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Estimating Energy, Demand, and Cost Savings from a Geothermal Heat Pump ESPC Project Through Utility Bill Analysis

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ABSTRACT

Energy savings performance contracts (ESPCs) are a method of financing energy conservation projects using the energy cost savings generated by the conservation measures themselves. Ideally, reduced energy costs are visible as reduced utility bills, but in fact this is not always the case. On large military bases, for example, a single electric meter typically covers hundreds of individual buildings. Savings from an ESPC involving only a small number of these buildings will have little effect on the overall utility bill. In fact, changes in mission, occupancy, and energy prices could cause substantial increases in utility bills. For this reason, other, more practical, methods have been developed to measure and verify savings in ESPC projects. Nevertheless, increasing utility bills—when ESPCs are expected to be reducing them—are problematic and can lead some observers to question whether savings are actually being achieved.

In this paper, the authors use utility bill analysis to determine energy, demand, and cost savings from an ESPC project that installed geothermal heat pumps in the family housing areas of the military base at Fort Polk, Louisiana. The savings estimates for the first year after the retrofits were found to be in substantial agreement with previous estimates that were based on submetered data. However, the utility bills also show that electrical use tended to increase as time went on. Since other data show that the energy use in family housing has remained about the same over the period, the authors conclude that the savings from the ESPC have persisted, and increases in electrical use must be due to loads unassociated with family housing. This shows that under certain circumstances, and with the proper analysis, utility bills can be used to estimate savings from ESPC projects. However, these circumstances are rare and over time the comparison may be invalidated by increases in energy use in areas unaffected by the ESPC.

INTRODUCTION

Energy savings performance contracts (ESPCs) are a method of financing energy conservation projects using the energy cost savings generated by the conservation measures themselves. Ideally, reduced energy costs are visible as reduced utility bills, as shown in Figure 1. When this is the case, utility bills are sometimes used to establish savings, in what the International Performance Measurement and Verification Protocol Committee (2002) and Federal Energy Management Program (2000) term "Option C" measurement and verification (M&V).

In large federal installations, however, a single utility meter often measures the energy use of hundreds of buildings. The energy savings from an ESPC involving a small number

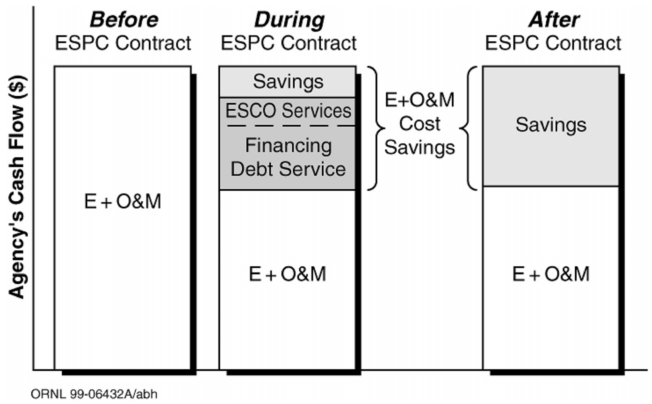

Figure 1 *Structure of an ESPC project. Energy and energy-related savings are used to finance infrastructure improvements.*

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of these buildings are rarely evident in the monthly bills for the entire facility because variations in weather, occupancy, and mission generally have a larger impact on energy use than the ESPC does. Changes in energy rates are a further complication, making it difficult to compare pre- and post-retrofit costs.

For these reasons, M&V methods based on inputs other than whole-building or facility metering are more practical and more commonly used to confirm that energy and cost savings are achieved. One of these methods is retrofit isolation, in which measurements on the installed equipment, or stipulations based on measurements, are used to ensure that it is operating according to specifications. This method is well established and has a great deal of credibility.

Nevertheless, any perceived deficiency in the evidence for cost savings is problematic. Increasing utility bills—when ESPCs are expected to be reducing them—can lead auditors and other observers to question whether savings are actually being achieved. In fact, we have heard ESPC customers remark upon receiving a retrofit isolation-based M&V report, "that's all well and good, but what do the utility bills say?"

The purpose of this paper is to show that more practical and more commonly used M&V techniques based on submetering and retrofit isolation can provide essentially the same estimates of savings as utility bill analysis. Results from a large ESPC in the family housing areas of Fort Polk, Louisiana, show that when energy savings are large enough, whole-facility metering—through regression analysis of utility bills—can indeed be used to determine a project's energy, demand, and cost savings. However, the data show that after a few years, increases in energy use in other areas of Fort Polk reduced the amount of savings apparent in the utility bills, even though energy use in family housing had remained about the same. With only utility bills to go on, it is difficult or impossible to adjust the baseline to account for new loads. For this reason, utility bill analysis is rarely a good option for long-term measurement and verification of savings in ESPC projects.

ENERGY SAVINGS

During the period from March 1995 through August 1996, gas and electric heating and air-conditioning equipment in all 4000 of Fort Polk's on-site family housing units were converted to geothermal heat pumps under an ESPC project. Prior to the retrofits, about 80% of the residences had electric air-source heat pumps, and the remainder had gas furnaces and electric central air conditioners. Using approximately one year of pre-retrofit data and one year of post-retrofit data (collected at 15-minute intervals from the electrical feeders that serve the family housing areas of the base and from individual housing units) we estimated (Shonder and Hughes 1997) that in a typical meteorological year (TMY) (Marion and Urban 1995) at the site,[1] the project would reduce electrical energy use in family housing by 25.8 million kWh and would reduce peak demand by 7.55 MW. The energy savings represent 33% of the total pre-retrofit electrical use in the family housing in a typical year, and the demand savings are 44% of peak electrical demand for the family housing in a typical year. In terms of the entire facility, the energy savings represent approximately 14% of the annual pre-retrofit electricity use, and the demand savings are 18% of peak demand.

Several years later, we obtained utility billing data for Fort Polk covering electrical use for the entire facility (family housing plus nonresidential areas) from the period June 1993 to June 2003. Although we believe the savings estimates made using the 15-minute-interval data in 1997 are accurate, it is of interest to know whether the utility bills tell the same story.

Fort Polk receives two monthly electric bills, one for the one for the South Fort and North Fort. Each one is based on its own separate meter and includes the monthly energy use in kWh and the peak electrical demand measured during the month. Table 1 presents the monthly electricity use in the South and North Fort areas for the last 12 months of the pre-retrofit period and the first 12 months of the post-retrofit period. Also included are the monthly base-65°F heating and cooling degree-days (HDDs and CDDs).

To normalize electricity use to a typical year, we fit the pre- and post-retrofit monthly electrical energy use for each area of the base to functions of heating and cooling degrees that have the following form:

$$E\ (\text{kWh}) = a + h \cdot \text{HDD} + c \cdot \text{CDD} \qquad (1)$$

where a, h, and c are constants that depend on the particular section of the base (South or North Fort) and the period (pre- or post-retrofit). This is essentially the same as the variable-base degree-day method described by Reddy et al. (1997a, 1997b), though here we have chosen the base temperatures for both heating and cooling to be 65°F. It would also have been possible to use the number of days in the billing period as an additional dependent variable (see ASHRAE [2002], Annex D), but because the billing period is fairly constant—varying only from 30 to 33 days—it was sufficient to use a constant value. Then, since the TMY data contains 1909 HDDs and 2493 CDDs, given the constants a, h, and c for a particular regression, the energy use in a typical year is calculated as $12 \cdot a + h \cdot 1909 + c \cdot 2493$.

The regression equations are as follows:

South Fort pre-retrofit:

$$E\ (\text{kWh}) = 9{,}177{,}092 + 3{,}638 \cdot \text{HDD} + 17{,}223 \cdot \text{CDD} \qquad (2)$$

1. In reality, there are no TMY2 weather data available for Fort Polk or the adjacent city of Leesville, LA. The nearest inland site with available TMY2 data is Lufkin, TX, which is approximately 90 miles to the east. Lufkin's weather is similar enough to that of Fort Polk for the energy services company to have used it to size equipment and to estimate energy, demand, and energy cost savings for the project. For this reason, we use the monthly heating degree-days, cooling degree-days, and high/low temperatures from Lufkin's TMY2 file to normalize savings calculations. Any mention of the phrases *typical weather* or a *typical year at the site* in this paper refers to the Lufkin TMY2 weather data.

Table 1. Pre- and Post-Retrofit Monthly Electricity Use and Base-65°F Heating and Cooling Degree-Days for North Fort and South Fort, Fort Polk

				Monthly Electricity Use (kWh)	
	Month	HDD	CDD	South Fort	North Fort
Pre-retrofit	Mar-94	182	50	10,791,312	2,334,600
	Apr-94	66	155	11,711,616	2,323,650
	May-94	7	231	13,867,308	2,686,450
	Jun-94	0	450	16,129,008	3,325,700
	Jul-94	0	486	17,445,540	3,511,700
	Aug-94	0	451	17,338,440	3,518,200
	Sep-94	4	323	15,002,316	2,908,100
	Oct-94	57	165	12,693,408	2,454,750
	Nov-94	118	60	10,116,372	2,114,200
	Dec-94	346	13	10,521,756	2,241,150
	Jan-95	424	12	11,405,604	2,629,900
	Feb-95	276	7	9,874,032	2,252,550
Post-retrofit	Sep-96	5	331	13,112,400	2,720,950
	Oct-96	41	147	10,815,084	2,240,500
	Nov-96	190	45	9,057,972	1,984,100
	Dec-96	311	21	9,313,584	2,013,200
	Jan-97	486	35	10,412,220	2,571,250
	Feb-97	321	23	8,923,068	2,146,850
	Mar-97	80	86	9,522,492	2,128,550
	Apr-97	86	48	9,299,304	2,011,800
	May-97	0	251	11,893,980	2,334,900
	Jun-97	0	401	13,884,024	3,033,450
	Jul-97	0	564	15,681,624	3,455,950
	Aug-97	0	511	15,210,300	3,389,450

North Fort pre-retrofit:

$$E\ (\text{kWh}) = 1{,}712{,}029 + 1{,}829 \cdot \text{HDD} + 3{,}766 \cdot \text{CDD} \quad (3)$$

South Fort post-retrofit:

$$E\ (\text{kWh}) = 8{,}376{,}563 + 2{,}249 \cdot \text{HDD} + 13{,}475 \cdot \text{CDD} \quad (4)$$

North Fort post-retrofit:

$$E\ (\text{kWh}) = 1{,}636{,}307 + 1{,}457 \cdot \text{HDD} + 3{,}322 \cdot \text{CDD} \quad (5)$$

Table 2 presents the r-squared values for these four regressions as well as the p-values for the regression coefficients. Eleven of the twelve regression coefficients are significant at the 95% confidence level. The coefficient of HDDs in the pre-retrofit data for the South Fort is not but could be considered significant at the 90% confidence level. The lower significance of this parameter is explained by the fact that in the pre-retrofit period, about 25% of the South Fort housing (by area) was heated by gas; thus, the electrical use was somewhat less dependent on HDDs than the use in the North Fort. In addition, during the pre-retrofit period, residential electrical use accounted for only about 37% of total electrical use in the South Fort (residential use was about 67% of total use in the North Fort). Electrical use in the commercial buildings may be less driven by heating, which would also reduce the effect of HDDs on total electrical use in the South Fort.

As shown in Figure 2, the regression equations fit the billed electrical use quite well for the South and North Forts in both the pre- and post-retrofit periods. In all four regressions, CV-RMSE (i.e., the ratio of the root mean square error of the regression divided by the mean monthly electrical use) is less than 4%.

Substituting the HDDs and CDDs from the TMY data into each of the four regression equations in turn gives the results shown in Table 3, which also provides estimated 95% confidence intervals for each of the parameters, obtained using a bootstrap technique (Davidson et al. 1997). The utility bills show a savings of 24.3 ± 4 million kWh in a typical year. Since this interval includes the 25.8 million kWh/yr estimated from analysis of the 15-minute-interval data from family housing alone, we conclude that the two estimates are in substantial agreement. Note also that the higher savings estimate is based

Table 2. R^2 Values of the Four Regressions of Electrical Energy Use vs. Heating and Cooling Degree-Days and P-Values for Regression Coefficients

		p-Values		
	r^2	HDD	CDD	Constant
South Fort pre-retrofit	0.9722	6.81E-02	7.21E-07	1.93E-08
North Fort pre-retrofit	0.9713	3.12E-04	1.67E-07	1.75E-08
South Fort post-retrofit	0.9859	2.53E-02	1.07E-08	8.31E-11
North Fort post-retrofit	0.9716	3.12E-04	7.23E-08	4.60E-09

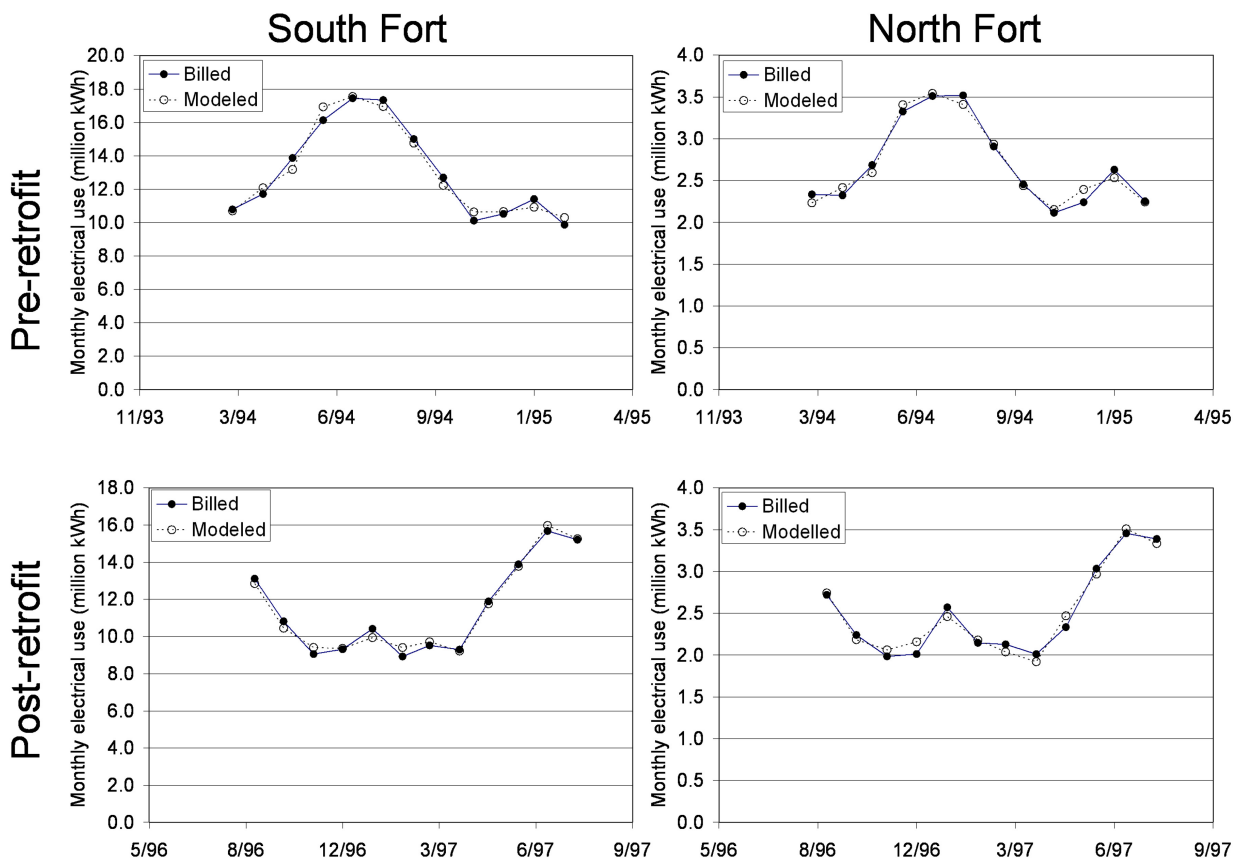

Figure 2 *Pre- and post-retrofit electrical use in South and North Fort areas as billed by the utility and modeled according to the correlations in Equations 2, 3, 4, and 5.*

on data from family housing only, while the lower figure includes commercial areas of the base as well. The difference of 1.5 million kWh could also be explained by load growth of 0.55% in commercial areas of Fort Polk in the 2.5 years between the pre- and post-retrofit periods.

DEMAND SAVINGS

As one might expect, patterns of peak electrical demand were more difficult to understand than patterns of monthly electrical energy use. In order to get a better idea of what was happening, we used 18 months of pre-retrofit data and 24 months of post-retrofit data instead of the one year pre- and post-retrofit used to estimate energy savings.

The reason it was necessary to use more data is that in the pre-retrofit period, peak monthly demand in both areas of Fort Polk depended on the season: for the most part, peak monthly demand for November through February appeared to be a function of the monthly low temperature (the lower the monthly low temperature, the higher the peak monthly demand), while for March through October peak monthly demand seemed to be a function of the monthly high temperature (the higher the monthly high, the higher the peak monthly demand). With only three or four heating months per year, one year's data was insufficient to develop meaningful regressions. Thus, Table 4 presents the monthly billed peak demand in Fort Polk's South and North Fort areas for the last 18 months of the pre-retrofit period, and Table 5 presents the peak demands for the first 24 months of the post-retrofit period. Monthly high and low temperatures are also included, as well as which of the two extremes (the high or the low) appeared to drive the demand in each month.

Table 3. Annual Electricity Use (Million kWh) in a Typical Meteorological Year at Fort Polk

	Pre-Retrofit	Post-Retrofit	Savings
South Fort	160.0 ± 3.4	138.4 ± 2.0	21.6 ± 3.9
North Fort	33.4 ± 0.6	30.8 ± 0.6	2.7 ± 0.9
Total	193.4 ± 3.5	169.2 ± 2.1	24.3 ± 4.0

Figure 3 presents the monthly peak demand for the South Fort, pre- and post-retrofit. In the pre-retrofit period, peak demand is plotted against monthly high temperatures for March through October and against monthly low temperatures for November through February. The exception is November of 1994, when the monthly low was 44°F (6.7°C) and the

Table 4. Pre-Retrofit Monthly Billed Peak Demand and Monthly High and Low Temperatures

Month	Monthly High (°F)	Monthly Low (°F)	South Fort Peak Demand (kW)	South Fort Demand Depends on	North Fort Peak Demand (kW)	North Fort Demand Depends on
Jun-93	96	58	30,072	Monthly high	5,920	Monthly high
Jul-93	99	71	32,424	Monthly high	5,760	Monthly high
Aug-93	101	72	33,399	Monthly high	9,740	Monthly high
Sep-93	99	51	31,786	Monthly high	6,820	Monthly high
Oct-93	89	30	26,107	Monthly high	5,040	Monthly high
Nov-93	84	29	19,421	Monthly low	5,240	Monthly low
Dec-93	75	28	20,496	Monthly low	5,200	Monthly low
Jan-94	72	21	25,133	Monthly low	7,900	Monthly low
Feb-94	78	24	23,923	Monthly low	7,020	Monthly low
Mar-94	83	32	21,034	Monthly low	6,020	Monthly low
Apr-94	87	36	25,805	Monthly high	5,240	Monthly high
May-94	87	53	26,813	Monthly high	6,160	Monthly high
Jun-94	94	66	30,778	Monthly high	6,920	Monthly high
Jul-94	94	63	31,752	Monthly high	6,600	Monthly high
Aug-94	93	63	30,576	Monthly high	6,700	Monthly high
Sep-94	93	48	29,602	Monthly high	6,160	Monthly high
Oct-94	91	43	26,712	Monthly high	5,160	Monthly high
Nov-94	84	44	21,538	Monthly high	4,700	Monthly high
Dec-94	78	29	21,336	Monthly low	5,520	Monthly low
Jan-95	76	25	23,285	Monthly low	6,660	Monthly low
Feb-95	78	30	22,075	Monthly low	6,600	Monthly low

monthly high was 84°F (29°C). For this month, peak demand for both the South and North Fort is plotted against monthly high temperature.

For the post-retrofit period, monthly peak demand seems to depend on only the monthly high temperature, and the data are plotted this way in Figure 3. It is likely that the dependence of monthly peak demand on monthly low temperature during winter months in the pre-retrofit period was the result of electric supplemental heating on the air-source heat pumps. This also explains why peak demand in November 1994 was driven by the monthly high rather than the monthly low temperature. At the low temperature for that month, the air-source heat pumps did not require supplemental heating. Once the heat pumps were replaced with ground source heat pumps (which have no supplemental heat), the dependence of peak demand on monthly low temperature disappeared.

Figure 4 plots pre- and post-retrofit monthly peak demand for the North Fort. With smaller electrical loads in this area, the data show more scatter than in the South Fort, but the pattern is still clear. Note that the August 1993 peak demand of 9740 kW is an outlier that does not seem to be consistent with the other data.

To estimate peak demand savings in a typical year, we correlated monthly billed peak demand with monthly low temperature for pre-retrofit winter months and with monthly high temperature for pre-retrofit summer months and all post-retrofit months. The outlier in Figure 4 was omitted. The regression equations are:

Pre-retrofit

$$\text{South Fort Summer: } D\text{ (kW)} = 612.6 \cdot T_{max} - 27{,}852 \quad (6)$$

$$\text{South Fort Winter: } D\text{ (kW)} = -436.2 \cdot T_{min} + 33{,}973 \quad (7)$$

$$\text{North Fort Summer: } D\text{ (kW)} = 100.5 \cdot T_{max} - 3{,}333.4 \quad (8)$$

$$\text{North Fort Winter: } D\text{ (kW)} = -193.4 \cdot T_{min} + 11{,}541 \quad (9)$$

Post-retrofit

$$\text{South Fort: } D\text{ (kW)} = 417.1 \cdot T_{max} - 14{,}829 \quad (10)$$

$$\text{North Fort: } D\text{ (kW)} = 75.6 \cdot T_{max} - 1{,}571.4 \quad (11)$$

Table 6 presents the r-squared values for the six regressions as well as the p-values for the regression coefficients. The scatter in the data that is evident in Figures 3 and 4 results in lower values for r-squared than those obtained for monthly energy use. P-values for two of the parameters—the intercept for the North Fort pre-retrofit summer demand and the inter-

Table 5. Post-Retrofit Monthly Billed Peak Demand and Monthly High and Low Temperatures

Month	Monthly High (°F)	Monthly Low (°F)	South Fort Demand (kW)	South Fort Demand Depends on	North Fort Demand (kW)	North Fort Demand Depends on
Oct-96	86	39	20,899	Monthly high	4,540	Monthly high
Nov-96	82	32	19,891	Monthly high	4,400	Monthly high
Dec-96	79	19	17,808	Monthly high	4,500	Monthly high
Jan-97	79	23	18,379	Monthly high	5,520	Monthly high
Feb-97	81	32	17,775	Monthly high	4,440	Monthly high
Mar-97	86	43	17,069	Monthly high	4,000	Monthly high
Apr-97	88	39	20,227	Monthly high	4,160	Monthly high
May-97	90	52	24,159	Monthly high	4,460	Monthly high
Jun-97	93	59	25,872	Monthly high	5,900	Monthly high
Jul-97	97	68	26,981	Monthly high	6,140	Monthly high
Aug-97	97	63	27,048	Monthly high	6,260	Monthly high
Sep-97	95	59	25,267	Monthly high	5,940	Monthly high
Oct-97	90	39	23,285	Monthly high	5,260	Monthly high
Nov-97	77	30	15,994	Monthly high	4,100	Monthly high
Dec-97	73	28	16,968	Monthly high	4,320	Monthly high
Jan-98	73	30	16,699	Monthly high	4,360	Monthly high
Feb-98	73	34	16,263	Monthly high	4,160	Monthly high
Mar-98	81	28	17,103	Monthly high	4,400	Monthly high
Apr-98	82	43	19,522	Monthly high	4,080	Monthly high
May-98	99	57	24,763	Monthly high	4,800	Monthly high
Jun-98	99	59	27,351	Monthly high	6,520	Monthly high
Jul-98	104	72	27,485	Monthly high	6,600	Monthly high
Aug-98	104	70	27,519	Monthly high	6,560	Monthly high
Sep-98	97	70	27,048	Monthly high	6,000	Monthly high

cept for the North Fort post-retrofit demand—are greater than 0.05, indicating they are not significant at the 95% confidence level. All other parameters are significant at the 95% confidence level, however.

In the TMY2 file for Lufkin, TX, which we assume to be a typical year for Fort Polk, the lowest temperature is 19.9°F (−6.7°C) and the highest temperature is 100.9°F (38.3°C). Equations 6 and 7 show that in the pre-retrofit period, the peak demand for the North Fort would occur in the winter, at 7,692 kW, compared with 6,810 kW in the summer. However, the overall pre-retrofit peak would occur in the summer when, according to Equation 8, the demand for the South Fort is 33,962 kW. Combined with the 6,810 kW in North Fort, annual peak demand in a typical year would be 40,772 kW.

In the post-retrofit, peak demand for the North Fort in a typical year is 6,057 kW and peak demand for the South Fort is 27,256 kW, for a combined peak of 33,313 kW. The demand savings for a typical year is then 40,772 – 33,313 = 7,459 kW. A 95% confidence interval for the demand savings is 7.5 ± 3.1 MW. Since this interval includes the demand savings of 7.55 MW estimated from analysis of the 15-minute-interval data from family housing alone, we conclude that the two estimates are in substantial agreement.

COST SAVINGS

Subtracting Equation 4 from Equation 2 gives an expression for the monthly savings in the North Fort as a function of heating and cooling degrees:

North Fort energy savings:

$$E\ (\text{kWh}) = 75{,}722 + 373 \cdot \text{HDD} + 444 \cdot \text{CDD} \qquad (12)$$

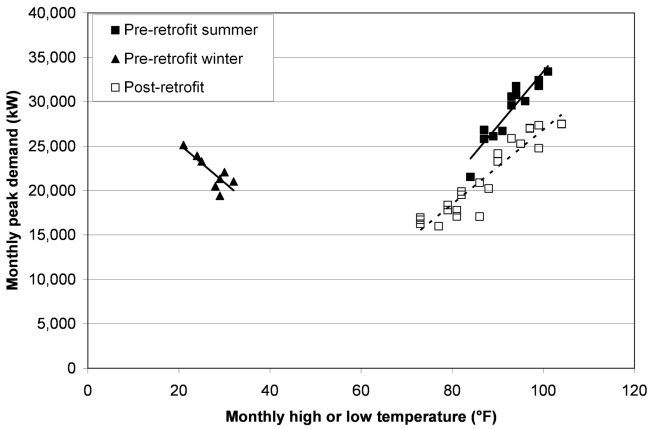

Figure 3 *South Fort billed monthly peak demand, pre- and post-retrofit. In the pre-retrofit, there are winter and summer peaks, whereas in the post-retrofit, peak demand is always a function of monthly high temperature.*

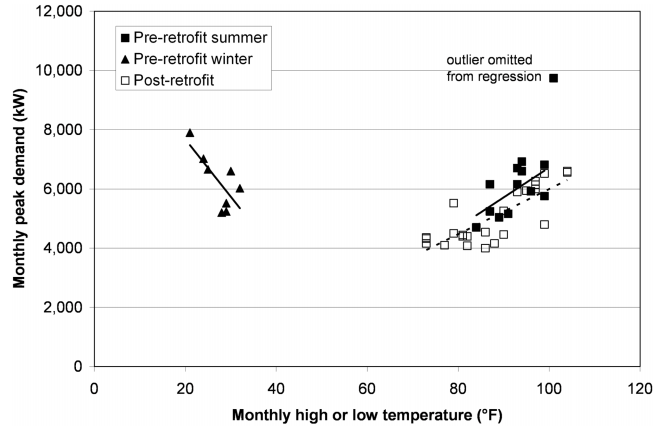

Figure 4 *North Fort billed monthly peak demand. Pre-retrofit demand had winter and summer peaks, while post-retrofit demand is always a function of monthly high temperature.*

Likewise, Equations 6, 7, and 10 can be used to determine the monthly demand savings. In this case, the savings depends on the season:

North Fort summer demand savings:

$$D\ (\text{kW}) = 24.9 \cdot T_{max} - 1{,}762 \qquad (13)$$

North Fort winter demand savings:

$$D\ (\text{kW}) = -193.4 \cdot T_{min} - 75.6 \cdot T_{max} + 13{,}112 \qquad (14)$$

These equations provide a means to estimate actual cost savings from the ESPC. For example, suppose that in a post-retrofit summer month with 250 CDDs and a high temperature of 90°F, the North Fort is billed for 2,334,900 kWh of energy use and a peak demand of 4,500 kW. Equation 12 predicts that, in that month, the ESPC is saving 186,722 kWh (75,722 + 444 · 250), which results in a demand reduction of 479 kW (24.9 · 90 – 1,762). Thus, it can be estimated that in the absence of the project, the North Fort would have consumed 2,334,900 + 186,722 = 2,521,622 kWh and demand would have been 4500 + 479 = 4,979 kW. These values, along with the energy and demand prices charged by the utility that month, can be used to determine what the utility bill would have been in that month had the project not been implemented. For Fort Polk it was necessary to consider demand for previous months as well, since the rate structure included a ratchet.

Using actual energy and demand rates taken from the utility bills, we estimate the first-year savings for the project to be approximately $1.45 million (Shonder and Hughes 2005). In fact, weather during the first post-retrofit year was milder than normal, so we calculate that had the weather corresponded to a typical year at the site, savings would have been $1.57 million. This is in substantial agreement with our original savings estimate of $1.55 million for a typical year (Hughes and Shonder 1998).

Table 6. R^2 Values for the Regressions of Peak Monthly Electrical Demand vs. Monthly High or Low Temperature and P-Values of Regression Coefficients

		p-Values	
	r-Squared	**Intercept**	**Slope**
	Pre-Retrofit		
South Fort summer	0.9330	0.0001	<0.0001
South Fort winter	0.8279	0.0112	<0.0001
North Fort summer	0.6291	0.3793	0.0284
North Fort winter	0.7366	0.0012	0.0372
	Post-Retrofit		
South Fort	0.8822	<0.0001	<0.0001
North Fort	0.6357	0.1571	<0.0001

SAVINGS PERSISTENCE

Figure 5 displays actual monthly kWh from the utility bills for June 1993 through June 2003. The construction period delineates the end of the pre-retrofit period and the beginning of the post-retrofit period. The bar graph shows that energy use peaks in the summer months fall to a minimum in the shoulder months and rise to a lower peak during the winter months. The highest peaks in the post-retrofit period are lower than those in the pre-retrofit and construction periods, but beyond this, not much information can be discerned from the graph.

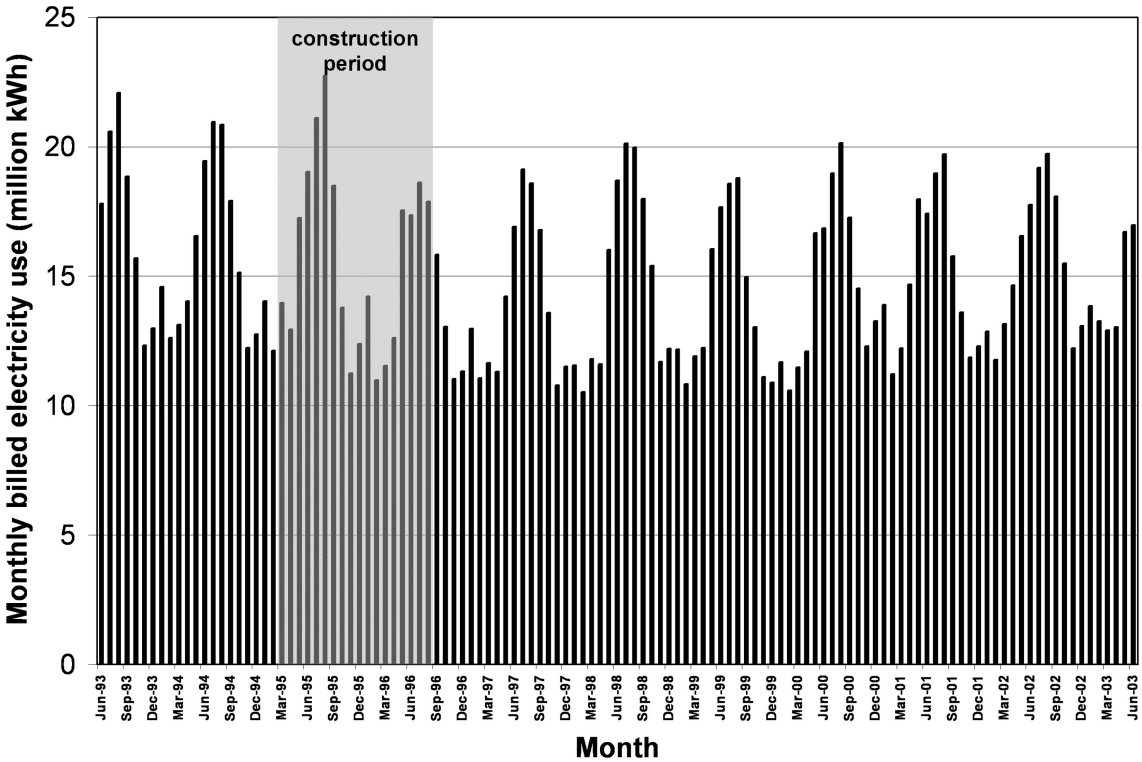

Figure 5 *Total monthly electricity use for Fort Polk, June 1993–June 2003.*

A clearer picture of the trend in electricity usage is obtained from Figure 6, which shows weather-normalized (TMY) data. Note that the first bar is for May 1994. To determine the height of that bar, we correlated the total monthly electric use at Fort Polk from April 1993 through May 1994 with HDDs and CDDs to develop a regression equation similar to Equation 1. Given the values of a, h, and c from the regression, the normalized annual energy use for April 1993 through May 1994 is then $12 \cdot a + 1909 \cdot h + 2493 \cdot c$. To determine the height of the bar for the next month, June 1994, the same calculation was performed using data from May 1993 through June 1994.

In this graph, the 24.3 million kWh annual savings attributable to the ESPC project is clearly visible. Annual consumption began to drop during construction and then was relatively stable for the next 24 months. In August 1998, consumption began to rise then fell again, but in July 2000 it began a steady, steep climb that continued until February 2003. Based on this figure alone, one might draw the conclusion that by June 2004, nearly half of the savings had disappeared.

This conclusion is incorrect, however. In our original study of the Fort Polk retrofit project, data loggers were attached to 14 of the 16 family housing electric submeters in order to read them electronically at 15-minute intervals. In July 2003, we attempted to rehabilitate the meters. Ten were found to be either inoperable or to produce unreliable data. Four of the meters (those attached to Feeders 3, 4, 6, and 16) were in good operating condition, allowing us to resume data collection at 15-minute intervals. Feeders 3, 4, 6, and 16 represent about 12% of the remaining 5 million square feet of family housing at Fort Polk, a sufficient sample size for representing all housing.

Data from feeders 3, 4, 6, and 16 were collected for approximately one year. For each feeder we fit daily electricity use to a five-parameter function of daily average temperature, using the technique described by Reddy et al. (1997a). This regression analysis allowed us to predict annual energy use for a typical year. If there have been no increases in energy use, then the TMY predictions from the two data sets should be roughly the same. Table 7 presents the estimated TMY energy use based on the 1996–1997 data and on the 2003–2004 data for the four feeders. The analysis indicates that energy use on some of the feeders has decreased and on some it has increased. Some of the changes are undoubtedly due to changes in occupancy, for which we have no information. Overall, energy use for the four feeders has increased by 2.2% over seven years. This is an annual rate of increase of just 0.3%.

Based on this analysis of a representative sample of Fort Polk's housing, we conclude that there have been only small increases in electricity use, if any, in Fort Polk's family housing since the retrofits were installed. This is despite the fact that the terms of the ESPC did not guarantee that weather-

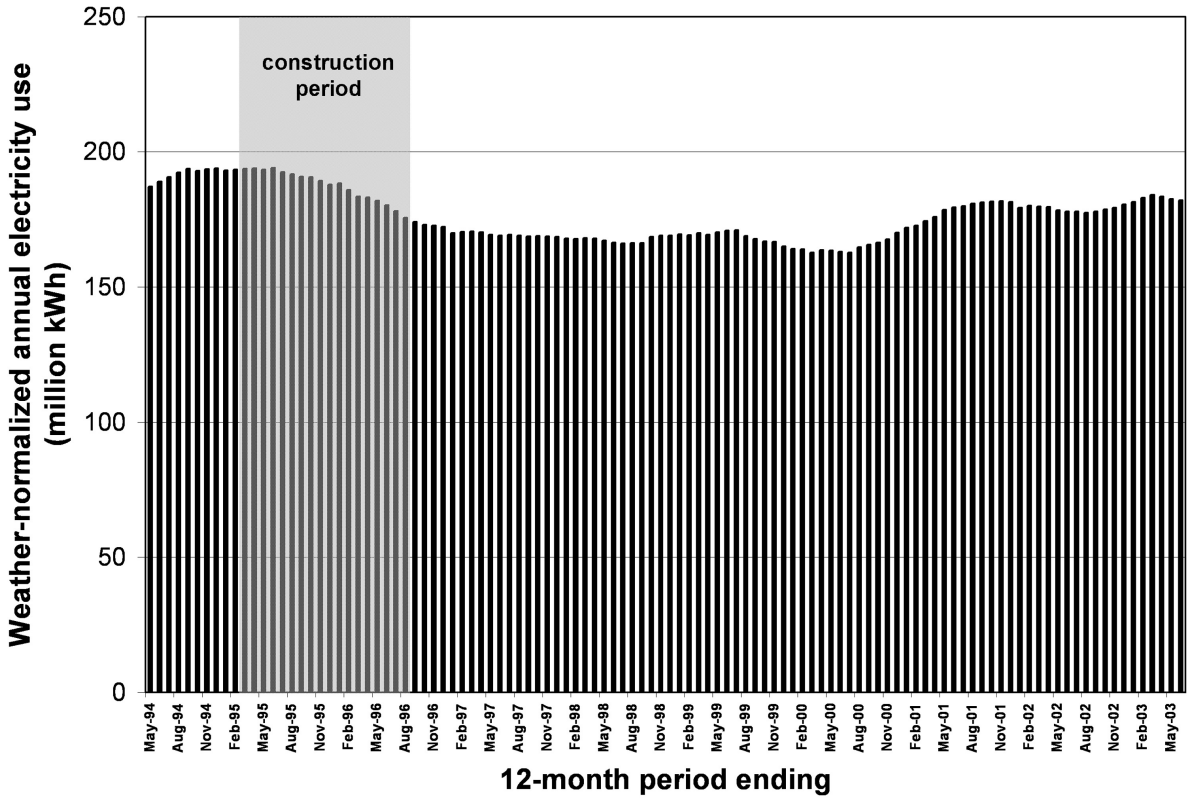

Figure 6 *Weather-normalized monthly total electrical use at Fort Polk. The height of each bar is based on a correlation of the electrical use for that month and the previous 11 months with HDDs and CDDs. The HDDs and CDDs for a TMY are substituted into the regression equation to determine the height of the bar.*

normalized electricity consumption in the housing area would remain the same, and a much larger increase was expected. In our original evaluation of the Fort Polk site, we projected that factors such as plug load growth would likely cause modest increases, in accordance with 1998 estimates (based on national averages at the time) that residential electricity use would grow by 1.54% annually. In fact this is about five times higher than the rate of increase observed on the four sampled feeders. We conclude that savings from the ESPC project are the same in 2003–2004 as they were in 1996–1997.

As for the cause of the large increases in electrical use outside of family housing, a page on Fort Polk's Web site (http://www.jrtc-polk.army.mil/aboutpolk.htm) states that "the installation is seeing one of its biggest construction booms ever with over $300 million in new construction and renovation projects in support of Fort Polk transformation over the next several years." The page mentions recent accomplishments including a new Consolidated Library and Education Center, a new Post Headquarters, and a newly renovated Soldiers Readiness Processing Center. Undoubtedly, Fort Polk's workload has also increased in recent years due to ongoing military operations.

CONCLUSIONS

Real ESPC projects are always more complicated than the idealized model shown in Figure 1, and utility bill analysis is generally not a practical strategy for measuring and verifying guaranteed savings. In a very real sense, however, the utility bill is the first, most logical place to look for the impacts of ESPC projects. Lack of obvious savings in utility bills can lead auditors and other observers to question whether savings are actually being achieved, and any perceived deficiency in the evidence for cost savings is problematic.

The benefit of the work reported here is its demonstration that when savings are a large enough part of metered utility use, energy, demand, and cost savings can be discerned through regression analysis of pre- and post-retrofit utility bill data. Using utility bills from the 12 months immediately before and after the retrofits, we showed that the annual electricity savings for Fort Polk were 24.3 ± 4.0 million kWh (a 95% confidence interval) in the year after the retrofit and that the utility bills predict peak summer demand savings of 7.5 ± 3.1 MW. These results agree with our 1998 evaluation of the project (Hughes and Shonder 1998) based on detailed, submetered energy use data.

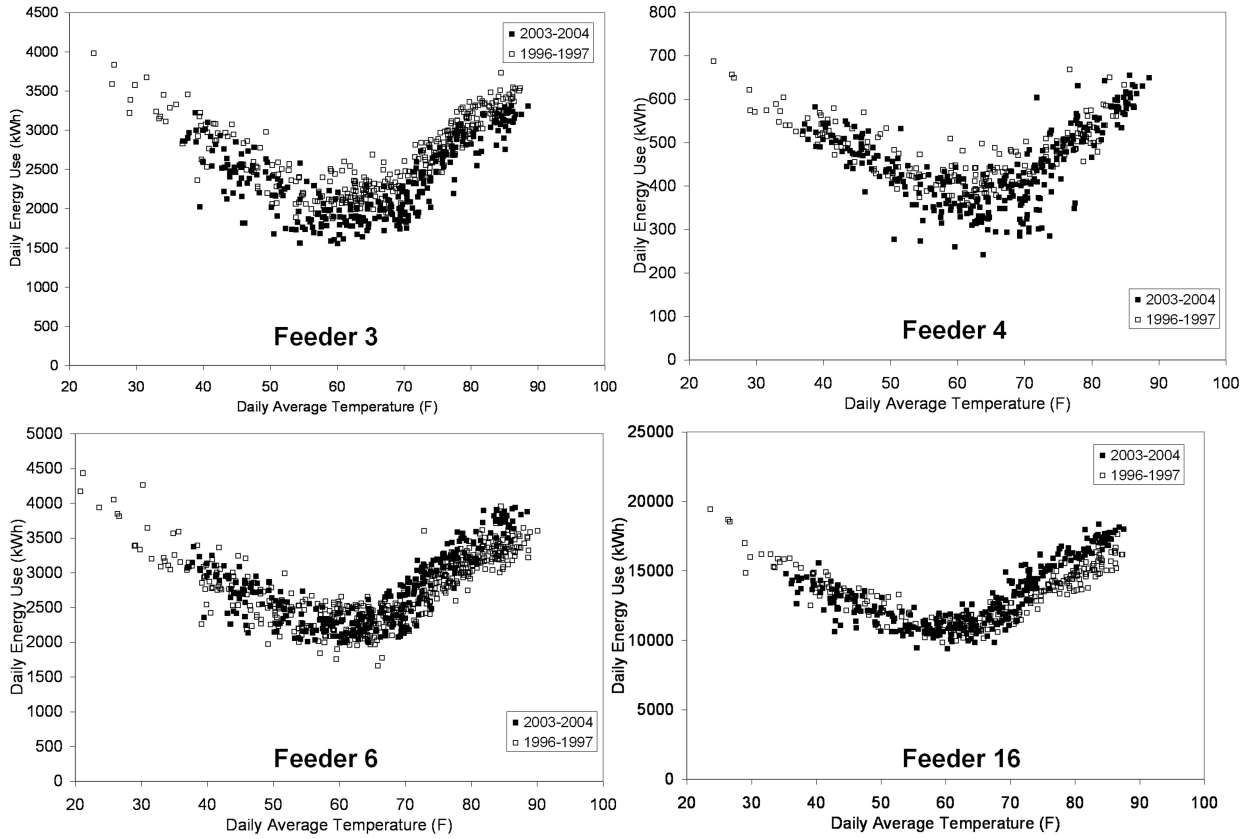

Figure 7 *Daily energy use vs. daily average temperature for four residential feeders at Fort Polk, 1996–1997 and 2003–2004.*

Table 7. Energy Use by Electrical Feeder, 1996–1997 and 2003–2004

Feeder	TMY Energy Use Based on 1996–1997 Data (kWh)	TMY Energy Use Based on 2003–2004 Data (kWh)	Percentage Change
3	977,428	882,651	–9.7%
4	176,601	166,838	–5.5%
6	999,035	1,037,816	3.9%
16	4,763,891	4,982,995	4.6%
Total	6,916,955	7,070,300	2.2%

We were also able to resolve cost savings from analysis of Fort Polk's utility bills. Based on actual weather data for the months during the analysis period and actual electricity rate structures in effect during the period, we estimated annual electricity cost savings from the ESPC to be $1.45 million. For a year with more typical weather, the savings would have been about $1.57 million, which is in agreement with our original estimate of $1.55 million for a typical year.

Whether utility bill data can be used to discern persistence of electricity use and demand savings over time is another question. The utility bills for large facilities like Fort Polk, where a single utility meter measures the energy use of hundreds of buildings, can tell us nothing about whether changes are due to growing plug loads, new buildings, degradation of equipment efficiency, or other factors. Fort Polk's utility bills indicate that the facility's total annual electricity use increased by about 13 million kWh, or about half of the ESPC project's savings, between 1997 and 2003. Only by analyzing data from four submetered feeders installed for our original study were we able to conclude anything about savings persistence. The submetered data show that between 1997 and 2003 the electricity use in the family housing area increased about 2.2%, or 0.31% per year, which is far less than the increase due to plug load growth that we predicted in 1998. The increase in electricity use in the family housing area accounts for about 1 million

of Fort Polk's total 13 million kWh increase since 1996, indicating that savings due to the GHP retrofits have persisted and that the majority of the increase in electricity use has occurred in areas other than family housing. These conclusions could not have been drawn solely from analysis of facility-wide utility bills.

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