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Electrical Energy and Demand Savings From A Geothermal Heat Pump Energy Savings Performance Contract at Ft. Polk, LA.

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ELECTRICAL ENERGY AND DEMAND SAVINGS FROM A GEOTHERMAL HEAT PUMP ENERGY SAVINGS PERFORMANCE CONTRACT AT FT. POLK, LA.

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ABSTRACT

At Fort Polk, LA the space conditioning systems of an entire city (4,003 military family housing units) have been converted to geothermal heat pumps (GHP) under an energy savings performance contract. At the same time, other efficiency measures such as compact fluorescent lights (CFLs), low-flow hot water outlets, and attic insulation were installed. Pre- and post-retrofit data were taken at 15-minute intervals on energy flows through the electrical distribution feeders that serve the family housing areas of the post. 15-minute interval data was also taken on energy use from a sample of the residences. This paper summarizes the electrical energy and demand savings observed in this data. Analysis of feeder-level data shows that for a typical year, the project will result in a 25.6 million kWh savings in electrical energy use, or 32.4% of the pre-retrofit electrical consumption in family housing. Results from analysis of building-level data compare well with this figure. Analysis of feeder-level data also shows that the project has resulted in a reduction of peak electrical demand of 6,541 kW, which is 39.6% of the pre-retrofit peak electrical demand. In addition to these electrical savings, the facility is also saving an estimated 260,000 therms per year of natural gas. It should be noted that the energy savings presented in this document are the "apparent" energy savings observed in the monitored data, and are not to be confused with the "contracted" energy savings used as the basis for payments. To determine the "contracted" energy savings, the "apparent" energy savings may require adjustments for such things as changes in indoor temperature performance criteria, additions of ceiling fans, and other factors.

KEYWORDS

Geothermal heat pumps; Energy savings performance contracts; Electrical energy savings

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At Fort Polk, LA the space conditioning systems of an entire city (4,003 military family housing units) have been converted to geothermal heat pumps (GHP) under an energy savings performance contract. At the same time, other efficiency measures such as compact fluorescent lights (CFLs), low-flow hot water outlets, and attic insulation were installed. Pre- and post-retrofit data were taken at 15-minute intervals on energy flows through the electrical distribution feeders that serve the family housing areas of the post. 15-minute interval data was also taken on energy use from a sample of the residences. This paper summarizes the electrical energy and demand savings observed in this data. Analysis of feeder-level data shows that for a typical year, the project will result in a 25.6 million kWh savings in electrical energy use, or 32.4% of the pre-retrofit electrical consumption in family housing. Results from analysis of building-level data compare well with this figure. Analysis of feeder-level data also shows that the project has resulted in a reduction of peak electrical demand of 6,541 kW, which is 39.6% of the pre-retrofit peak electrical demand. In addition to these electrical savings, the facility is also saving an estimated 260,000 therms per year of natural gas. It should be noted that the energy savings presented in this document are the "apparent" energy savings observed in the monitored data, and are not to be confused with the "contracted" energy savings used as the basis for payments. To determine the "contracted" energy savings, the "apparent" energy savings may require adjustments for such things as changes in indoor temperature performance criteria, additions of ceiling fans, and other factors.

1. INTRODUCTION

1.1 Background

An independent evaluation of the energy savings performance contract (ESPC) at Fort Polk has been performed. The ESPC implements a number of measures in Ft. Polk's family housing to save energy and maintenance costs, the most important of which is the installation of geothermal heat pumps (GHPs) in each of the facility's 4,003 housing units. Given the scale of the retrofit, the ESPC represents a unique opportunity to obtain statistically valid data to establish the energy, demand, and maintenance savings associated with comprehensive energy efficiency retrofits anchored by GHPs. Also, since the up-front costs of housing rehabilitation were borne by an energy services company (ESCO) in exchange for a share of the energy and maintenance savings realized by the Army, the results of the evaluation will be of value to owners, ESCOs and funders in the development of future comprehensive energy efficiency projects.

1.2 Scope of ESPC

The Fort Polk Joint Readiness Training Center is located in west-central Louisiana just outside of Leesville. The 300-square-mile facility contains military offices, training centers, equipment and storage warehouses, and a hospital. The family housing stock, located in two distinct areas called North Fort and South Fort, consists of 4,003 living units in 1,292 buildings which were constructed in nine phases between 1972 and 1988. The size of the living units ranges from 1,073 to 2,746 square feet, with an average area of 1,393 square feet. Prior to implementation of the ESPC, 3,243 (or about 81%) of the residences were served by air source heat pumps and electric water heaters, while the remaining 760 had central air conditioners, natural gas forced-air furnaces, and natural gas-fired water heaters.

In January 1994, the U.S. Army awarded a 20-year ESPC of the shared savings type to an ESCO. Under the terms of the contract, the ESCO replaced the space conditioning systems in all of Ft. Polk's family housing with GHPs. The total capacity of GHPs is 6,593 tons, installed in nominal capacities of 1.5, 2, and 2.5 tons, with one heat pump per living unit. This is an average of 1.65 tons per housing unit. Each heat pump has its own ground heat exchangers of the vertical u-tube type, with one circuit (two pipes) per bore and two circuits in parallel (two single-family housing units for high-ranking officers had 2.5 ton heat pumps and three circuits in parallel). A total of 1,834,652 feet of 4 1/8 inch vertical bore was drilled (since the upper 3 feet of the bore is not part of the heat exchanger, the total installed vertical heat exchanger length is 1,810,628 feet, and a total of 3,621,256 feet of 1-inch SDR-11 high density polyethylene pipe - about 686 miles - was installed in the bores). The bores were backfilled with standard bentonite based grout. No extraordinary measures were taken to thermally enhance the grout or to maintain space between the up and down pipes in the bore.

The gas-fired water heaters were also replaced with electric water heaters. Approximately 75% of the new GHPs include desuperheaters to supplement domestic hot water heating with energy recovered from the GHP when it is operating for heating or cooling. Additional energy conservation measures included low-flow hot water outlets and compact fluorescent lighting (all indoor and outdoor fixtures attached to housing) installed in all units, and attic insulation installed as needed. Hot water tank wraps and weather stripping were identified as optional energy conservation measures that may be implemented during ongoing maintenance, but these measures are not installed at this time and the energy savings reported here were achieved without these ECMs. Table 1 summarizes the characteristics of the housing stock on each feeder. Further details of the project have been presented by Aldridge (1995).

2. EVALUATION METHODOLOGY

The evaluation approach (Hughes and Shonder, 1996), shown schematically in Figure 1, includes three interrelated levels of field data collection (Levels 1, 2, and 3). The fourth level of data collection (Energy Balance data) supports the advancement of GHP system design and energy estimating methods.

Level 1 addresses the population of housing: data on electrical demand and consumption were collected at fifteen minute intervals from submeters on fourteen of the sixteen electrical feeders that supply electricity to the family housing areas of the Fort (the original intent of course was to monitor all feeders, but the project's recording equipment could not be interfaced with existing metering on two feeders). Temperature and humidity data were also collected at fifteen-minute intervals at four different locations within the family housing area. Level 1 data allows comparison of pre- and post-retrofit energy usage patterns on the aggregate of all loads served by each feeder. As indicated in Table 1, most feeders serve one housing construction vintage, but several serve a mixture of vintages. In addition, all feeders serve street lighting and some serve other loads, as discussed below in Section 3.2.

Level 2 data collection focuses on a sample of 42 individual housing units in 16 buildings. Total premise energy use and the energy use of the heat pump (or of the air conditioner/gas furnace combination in some of the pre-retrofit units) were collected at fifteen-minute intervals. Level 2 data allows the determination of the coefficient of variation of savings across buildings and apartments. As expected, variation in savings was greatest at the apartment level and somewhat less at the building level. If pilot testing is used during the development of future projects of this nature, the coefficient of variation observed in this project can be used to calculate the required sample size if the pilot test results are to represent the population with stated confidence and error bounds.

In Level 3, more detailed energy use data were collected on a subsample of 18 of the 42 Level 2 units (7 of the 16 buildings). In addition to total premise and space conditioning energy, fifteen-minute interval data are collected to isolate the energy use of the hot water heater, the air handling system, and the furnace in the pre-retrofit condition. Again the subsample includes buildings of varying floor areas, construction vintages, and other characteristics. This technical sample is useful for understanding the relative importance of the weather-sensitive end-uses versus base loads, and supports analysis to determine the savings attributable to the various conservation measures.

This paper documents the total energy and demand savings from the project using available Level 1 and Level 2 data. A further check on the savings calculation was obtained by analyzing a set of meter readings from 145 living units made available by the ESCO.

3. ELECTRICAL ENERGY SAVINGS

3.1 Methodology

In order to determine electrical energy savings for each feeder, the 15-minute-interval energy consumption data was totaled for each day in the pre- and post-retrofit periods. Note that since construction took more than a year to complete, the pre- and post-retrofit periods are somewhat different for each feeder. The construction start and finish dates shown in Table 1 for each feeder (i.e., the dates when the first housing unit was started and the last housing unit was completed) were obtained from construction records; energy consumption data between these dates was excluded from the analysis.

In Figure 2, daily energy consumption is plotted vs. daily average temperature for a typical all-electric feeder in the pre-retrofit periods. It is seen that the data falls into three distinct regions: a heating region, in which energy consumption is a linear function of temperature with negative slope; a cooling region, in which energy consumption is also a linear function of temperature, but with positive slope; and a baseline region in which energy consumption is constant regardless of temperature.

Using the terminology of Ruch and Claridge (1991), Figure 2 suggests that a five-parameter, two changepoint model can be used to describe the post-retrofit data for each feeder, and the pre-retrofit data for those feeders which served all-electric residences. Daily energy consumption for these cases was correlated to a function of the form:

$$E = \begin{cases} E_0 + m_h(T-T_h) & T<T_h \\ E_0 & T_h<=T<=T_c \\ E_0 + m_c(T-T_c) & T>T_c \end{cases} \quad (1)$$

where E_0 is the baseline consumption, T_h and T_c are the heating and cooling changepoint temperatures, and m_h and m_c are the slope of energy use vs. daily average temperature in the heating and cooling regions, respectively.

A computer program was written which allows determination of the parameters in Eq. (1) for a given data set. Given an initial guess for the changepoint temperatures, the algorithm calculates the baseline consumption as the average energy consumption for all points corresponding to temperatures between the changepoints. Points with temperatures below the heating changepoint temperature are correlated to a line which passes through the baseline energy consumption at the heating changepoint temperature. This determines the slope of the heating line. Correspondingly, points at temperatures above the cooling changepoint temperature are correlated to a line which passes through the baseline energy consumption at the cooling changepoint temperature. Note that by using this algorithm, a trial five-parameter model is fixed once the two changepoint temperatures are selected. The program calculates the sum of squared errors between the energy consumption data and the energy consumption predicted by the trial five-parameter model. A gradient search technique is then used to determine the changepoint temperatures that minimize the sum of squared errors between the data and the model.

Figure 3 is a plot of daily energy consumption vs. daily average temperature for a typical feeder on which the residences were originally heated by natural gas. It is seen that for these feeders, the data falls into only two regions: a cooling region, in which energy consumption is a linear function of daily average temperature, and a baseline region in which energy consumption is independent of daily average temperature. For these feeders, a three-parameter, single changepoint model was used, and the data was correlated to a function of the form:

$$\begin{array}{ll} E_0 & T<=T_c \\ E_0 + m_c(T-T_c) & T>T_c \end{array} \quad (2)$$

where E_0 is the baseline consumption, T_c is the cooling changepoint temperature, and m_c is the slope of energy use vs. daily average temperature in the cooling region. As with the algorithm for the 5-parameter correlation, selecting a changepoint temperature fixes the values of the baseline energy consumption and the cooling slope. An algorithm similar to the one described above is used to determine the changepoint temperature that results in a model with the lowest sum of squared errors.

Daily energy consumption vs. daily average temperature was correlated to a 5 or 3 parameter model as required for all fourteen feeders in their respective pre- and post-retrofit periods. The complete data set is shown in Figure 4. Table 2 presents the parameters for each model.

3.2 Level 1 Energy Savings Calculations

Once pre- and post-retrofit correlations were developed for each feeder, energy consumption was normalized to a typical meteorological year (TMY). Lufkin, Texas is the nearest inland location to Ft. Polk for which TMY data exists, and the climate is similar. The average daily temperature was calculated for each TMY day, and the daily energy consumption for each feeder in the pre- and post-retrofit condition was determined using the models described in Table 2. Values for daily energy consumption were then totaled to give annual energy consumption for each feeder. The results of this analysis are shown in Table 3.

Since no data were available for feeders 18 and 19, energy savings were estimated using data from the other all-electric feeders. It was thought initially that energy consumption in these housing units would correlate well with year of construction. Figure 5 shows that this is not the case. However there does seem to be a strong relationship between energy consumption per housing unit and the average floor area of the units. These correlations were used to estimate electrical consumption from the housing on feeders 18 and 19.

Based on this analysis, it is seen that the total electrical energy consumption in family housing for a typical year at Ft. Polk drops from 79.2 million kWh to 53.6 million kWh, a reduction of about 25.6 million kWh, or 32.4% of the pre-retrofit consumption. Note that for units which were all-electric in the pre-retrofit period (housing on feeders 1,2,3,6,7,15,16,17,18 and 19) the average savings is 35.1%, whereas for units which had natural gas heat prior to the retrofit (housing on feeders 5,11,12,13 and 14) the average savings is 14.3%.

A possible shortcoming of the analysis is that the feeders may contain loads other than family housing. All feeders include street lighting, but it is known that Feeder 2, for example, serves both a sewage lift station and the offices of a maintenance contractor. Energy consumption for these non-housing loads may not be the same for the pre- and post-retrofit periods. This seems almost certain to be the case for feeder 4, which shows a net increase in energy consumption as a result of the retrofits. The large reduction seen on feeder 7 may also be due, in part, to a reduction in non-residential loads. Another possibility is that some of the housing on feeder 7 was switched to other feeders during the post-retrofit period (the housing area feeders have switches and interconnects to enable power restoration when the normal configuration requires repair).

3.3 Level 2 Energy Savings

In addition to the feeder-level data, 15-minute interval data on energy consumption was also collected for a sample of 42 housing units in 16 separate buildings. As with the Level 1 data, 5-parameter, dual changepoint models of daily energy consumption versus daily average temperature were developed in order to normalize energy consumption to a TMY. However, given the high degree of scatter evident in the data, it was decided to develop models for individual buildings rather than individual apartments, by totaling the energy consumption for individual apartments within each monitored building. At present, sufficient post-retrofit data exists for 12 of these buildings (38 individual housing units). Physical characteristics of the buildings analyzed are presented in Table 4, and parameters for the dual changepoint models for each building, pre- and post-retrofit, are presented in Table 5.

Normalized TMY energy consumption for the 12 buildings, pre- and post-retrofit, is presented in Table 6. Note that the apartments in these 12 buildings were all-electric in the pre-retrofit. The aggregate figure of 33.6% energy savings is comparable to the figure of 35.1% savings for those feeders containing housing which was all-electric in the pre-retrofit. It is to be expected that feeder level savings would be slightly higher, because power is transformed to 220 volts for the building service entrances (i.e., lower power consumption after retrofit reduces the load on the transformers, thereby reducing losses).

3.4 ESCO Metered Data

As part of its own efforts to document pre- and post-retrofit energy use, the ESCO manually recorded data from existing kilowatt-hour meters on a number of housing units at Ft. Polk. Two sets of meter readings were obtained from the ESCO, one from 3/95 through 11/96 covering 50 units, and another from 10/95 through 11/96 covering an additional 95 units. Beginning in 10/95, the meters were read on the same day of the month for both sets, allowing them to be combined into a single set. Since the retrofit date for each unit was known, the combined readings were then divided into pre- and post-retrofit sets.

In order to develop an independent estimate of energy savings based on these meter readings, it was necessary to normalize them to a TMY. This was achieved by correlating average daily consumption (in kWh/ft^2/day) from the meter readings with the average heating and cooling degree days per day in each month (base 65°F), for the pre- and post-retrofit data. Note that since construction was ongoing during the period the meter readings were taken, the number of readings which fall into the pre- and post-retrofit categories varies from month to month. In each month, energy consumption was totaled for those units which had readings. This total was divided by the total square feet of living space contained in the units for which readings had been taken, and by the number of days in the period. This gave the average kWh/ft^2/day for the period. Figures for heating and cooling degree days per day for each period were obtained from the project's monitored weather data.

A problem with the ESCO's data was that it included only ten apartments which had gas/electric systems in the pre-retrofit. Since the ratio of gas/electric apartments in the sample is much smaller than the ratio in the housing population, a separate correlation was attempted for the gas/electric apartments. However, of the ten apartments in the sample, only seven included any pre-retrofit data, and then for an average of only five months in each case. The correlation did not produce a reliable value of annual energy consumption per square foot for pre-retrofit gas/electric apartments, based on comparison with the figures in Table 3. Thus it was decided to eliminate the ten gas/electric apartments from the data.

Table 7 presents the results of the analysis of the ESCO's meter readings for the pre- and post-retrofit; the data is plotted as Figure 6. When normalized to a TMY, the ESCO's meter readings indicate an average pre-retrofit energy consumption of 14.89 kWh/ft^2 and an average post-retrofit consumption of 9.79 kWh/ft^2, a savings of 34.4%, which compares well with the value of 35.1% obtained from our feeder-level data, and 33.6% from our building-level data. The ESCO data was obtained from meters that were never calibrated or read on a regular basis until the ESCO started to do so in 1995. Under the circumstances, the level of agreement is surprising.

4. DEMAND SAVINGS

In cooling-dominated climates such as Ft. Polk's, the peak demand hour typically occurs during the summer, on or near the hottest day of the year, usually from 4:00 to 5:00 in the afternoon. In general, electrical demand is a complex phenomenon which depends on numerous variables such as time of day and day of the week, outdoor temperature, average temperature during a number of past hours, average temperature during a number of past days, and others. Utilities commonly use five years or more of historical data for their demand models (Kim, 1982). A rigorous analysis of electrical demand savings of the Ft. Polk project would require the development of such models for both the pre- and post-retrofit for each feeder. As in the case of annual energy consumption, the models would then be normalized to a typical meteorological year to determine the savings.

For the purposes of this evaluation, a simpler approach, more appropriate for the project (one year pre-retrofit and eventually one year post-retrofit data) was used. The assumption was made that daily average temperature is the dominant variable in determining peak electrical demand. The 15-minute interval energy consumption data allowed us to determine daily electrical demand profiles for each feeder. The hour of interest (coincident with serving utility peak demand) was taken to be 4-5 PM. Demand profiles from three pre-retrofit and three post-retrofit days with essentially identical temperatures were selected and used to establish three-day-average pre- and post-retrofit profiles. Demand savings was determined as the difference between the three-day-average profiles averaged over the 4-5 PM time period.

Pre- and post-retrofit demand profiles for a typical feeder, feeder 2, are shown in Figure 7. The average temperature for the pre- and post-retrofit periods corresponds to the highest temperature observed in the post-retrofit period. The post-retrofit data are not available at the most extreme (high) daily average temperatures observed in the pre-retrofit on some feeders. This is a consequence of summer 1996 being relatively mild, and retrofit construction on some feeders not being completed until well into August 1996. Since the demand savings of interest is the demand savings on the extreme days, it was necessary to repeat our matched group analysis (three days pre/post at essentially identical average daily temperatures) at several daily average temperatures and extrapolate up to the most extreme daily average temperature observed in the pre-retrofit data (91.58 °F). Figure 8 shows the results of this analysis for a typical feeder (Feeder 2).

The results of the analysis are shown in Table 8. In order to develop estimates for demand reductions on feeders 11-19, gas/electric feeders were assumed to have the same average load factor as feeder 5, while all-electric feeders were assumed to have the same average load factor as feeders 1, 2, 3, 6 and 7 (the anomalously high post-retrofit load factor for feeder 4 was ignored). The total peak demand reduction for the family housing area is estimated at 6,541 kW, or 39.6% of the pre-retrofit peak demand.

5. CONCLUSIONS

At Ft. Polk, Louisiana, the space conditioning systems of 4,003 housing units have been replaced with ground-source heat pumps as part of a major energy savings performance contract (ESPC). Other smaller-scale energy conservation measures have also been carried out. Analysis of feeder-level data shows that for a typical year, the project will result in a 25.6 million kWh savings in electrical energy use, or 32.4% of the pre-retrofit electrical consumption in family housing. Results from analysis of building-level data compare well with this figure. Analysis of feeder-level data also shows that the project has resulted in a reduction of peak electrical demand of 6,541 kW, which is 39.6% of the pre-retrofit peak electrical demand. These electrical savings were achieved even though 100% of the housing was all-electric after the retrofit, compared with 80% before (the remainder originally had gas furnaces and water heaters). In addition to these electrical savings, the facility is also saving an estimated 260,000 therms per year of natural gas. Based on these results, Fort Polk is exceeding the mandate of Executive Order 12902, "Energy Efficiency and Water Conservation at Federal Facilities, signed by President Clinton on March 8 1994. The order directs Federal agencies to develop and implement a plan for achieving a 30% reduction of energy use in all their facilities, relative to 1985 consumption, by the year 2005.

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Feeder	Pre-retro HVAC	Number of Bldgs	Number of units	Construction vintage	Total sq. ft.	Average sq.ft./unit	Installed tons	Retrofit Construction Start	End
1	all-electric	46	200	1981	231248	1156	300.0	8/10/95	9/1/95
2	all-electric	416	1220	1976/1980	1741947	1428	2034.5	10/20/95	3/25/96
3	all-electric	40	40	1976	74966	1874	80.5	3/11/96	3/18/96
4	mixture	6	6	1975-1984	12004	2001	12.0	6/12/95	8/8/96
5	gas/elect.	45	100	1972/1975	149480	1495	190.0	5/30/95	8/10/95
6	all-electric	22	80	1977	108768	1360	130.0	7/13/95	8/10/95
7	all-electric	193	571	1977	907593	1589	987.5	3/12/95	4/30/96
11	gas/elect.	57	152	1975	212170	1396	269.0	4/11/95	4/17/96
12	gas/elect.	50	142	1975	184992	1303	243.0	4/23/95	5/15/96
13	gas/elect.	47	162	1975	202168	1248	265.0	4/29/95	5/16/96
14	gas/elect.	63	200	1972	250134	1251	344.0	5/13/95	6/5/96
15	all-electric	49	200	1984	276794	1384	300.0	5/22/95	6/24/96
16	all-electric	77	306	1987	387846	1267	459.0	6/5/96	7/1/96
17	all-electric	82	275	1987	351873	1280	413.0	6/18/96	8/1/96
18	all-electric	43	168	1988	232519	1384	273.5	6/18/96	8/1/96
19	all-electric	56	181	1988	252110	1393	292.0	6/18/96	8/1/96
TOTAL		**1292**	**4003**		**5576612**	**1393**	**6593.0**		

Table 1: Characteristics of Ft. Polk family housing stock.

Feeder	Status	E_0 (kWh)	T_h (°F)	T_c (°F)	m_h (kWh/°F)	m_c (kWh/°F)	RMSE
1	pre	6597.5	56.9	69.8	-200.7	187.5	405.7
	post	4729.6	49.1	65.7	-97.6	104.7	461.7
2	pre	59304.4	57.0	68.5	-2676.0	2053.3	4341.8
	post	43003.9	54.5	65.7	-916.7	1132.5	2345.4
3	pre	2752.3	57.5	68.1	-108.8	89.3	271.1
	post	2194.5	54.8	66.6	-51.3	65.5	168.9
4	pre	350.9	62.4	69.1	-6.6	19.7	37.9
	post	413.4	55.4	66.3	-7.5	9.2	33.6
5	pre	2295.8	n/a	64.2	n/a	176.9	367.2
	post	3035.2	56.9	65.6	-49.6	63.6	388.3
6	pre	3430.8	56.7	67.9	-111.7	106.7	297.4
	post	2280.1	53.5	65.5	-53.2	57.0	207.9
7	pre	30197.2	57.6	69.6	-1488.0	927.3	2347.4
	post	13708.4	57.6	65.4	-355.0	365.3	1047.3
11	pre	4149.7	n/a	65.3	n/a	320.8	531.8
	post	4212.6	53.9	64.3	-89.7	121.0	365.6
12	pre	3594.6	n/a	63.7	n/a	253.0	427.8
	post	3649.1	57.0	65.4	-79.8	115.4	257.7
13	pre	3968.9	n/a	64.3	n/a	297.1	478.3
	post	3994.3	54.6	65.4	-88.3	140.3	254.0
14	pre	4118.9	n/a	63.9	n/a	383.1	636.3
	post	4435.0	56.6	64.8	-109.6	144.8	359.1
15	pre	9000.9	57.2	69.5	-465.5	264.2	898.5
	post	6120.3	57.0	66.3	-169.7	135.6	427.6
16	pre	13151.1	54.1	70.0	-696.1	576.4	1329.0
	post	11000.2	55.4	65.7	-221.3	250.7	630.3
17	pre	8736.7	54.2	70.6	-483.9	368.3	747.9
	post	7113.0	54.9	66.1	-156.0	151.6	413.9

Table 2: Constants for 5-parameter, dual changepoint model for each feeder, pre- and post-retrofit.

Feeder	Pre-Retrofit Annual kWh	Pre-Retrofit Annual kWh/ft²	Pre-Retrofit Daily kWh/unit	Post-Retrofit Annual kWh	Post-Retrofit Annual kWh/ft²	Post-Retrofit Daily kWh/unit	Total Savings	Percent Savings	Savings kWh/unit	Savings kWh/ft²	Savings kWh/ton
1	2873622	12.43	39.36	2001455	8.66	27.42	872167	30.4%	4361	3.77	2907
2	27722779	15.91	62.26	18957249	10.88	42.57	8765530	31.6%	7185	5.03	4308
3	1273012	16.98	87.19	977428	13.04	66.95	295584	23.2%	7390	3.94	3672
4	170119	14.17	77.68	176601	14.71	80.64	-6482	-3.8%	-1080	-0.54	-540
5	1299381	8.69	35.60	1301597	8.71	35.66	-2215	-0.2%	-22	-0.01	-12
6	1551831	14.27	53.14	999095	9.19	34.22	552736	35.6%	6909	5.08	4252
7	13918902	15.34	66.78	6217805	6.85	29.83	7701097	55.3%	13487	8.49	7799
11	2278945	10.74	41.08	1912352	9.01	34.47	366593	16.1%	2412	1.73	1363
12	2002139	10.82	38.63	1678039	9.07	32.38	324100	16.2%	2282	1.75	1334
13	2216799	10.97	37.49	1852790	9.16	31.33	364009	16.4%	2247	1.80	1374
14	2530362	10.12	34.66	2076470	8.30	28.44	453892	17.9%	2269	1.81	1319
15	4137766	14.95	56.68	2687859	9.71	36.82	1449907	35.0%	7250	5.24	4833
16	6112001	15.76	54.72	4763891	12.28	42.65	1348110	22.1%	4406	3.48	2937
17	4015635	11.41	40.01	3049713	8.67	30.38	965922	24.1%	3512	2.75	2339
18	3393767	14.60	55.35	2343163	10.08	38.21	1050604	31.0%	6254	4.52	3841
19	3694537	14.65	55.92	2559794	10.15	38.75	1134743	30.7%	6269	4.50	3886
TOTAL (TMY)	**79191597**	**14.20**	**54.20**	**53555301**	**9.60**	**36.65**	**25636297**	**32.4%**	**6404**	**4.60**	**3888**

Notes:

(1) Calculations based on typical meteorological year for Lufkin, TX, which is the nearest location to Ft. Polk with complete TMY data.
(2) Average family housing electrical use for 1989-1992 was 81417898 kWh/yr, 2.9% higher than 94-95 baseline normalized to Lufki
(3) Percent savings varies by feeder due to a number of factors:
- Type of HVAC equipment replaced (all-electric or gas/electric)
- Retrofits installed (e.g., not all housing received additional attic insulation)
- Existence of non-housing loads on some feeders; see note (4).

(4) Meter 2 includes a sewage lift station and the offices of a maintenance contractor; feeder 4 also likely contains significant non-hou
(5) No family housing on feeders 8 and 10; meter for feeder 7 includes feeder 9
(6) Pre- and post-retrofit energy use are estimated for feeders 18 and 19.

Table 3: Pre- and post-retrofit TMY energy use by feeder for level 1 data.

Building	Feeder	No. of units	Total sq. ft.	sq.ft./ unit	Installed tons	Const. vintage
209	7	4	7016	1754	6	1977
210	6	4	4696	1174	6	1977
211	3	1	1794	1794	2	1976
213	1	4	4632	1158	6	1981
214	2	2	3456	1728	4	1976
215	2	4	4292	1073	6	1976
216	2	2	3396	1698	4	1976
217	2	2	3728	1864	4	1976
218	2	4	4292	1073	6	1976
219	2	4	4292	1073	6	1976
220	2	5	6282	1256	7.5	1980
223	19	2	2542	1271	3	1988

Table 4: Characteristics of the twelve level 2 buildings analyzed.

Building	Status	E_0 (kWh)	T_h (°F)	T_c (°F)	m_h (kWh/°F)	m_c (kWh/°F)	RMSE
209	pre	228.5	59.7	68.1	-12.38	9.74	54.0
	post	135.7	59.5	64.2	-6.26	5.82	38.8
210	pre	145.6	46.9	61.3	-8.24	3.78	26.5
	post	68.9	56.2	64.8	-2.38	2.56	22.7
211	pre	58.6	59.7	68.2	-2.13	2.12	19.9
	post	41.4	53.2	67.7	-1.75	1.38	12.0
213	pre	132.2	50.2	73.3	-10.07	3.68	19.9
	post	97.6	56.1	63.9	-1.70	1.00	20.0
214	pre	90.2	51.3	54.3	-5.56	3.46	24.8
	post	99.4	51.7	52.9	-0.53	0.10	15.5
215	pre	207.5	58.5	75.1	-4.94	10.07	42.4
	post	98.5	57.2	65.3	-1.56	5.72	21.1
216	pre	92.0	60.9	71.1	-7.61	4.43	26.3
	post	115.2	60.9	62.7	-4.38	0.93	18.2
217	pre	122.9	53.5	68.2	-5.64	3.37	37.0
	post	80.2	61.2	74.8	-1.61	2.91	20.1
218	pre	155.3	56.7	68.8	-6.12	6.23	33.7
	post	136.1	56.1	65.5	-1.41	4.29	23.1
219	pre	185.2	60.5	68.0	-6.11	4.71	36.7
	post	95.0	61.9	78.0	-1.20	2.78	17.5
220	pre	166.3	52.8	68.4	-8.41	5.79	29.2
	post	133.3	54.6	72.7	-3.81	2.01	17.4
223	pre	77.7	54.6	72.7	-4.69	5.95	33.5
	post	70.1	47.6	66.6	-0.71	2.71	15.0

Table 5: Constants for 5-parameter dual changepoint models for the twelve level 2 buildings.

	Pre-Retrofit			Post-Retrofit			Projected Savings				
Building	Annual kWh	Annual kWh/ft^2	Daily kWh/unit	Annual kWh	Annual kWh/ft^2	Daily kWh/unit	Annual kWh	Annual kWh/unit	Annual kWh/ft^2	Annual kWh/ton	Percent Savings
209	116205	16.6	79.6	72327	10.3	49.5	43878	10970	6.25	7313	37.8%
210	67633	14.4	46.3	33553	7.1	23.0	34079	8520	7.26	5680	50.4%
211	27796	15.5	76.2	18769	10.5	51.4	9027	9027	5.03	4514	32.5%
213	55797	12.0	38.2	39768	8.6	27.2	16030	4007	3.46	2672	28.7%
214	53435	15.5	73.2	37121	10.7	50.9	16314	8157	4.72	4078	30.5%
215	87845	20.5	60.2	51018	11.9	34.9	36827	9207	8.58	6138	41.9%
216	49577	14.6	67.9	50786	15.0	69.6	(1,209)	(605)	(0.36)	(302)	(2.4%)
217	54443	14.6	74.6	33578	9.0	46.0	20866	10433	5.60	5216	38.3%
218	72648	16.9	49.8	60910	14.2	41.7	11738	2934	2.73	1956	16.2%
219	84212	19.6	57.7	37417	8.7	25.6	46795	11699	10.90	7799	55.6%
220	75739	12.1	41.5	53419	8.5	29.3	22320	4464	3.55	2976	29.5%
223	37717	14.8	51.7	31491	12.4	43.1	6227	3113	2.45	2076	16.5%
TOTAL TMY:	**783045**	**15.5**	**56.5**	**520155**	**10.3**	**37.5**	**262890**	**6918**	**5.21**	**4345**	**33.6%**

Table 6: Pre- and post-retrofit TMY energy use for the twelve level 2 buildings.

Pre-Retrofit

Days in period	Average degree-days per day	kWh/ft^2 per day	Total square feet
28	9.05	0.0337	49500
35	6.01	0.0328	49500
35	14.09	0.0421	49500
28	16.99	0.0453	49500
28	21.10	0.0509	43740
35	21.85	0.0512	38874
30	14.70	0.0552	121423
27	4.95	0.0325	109981
33	11.08	0.0321	112736
29	16.67	0.0447	111546
33	20.07	0.0540	109400
29	10.49	0.0389	93215
31	11.22	0.0372	53214
31	6.64	0.0409	31791
31	12.09	0.0409	29153
34	16.46	0.0495	11095

Post-Retrofit

Days in period	Average degree-days per day	kWh/ft^2 per day	Total square feet
28	9.05	0.0264	19702
35	6.01	0.0241	19702
35	14.09	0.0270	19702
28	16.99	0.0322	18121
28	21.10	0.0355	18121
35	21.85	0.0356	18121
30	14.70	0.0311	43319
27	4.95	0.0235	61088
33	11.08	0.0238	78016
29	16.67	0.0256	80002
33	20.07	0.0304	80002
29	10.49	0.0247	82148
31	11.22	0.0251	100672
31	6.64	0.0250	145406
31	12.09	0.0245	165639
34	16.46	0.0315	157406
30	18.64	0.0275	180837
33	15.06	0.0305	191567
28	8.96	0.0254	195948
37	3.52	0.0212	192628

Table 7: Summary of ESCO Meter Readings, pre- and post-retrofit.

	Pre-Retrofit			Post-Retrofit			Demand	Percent
feeder	peak kW	annual kWh	load factor	peak kW	annual kWh	load factor	Reduction	Reduction
1	551	2873622	0.59	384	2001455	0.60	168	30.4%
2	5200	27722779	0.61	3448	18957249	0.63	1752	33.7%
3	267	1273012	0.54	222	977428	0.50	45	16.8%
4	43	170119	0.45	22	176601	0.93	22	49.7%
5	459	1299381	0.32	246	1301597	0.60	213	46.4%
6	356	1551831	0.50	175	999095	0.65	181	50.7%
7	2304	13918902	0.69	1128	6217805	0.63	1176	51.0%
11	806	2284612	0.32	363	1910931	0.60	443	54.9%
12	708	2008792	0.32	317	1670374	0.60	391	55.2%
13	781	2214590	0.32	351	1848926	0.60	430	55.0%
14	892	2530362	0.32	396	2085527	0.60	496	55.6%
15	804	4132427	0.59	507	2669872	0.60	296	36.9%
16	1188	6111433	0.59	904	4755023	0.60	285	24.0%
17	781	4015635	0.59	576	3032894	0.60	205	26.2%
18	660	3393136	0.59	447	2354659	0.60	212	32.2%
19	718	3693865	0.59	488	2570669	0.60	230	32.0%
Total	**16519**	**79194498**	**0.55**	**9977**	**53530105**	**0.61**	**6541**	**39.6%**

Table 8: Peak demand, annual consumption and load factor by feeder, pre- and post-retrofit.

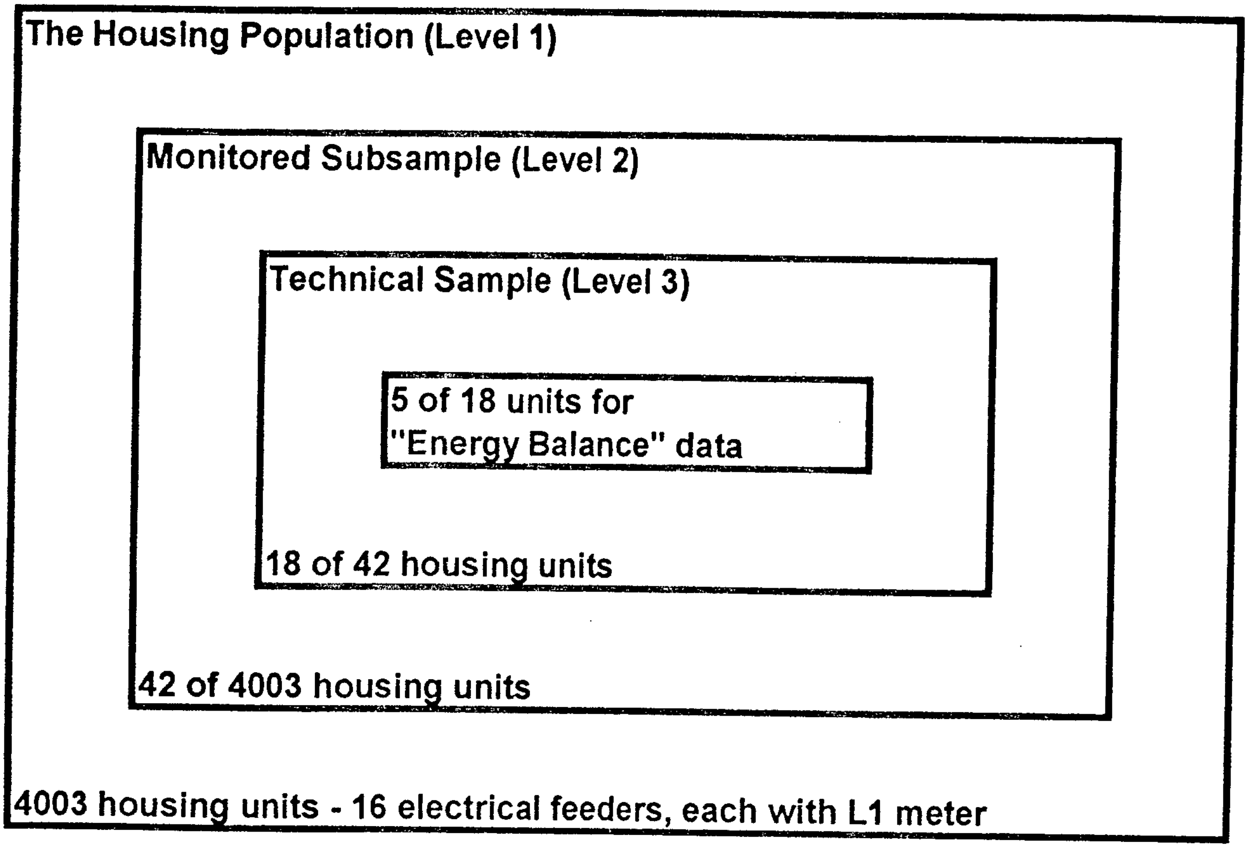

Figure 1: ORNL evaluation approach.

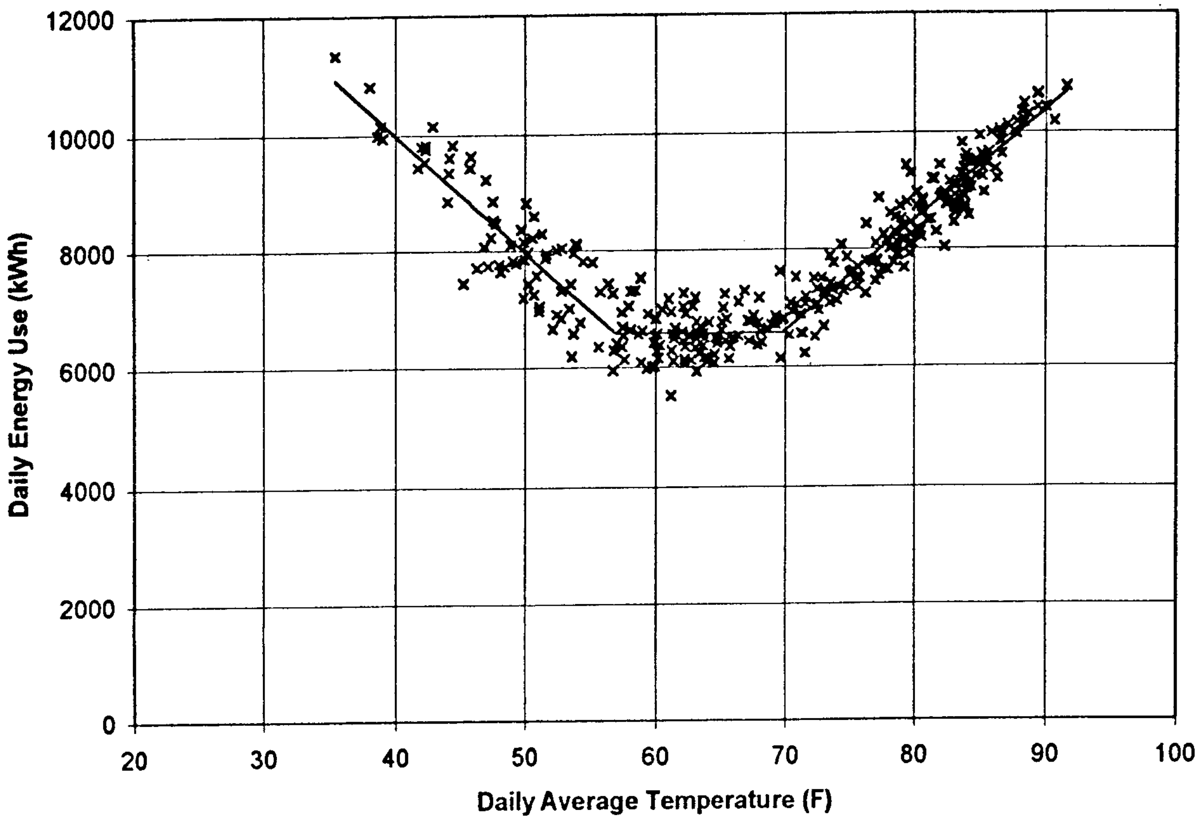

Figure 2: Daily electrical energy use for a typical feeder serving housing which was all-electric prior to the retrofits.

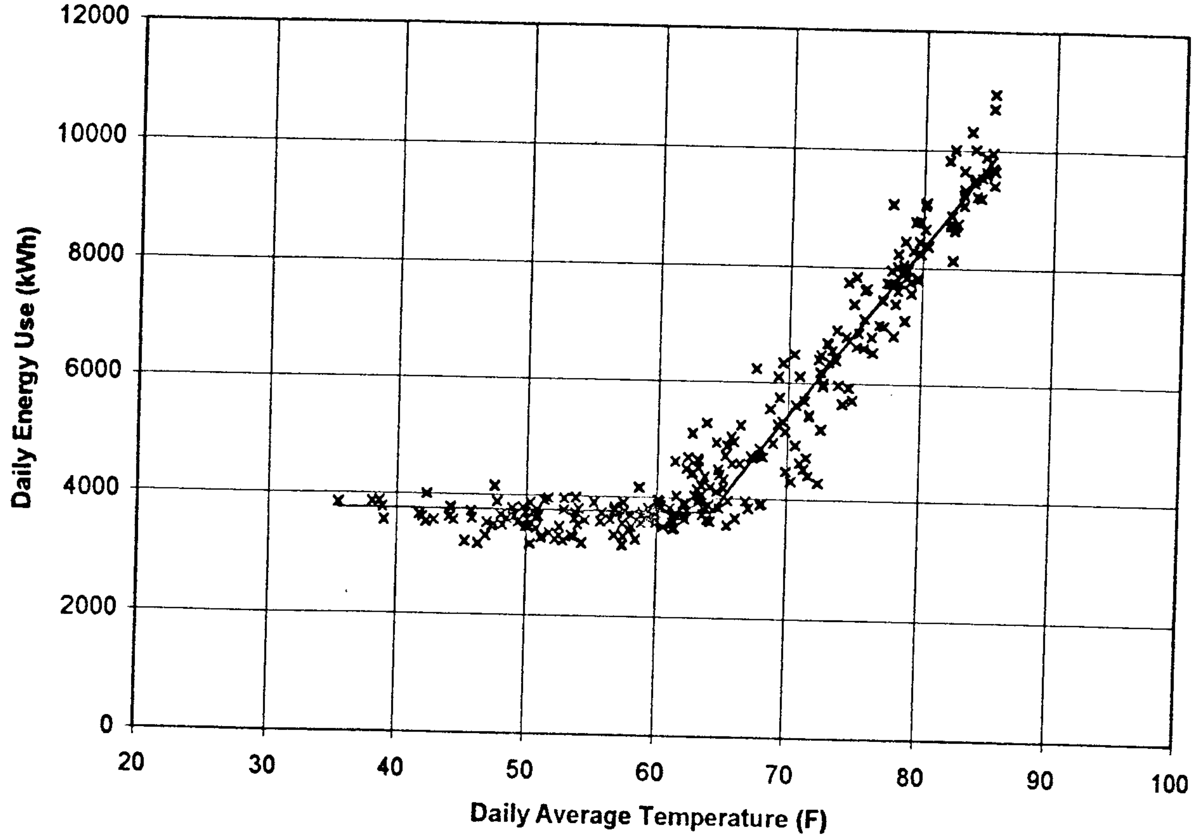

Figure 3: Daily electrical use for a typical feeder serving housing which was gas/electric prior to the retrofits.

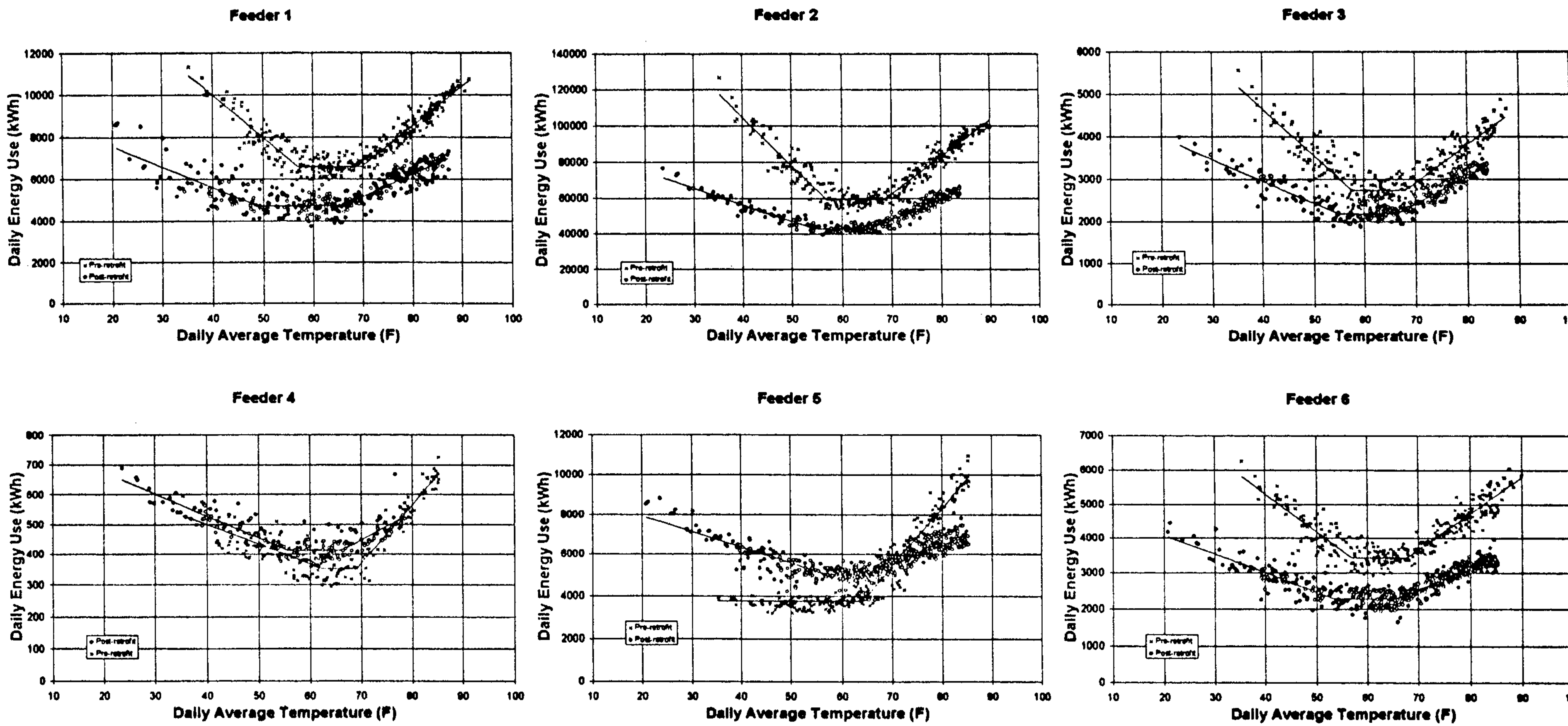

Figure 4: Pre- and post-retrofit daily electrical energy use for the fourteen monitored feeders.

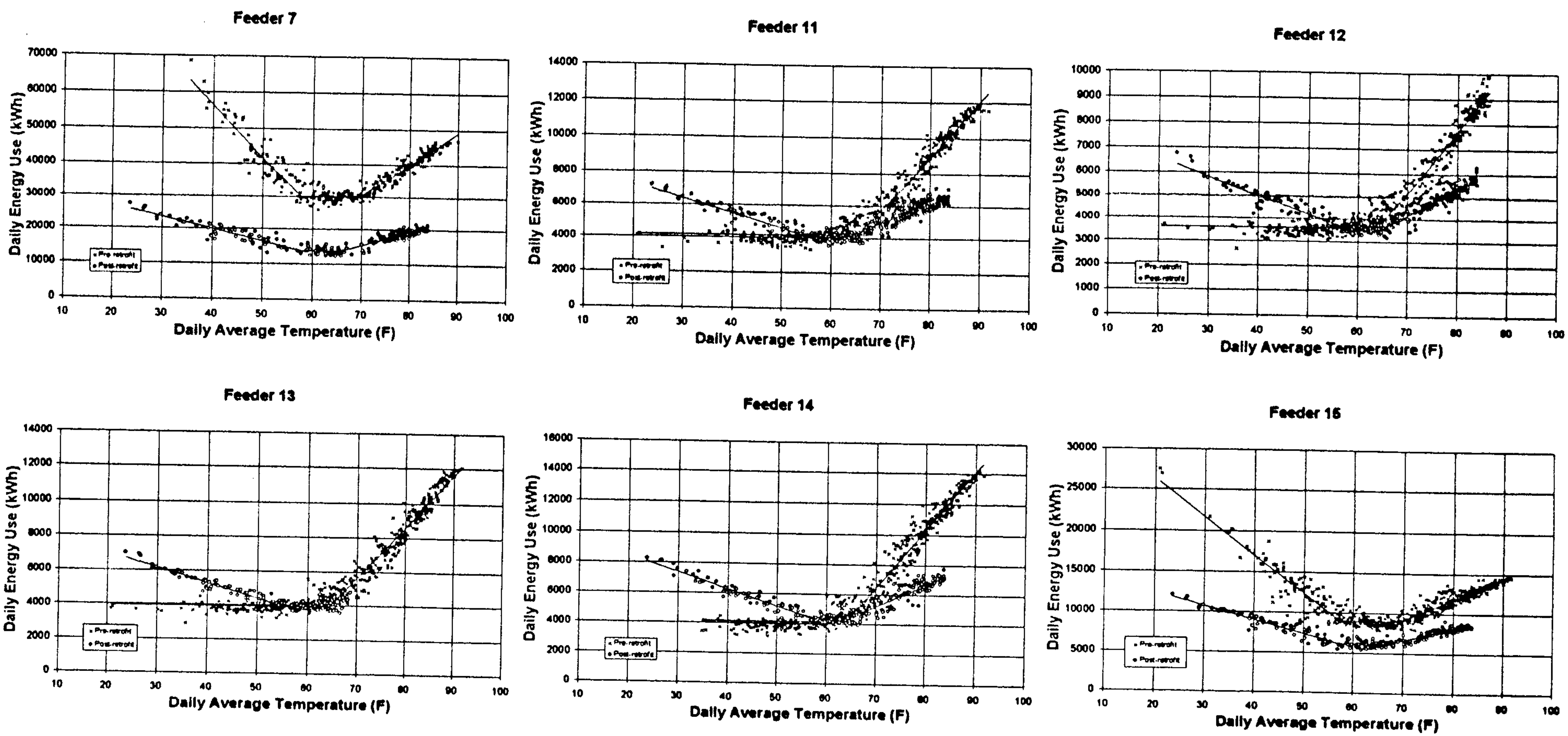

Figure 4 (continued)

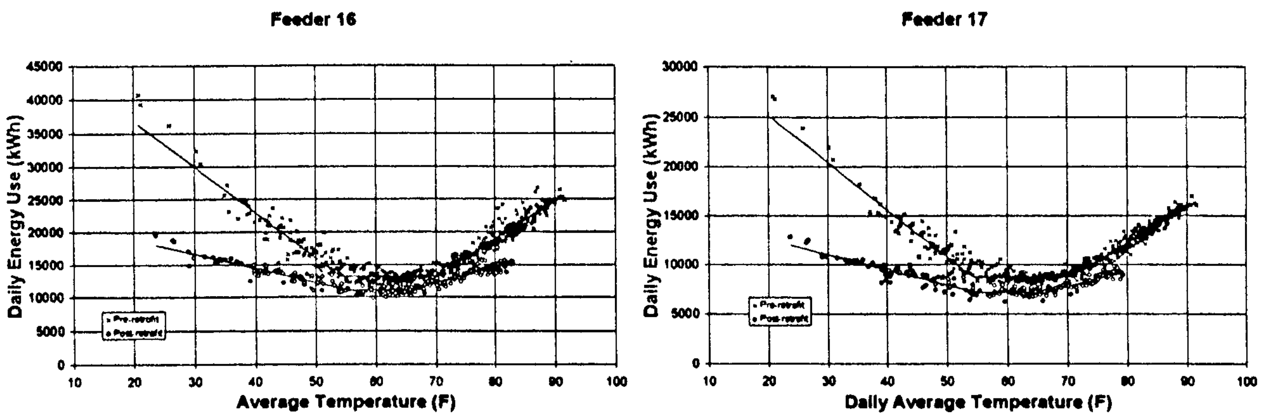

Figure 4 (continued)

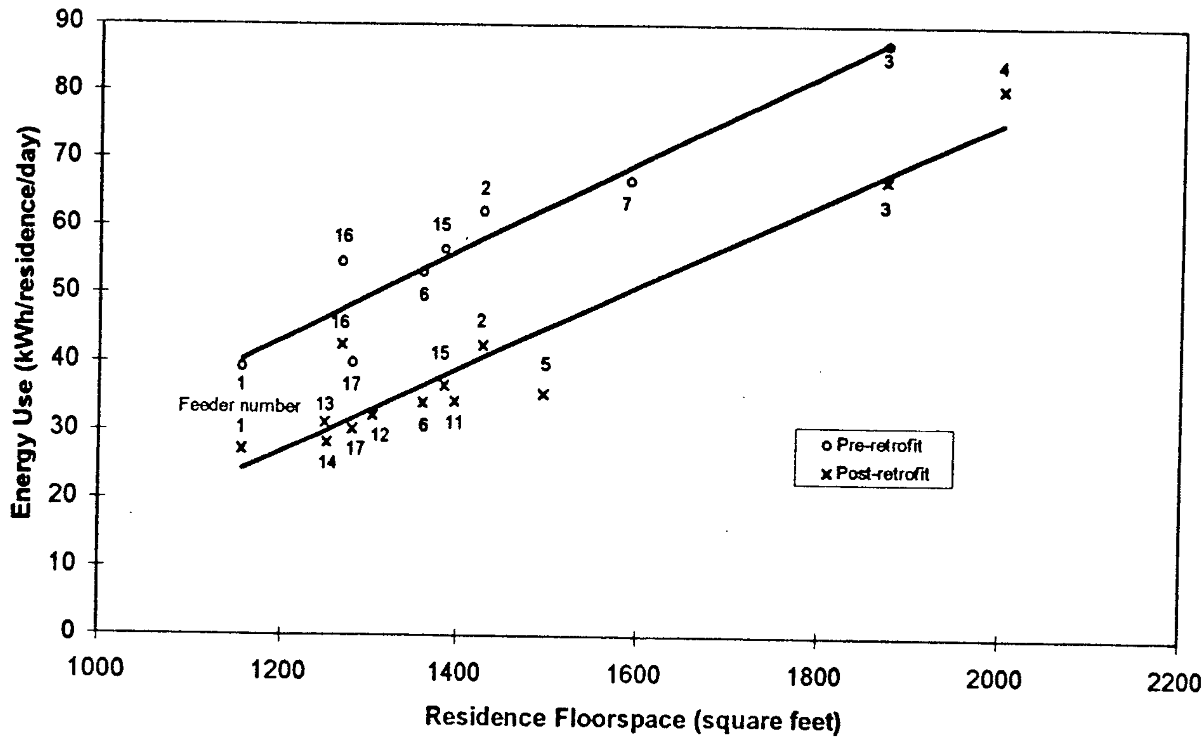

Figure 4: Annual electrical use on feeders serving all-electric housing, pre- and post-retrofit.

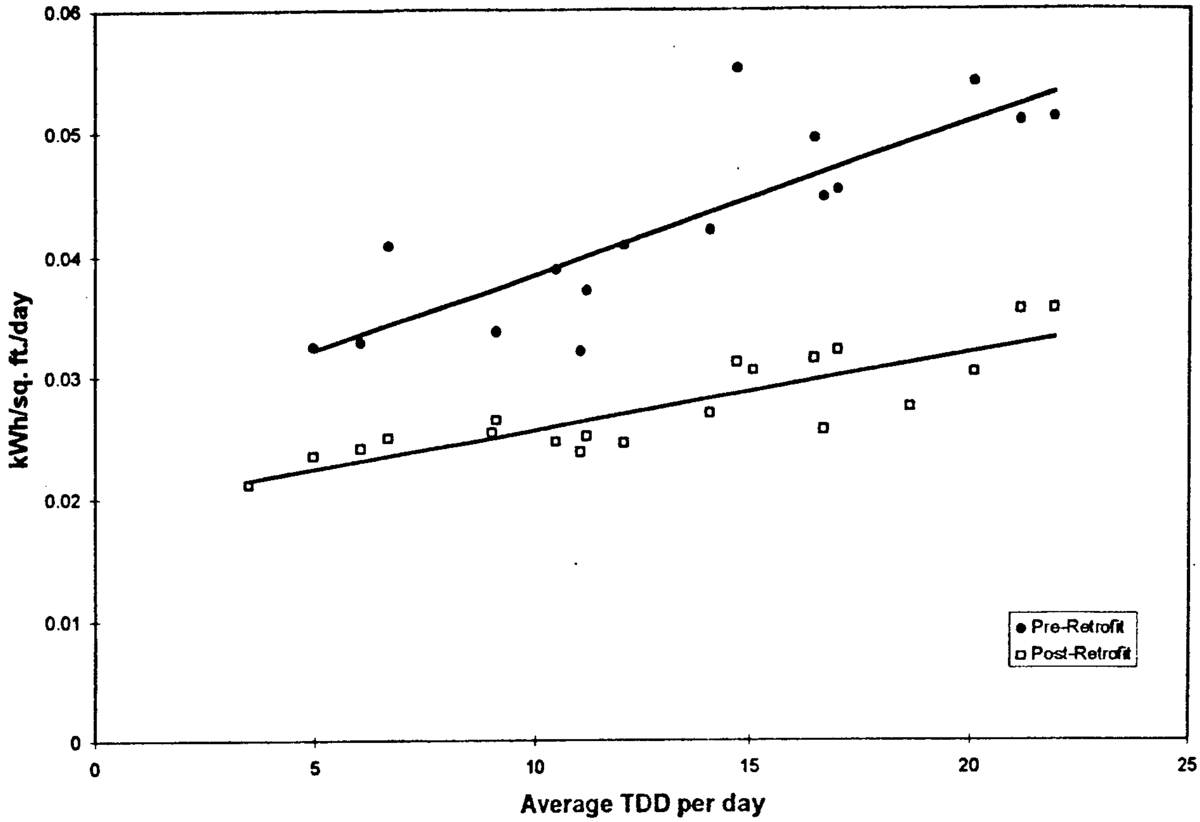

Figure 5: Electrical use per square foot per day from ESCO monthly meter readings, pre- and post-retrofit.

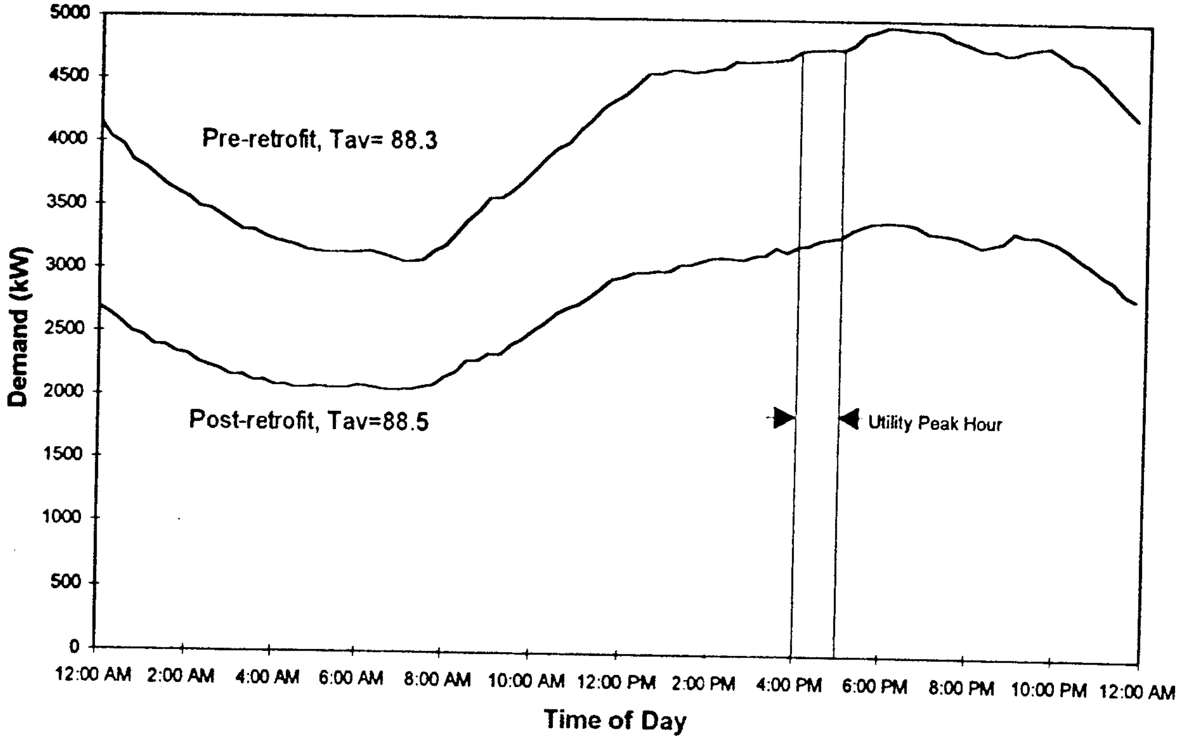

Figure 6: Pre- and post-retrofit demand profiles for peak day, feeder 2

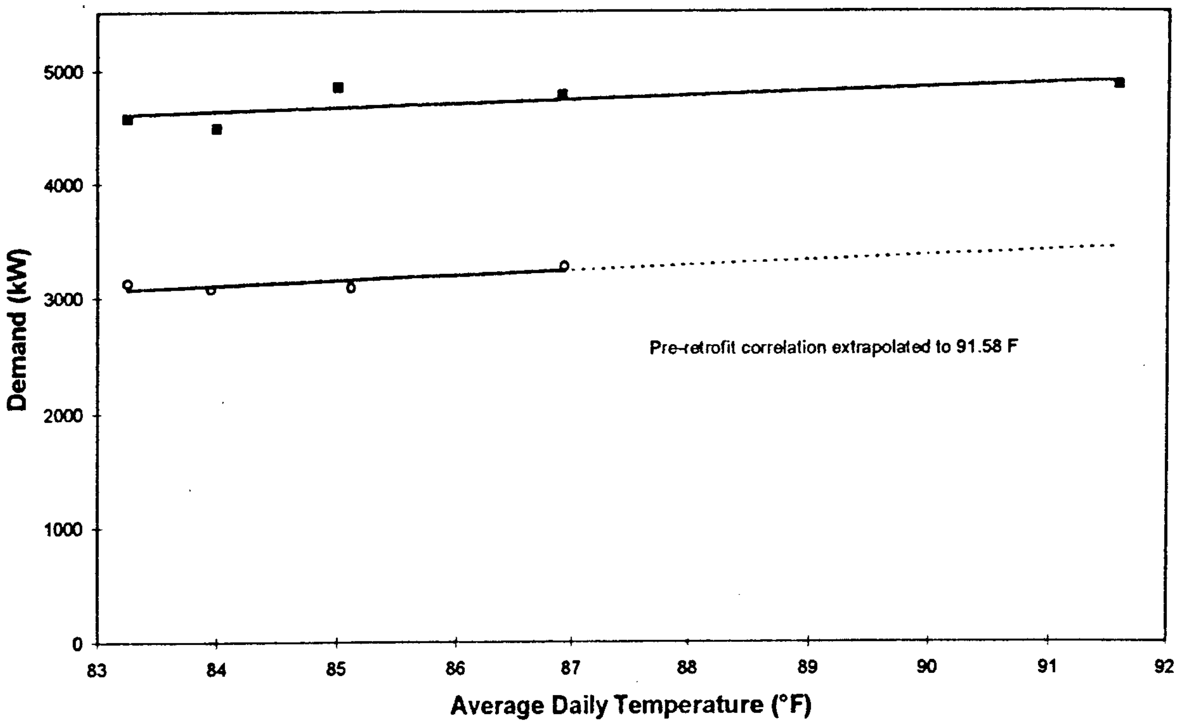

Figure 7: Demand during utility peak hourvs. daily average temperature, pre- and post-retrofit.

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