40-50°F higher in the "Pre" period compared to "Post" period. The air temperature in the plenum under area "A" is about 20-25°F higher in the "Pre" period compared to "Post" period. The under-roof temperature in the conditioned and unconditioned areas "B" an "C" (areas without a plenum) is about 15-20°F higher in the "Pre" period compared to "Post" period.

The inside temperature in both conditioned and non-conditioned areas appear to be a few degrees cooler in the "Post" period compared to "Pre" period. In fact, according to Figure 2, the daytime average indoor temperatures at locations "A and B" are about 1.5-2°F cooler in the "Post" period. In the unconditioned area (location "C"), the daytime average indoor temperature is about 3°F cooler in the "Post" period.

Air Conditioning Energy Use and Savings

Figure 3 shows the hourly and daily electricity use for the air conditioning system 1 (AC1: RTU1 - RTU5), air conditioning 2 (AC2: RTU6 used in the office area), and the other (OTH: lighting, etc.) usages. The hourly data are shown for a period of two weeks before and after the installation of roof coating; the daily data are for the entire monitoring period through September 30. The AC2 is a small unit used in the office area with a weekly schedule that is off on Saturdays and Sundays. The AC1 is the main air conditioning system used in the sale area. In the "Pre" period, the AC1 has a peak usage of about 35 average kW. During the "Post" period, for a similar outdoor temperature, the peak AC1 usage is about 18 average kW. This suggests a peak demand savings of about 17 average kW (slightly less than 50%!). We will statistically quantify peak demand savings later on.

The same impressive results can be obtained by observing the daily electricity use for AC1. For days with similar average temperature, the "Pre" AC2 usage is about 220 kWh/day and for "Post" is about 120 kWh/day. This also suggests savings of about 100 kWh/day (slightly less than 50%!) on hot summer days.

It is also noted that the both hourly and daily electricity use for OTH during "Pre" and "Post" period are similar; typically around 250 kWh/day during the week days. During the daytime hours, the OTH electricity use ranges from13-15 kWh per hour.

Figure 4 shows the daily air-conditioning electricity use for AC1 and AC2 as a function of daily outside temperature (Tout) and the difference between outside and inside temperatures ($\Delta T = T_{out} - T_{in}$). We performed statistical analysis of a/c electricity use versus outside temperature, difference between outside and inside temperatures ($\Delta T = T_{out} - T_{in}$), and daily total insolation. The results showed strong correlation between the a/c electricity use with temperature and temperature difference. The regressions against insolation were not statistically significant and did not improve the overall regression models. Table 1 summarizes the results of the regression for temperature as independent parameter. Generally, the electricity usage for both AC1 and AC2 systems were lower during the "Post" period.

Using the correlation in Table 1, we estimated the total air conditioning (AC1+AC2) daily electricity use for the building. During the "Pre" period (August 8 to September 9, 2002), the daily average a/c use was 161 kWh per day. During the "Post" period (September 11-30, 2002), the average daily a/c electricity use was 80 kWh per day. As we indicated earlier, the average outdoor temperature during the "Pre" and "Post" period was fairly similar. Hence, without correcting for weather conditions of the "Pre" and "Post" period, the savings are estimated at 81 kWh/day (51%). Using the average daily outdoor temperature as a predictor, the estimated savings during the "Pre" and "Post" periods are estimated at 83 kWh/day and 85 kWh/day (52% and 52%), respectively. Using the difference of average outdoor and indoor temperatures, the savings were estimated at 94 kWh/day and 105 kWh/day (58% and 57%) for "Pre" and "Post" periods, respectively.

The daily a/c electricity savings increases with increasing outdoor temperature. When the average outdoor daily temperature is 87°F, we estimate that a cooling electricity use of 274 kWh/day and 139 kWh/day for the "Pre" and "Post" period, respectively. The estimated savings for both periods is 135 kWh/day (49%). Using the difference of outdoor and indoor as a predictor, for a ΔT of 7°F the estimated cooling electricity use is 273 kWh/day and 129 kWh/day for "Pre" and "Post" period, respectively. The estimated savings are 144 kWh/day and 146 kWh/day (53%). All estimates indicate savings in excess of 50%!

To estimate the effect of cool roofs on peak demand electricity use, we inspected the hourly AC1 data for hours 12 through 15 (see Figure 5). Figure 5 clearly depicts a substantial reduction in hourly a/c electricity use for all hours. The peak demand reductions are higher for higher outdoor temperature. We correlated the hourly AC1 electricity use with the hourly outdoor temperature; the correlation statistics are summarized in Table 3. The correlations indicate that the average (for hours 12-17) peak demand savings is about 13.1 kW when the outside temperature is 105°F (11 kW for 100 °F). The average peak demand savings increases by about 0.4kW/°F for outdoor temperatures above 72.6°F. On hot days, AC2 is approximately 9% of AC1 (see Table 2), hence the total the peak demand savings for AC1+AC2 is estimate at 14.3 kW when the outside temperature is 105°F (12 kW for 100 °F).

Simulated Air Conditioning Energy Use and Savings

To be added.

Some Notes on Cost-Benefit Analysis

Conditioned area: 14,500 ft2

kWh/day: 83, 85, 94, 105 (Av = 91.8)

kWh/day/1000ft2: 5.7, 5.9, 6.5, 7.2

T = 87F: kWh/day/1000ft2 = 135/14.5= 9.3

(ΔT) DT = 7F: kWh/day/1000ft2 = (144,146)/14.5 = 10

Peak kW: 105F: 14.3/14.5 = 0.99 kW/1000ft2; 100F: 12/14.5= 0.83 kW/1000ft2.

$Savings: 0.10 kWh, $20 kW/month

$Savings at average: 0.10 ($/kWh)*80(kWh/day) + 20 ($/month/kW)/30 (days/month)*10kW

$Savings at average day: $8/day + $7/day = $15

Assuming 130 days of cooling per year

$Savings per year: 130*15=$1950/year

$Incremental project cost = 0.20 ($/ft2)*14,500ft2 = $2900

Payback = $2900/1950 ($/yr)= 1.5 years!

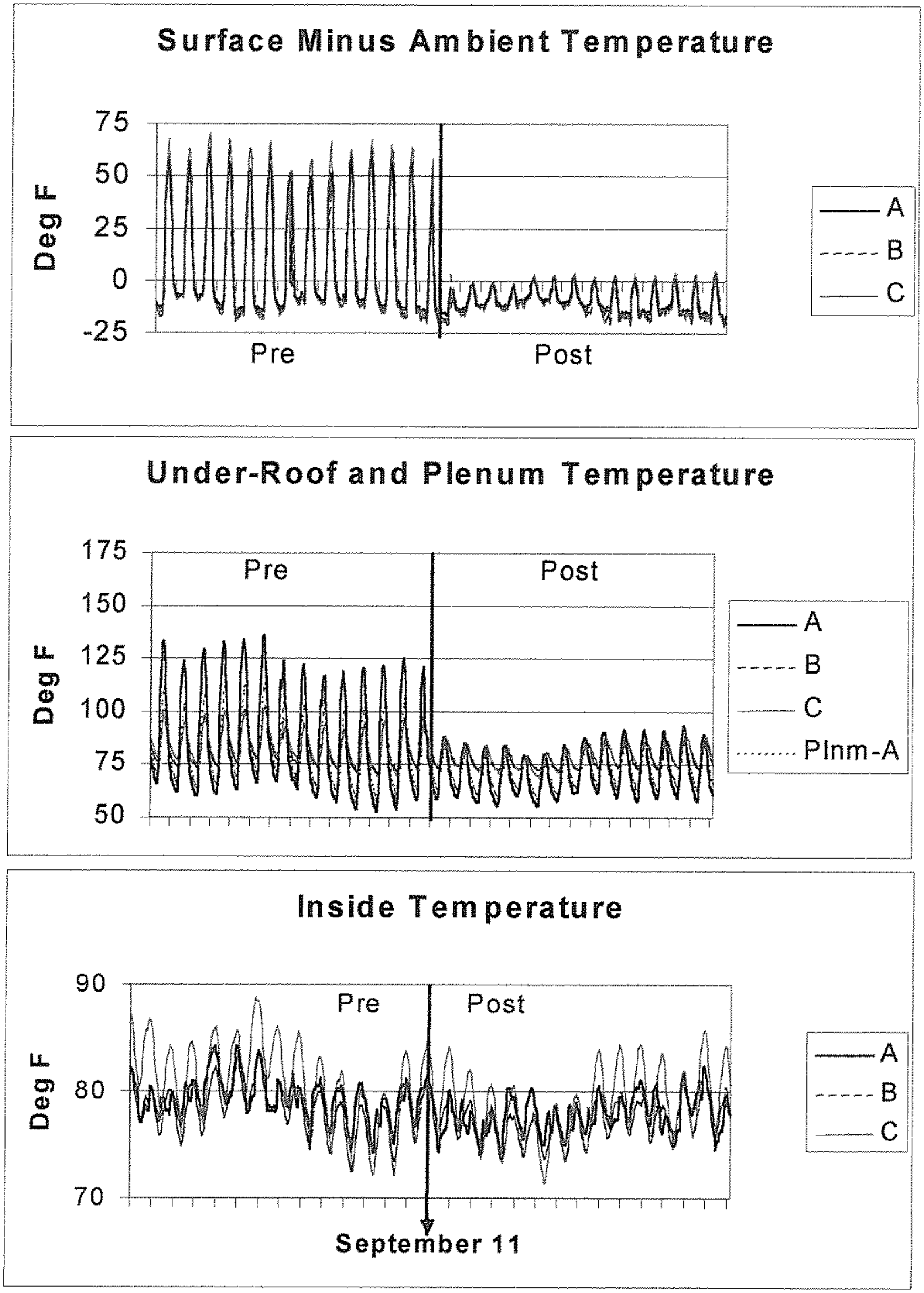


Figure 1. Hourly temperatures for a two-week period before and after installation of reflective roof coating on September 11, 2002.

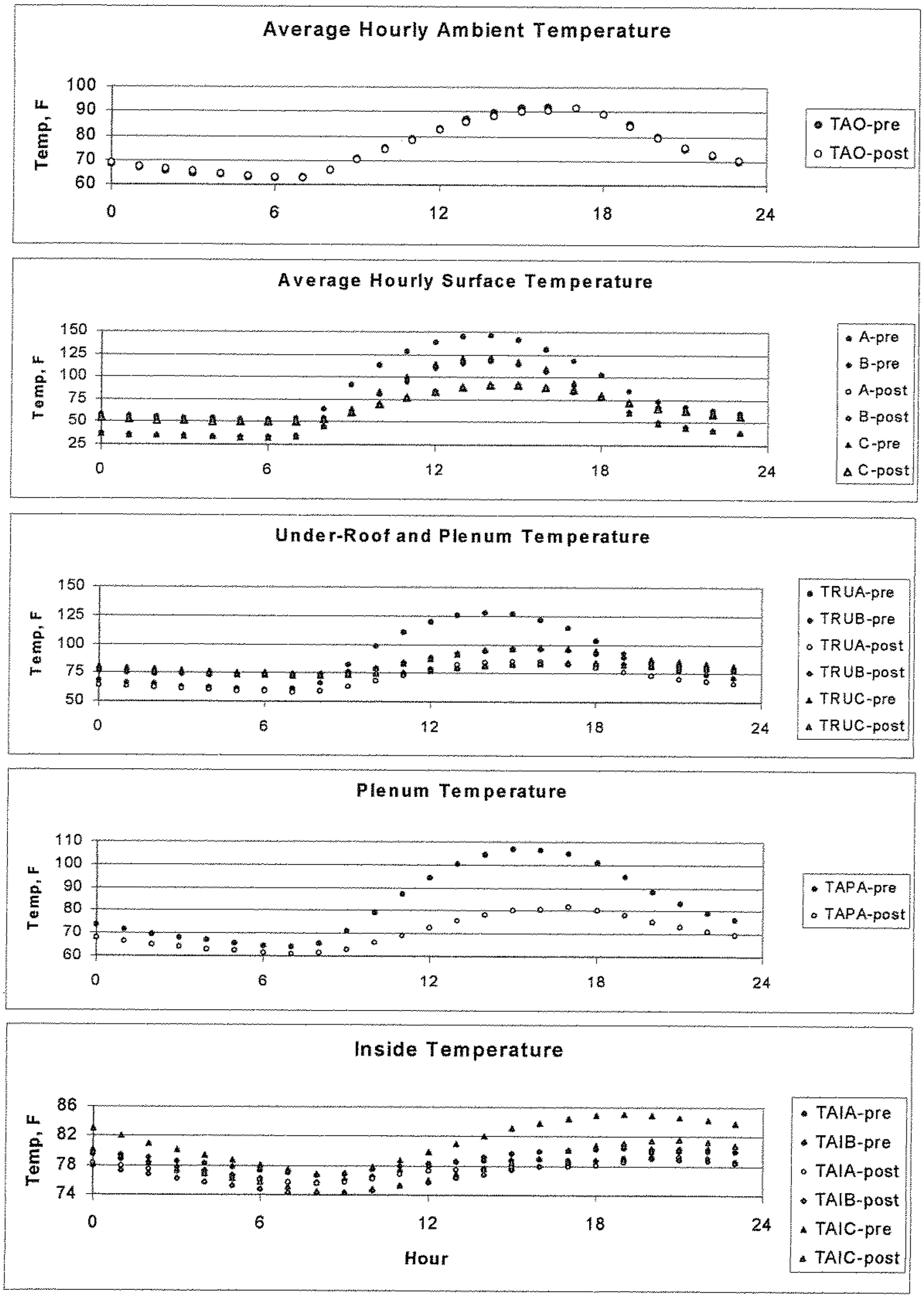


Figure 2. Average hourly temperatures before and after installation of reflective roof coating.

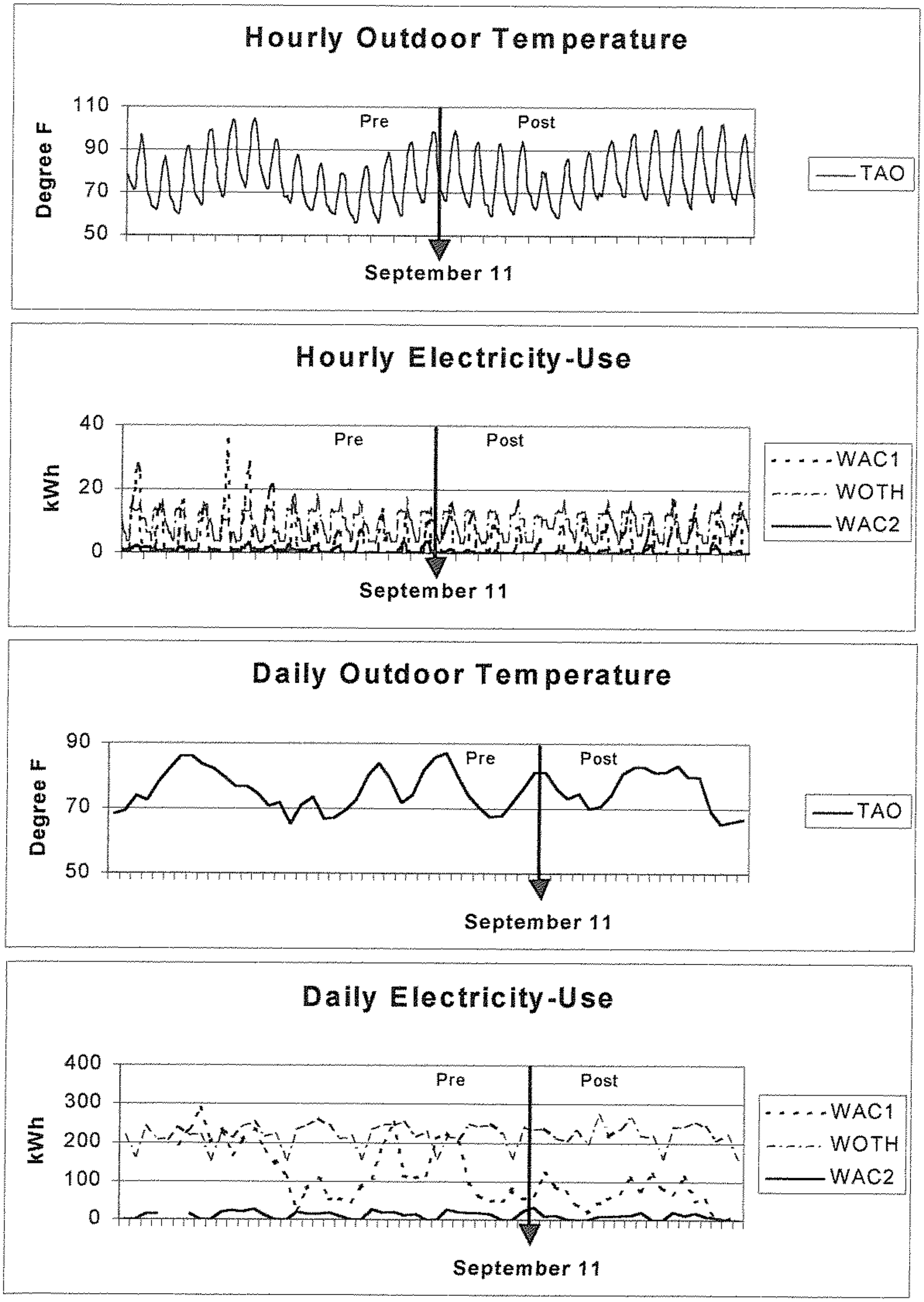
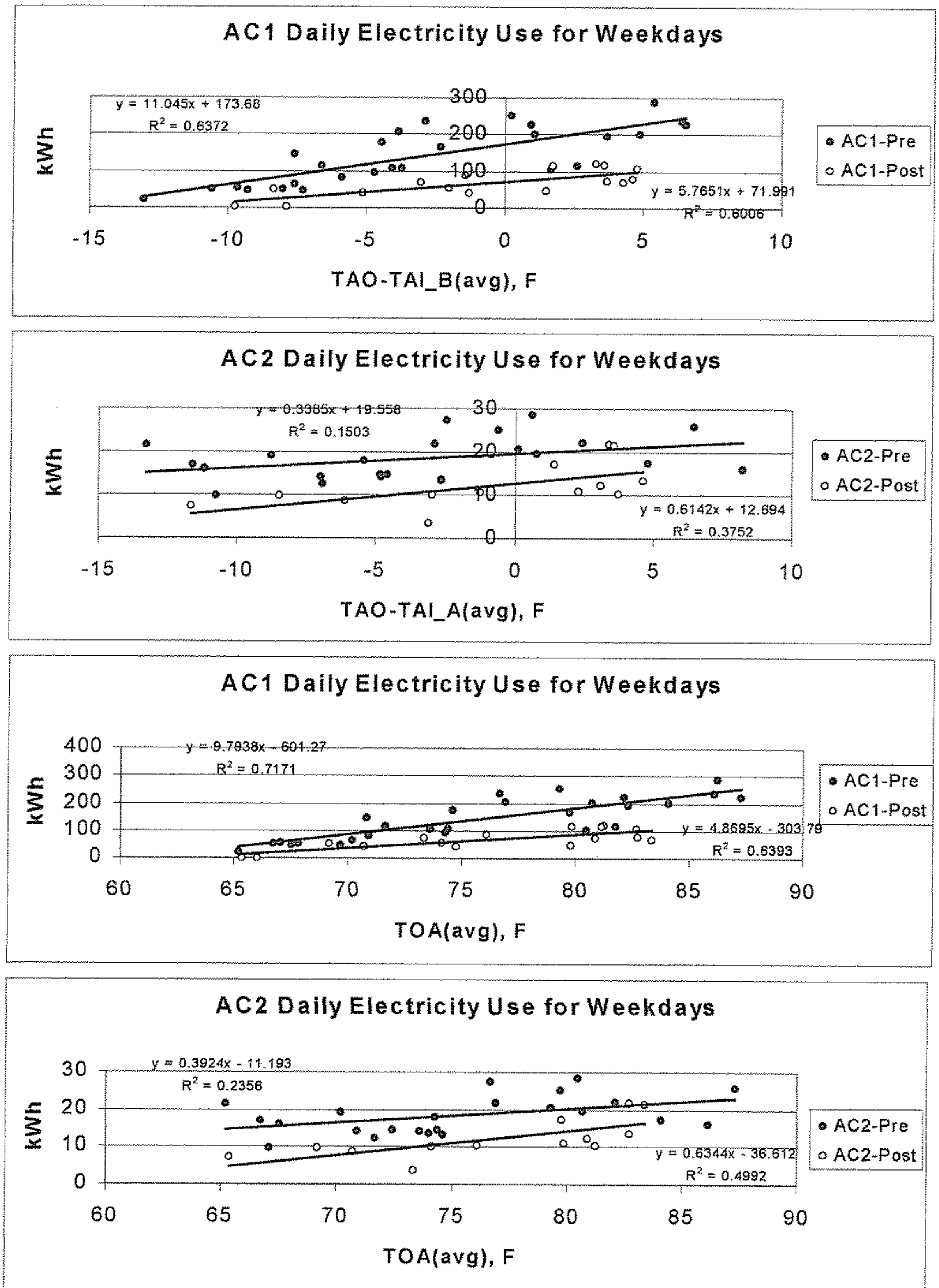


Figure 3. Hourly and daily air conditioning energy use.

Figure 4. Daily electricity use for weekdays for AC1 and AC2 as a function of daily outdoor temperature, and daily outdoor and indoor temperature difference. On hot days when the daily average ambient temperature is about over 85°F, daily savings are about 107 kWh. Daily savings increases by about 5.3 kWh/°F for outdoor/indoor temperatures above –19.3°F.



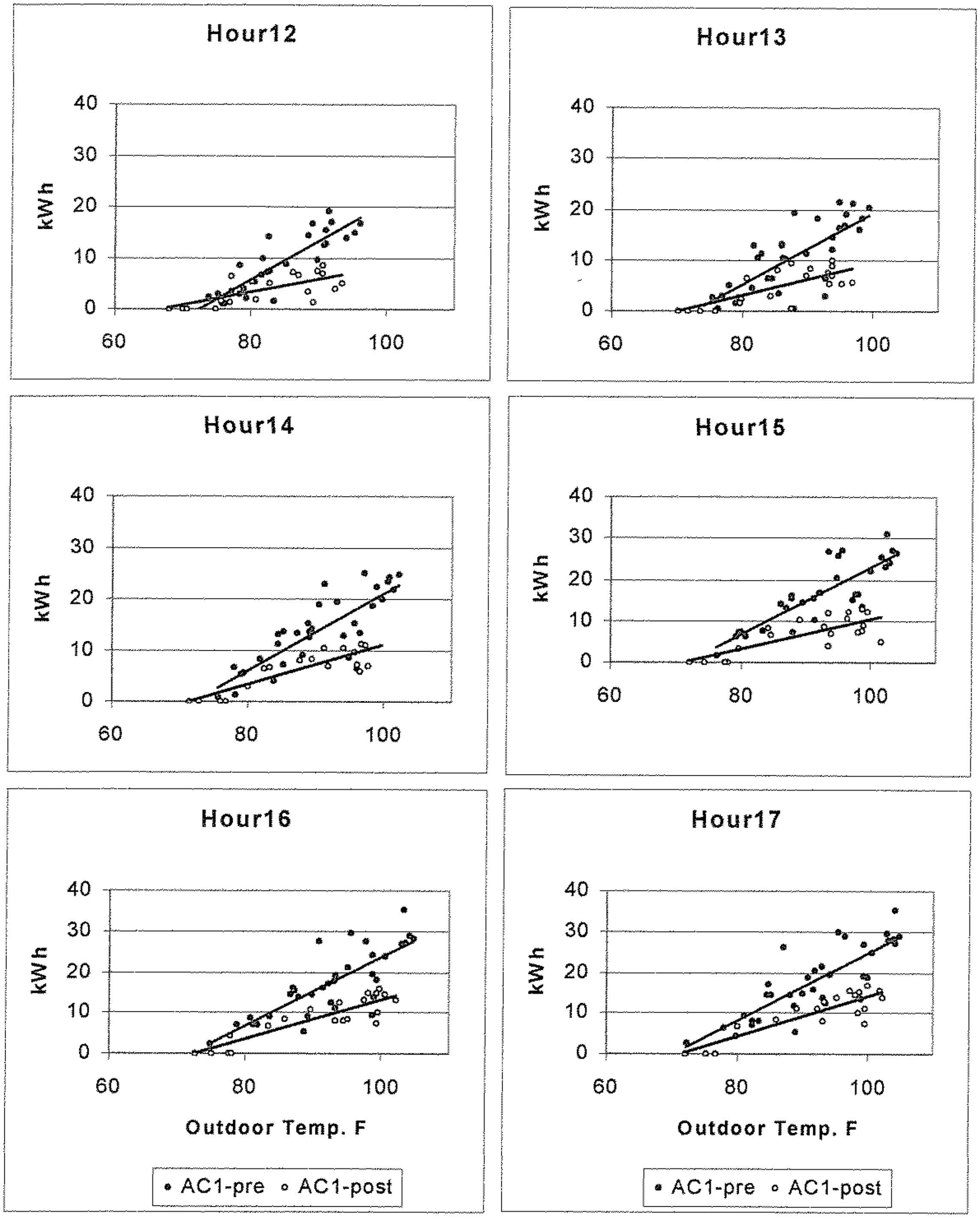


Figure 5. Hourly electricity use as a function of outdoor temperature for AC1.

Table 1. Daily electricity use regression statistics for the air conditionings.

A/C System	Pre			Post		
	C_0	C_1	R^2	C_0	C_1	R^2
AC1						
$kWh = C_0 + C_1 T_{out}$	- 601.27	9.7938	0.7171	- 303.79	4.8695	0.6393
$kWh = C_0 + C_1(T_{out} - T_{in})$	173.68	11.045	0.6372	71.991	5.7651	0.6006
AC2						
$kWh = C_0 + C_1 T_{out}$	- 11.193	0.3924	0.2356	- 36.612	0.6344	0.4992
$kWh = C_0 + C_1(T_{out} - T_{in})$	19.558	0.3385	0.1503	12.694	0.6142	0.3752

Table 2. Estimates of daily a/c electricity savings. Method 1 is based on the regressions with T_{out} and Method 2 is based on ($\Delta T = T_{out} - T_{in}$). The "Pre" shows average measured daily a/c use, estimates of a/c usages when the T_{out} = 87°F and ΔT = 7°F, and estimates of savings (Methods 1 and 2), for the period of August 8 to September 10, 2002. "Post" shows data for the period of September 11-30, 2002.

A/C System	Pre: August 8 to September 10					Post: September 11-30				
	Base use	Estimated Savings				Base use	Estimated Savings			
		Method 1		Method 2			Method 1		Method 2	
	(kWh/d)	(kWh/d)	%	(kWh/d)	%	(kWh/d)	(kWh/d)	%	(kWh/d)	%
AC1 Daily Average	**142**	*76*	54	*86*	61	**68**	*78*	53	*98*	59
T_{out} = 87°F	**251**	*131*	52			**120**	*131*	52		
ΔT = 7°F	**251**			*139*	55	**112**			*139*	55
AC2 Daily Average	**18.8**	*7.4*	39	*8.2*	44	**12.2**	*6.8*	36	*7.1*	37
T_{out} = 87°F	**22.9**	*4.4*	19			**18.6**	*4.4*	19		
ΔT = 7°F	**21.9**			*4.9*	22	**17.0**			*4.9*	22
AC1 + AC2 Daily Average	**161**	*83*	52	*94*	58	**80**	*85*	52	*105*	57
T_{out} = 87°F	**274**	*135*	49			**139**	*135*	49		
ΔT = 7°F	**273**			*144*	53	**129**			*146*	53

Table 3. Hourly electricity use regression statistics for AC1 ($kW = C_0 + C_1T$). The average peak demand savings is about 13.1 kW when the outside temperature is 105°F. The average peak demand savings increases by about 0.4kW/°F for outdoor temperatures above 72.6°F.

Hour	Pre			Post		
	C_0	C_1	R^2	C_0	C_1	R^2
12	- 54.542	0.7532	0.7577	- 17.014	0.2531	0.5026
13	- 51.158	0.7047	0.56	- 22.589	0.3199	0.5814
14	- 53.766	0.7472	0.6643	- 26.782	0.3766	0.7543
15	- 58.455	0.8152	0.7304	- 25.376	0.3578	0.5961
16	- 61.212	0.8471	0.6436	- 35.105	0.4813	0.7944
17	- 57.469	0.8208	0.6696	- 34.339	0.4824	0.7811
Average	- 56.100	0.7814		- 26.8675	0.3785	


Carpeteria
NO PAYMENT, NO INTEREST for 12 MONTHS