Geothermal Heat Pump Energy Savings Performance Contract at Fort Polk: Lessons Learned

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ABSTRACT

At Fort Polk, Louisiana, the space-conditioning systems of 4,003 military family housing units have been converted to geothermal heat pumps (GHPs) under an energy savings performance contract. At the same time, other efficiency measures, such as compact fluorescent lights, low-flow shower heads, and attic insulation, were installed. An independent evaluation of the Fort Polk energy savings performance contract was carried out. Findings indicate that the project has resulted in a 25.6 million kWh savings in electrical energy use, or 32.4% of the pre-retrofit electrical consumption in family housing, for a typical meteorological year. Peak electrical demand has also been reduced by 6,761 kW, which is 40.2% of the pre-retrofit peak demand. Natural gas savings are about 260,000 therms per year. In addition, the energy savings performance contract has allowed the Army to effectively cap its future expenditures for family housing HVAC maintenance at about 77% of its previous costs. Given these successful results, the Fort Polk performance contract can provide a model for other contracts in both the public and the private sectors. The purpose of this paper is to outline the method by which the contract was engineered and implemented, both from the standpoint of the facility owner (the U.S. Army) and the energy services company that is carrying out the contract. The lessons learned from this experience should be useful to other owners, service companies, and investors in the implementation of future service contracts. 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 mistaken for 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.

INTRODUCTION

The Fort Polk Joint Readiness Training Center is located in west-central Louisiana just outside of Leesville. The 200,000-acre facility contains military offices, training centers, equipment and storage warehouses, a hospital, and housing for some 15,000 service members and their families. Approximately 12,000 people live in on-post family housing, which is the focus of the energy savings performance contract. Located in two distinct areas called North Fort and South Fort, the family housing stock consists of 4,003 living units in 1,292 buildings that were constructed in nine phases between 1972 and 1988. Units range in size from 1,073 to 2,746 ft^2, with an average area of 1,393 ft^2. Prior to the implementation of the energy savings service contract, 3,243 (or about 81%) of the units 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 energy savings performance contract of the shared savings type to an energy services company. Under the terms of the contract, the company replaced the space-conditioning systems in all of Ft. Polk's family housing with geothermal heat pumps (GHPs). The total capacity of the GHPs is 6,593 tons, installed in heat pump nominal capacities of 1.5, 2, and 2.5 tons, with one heat pump per living unit at an average size across the entire project of 1.65 tons. Each heat pump has its own ground heat exchanger 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. (Because the upper 3 feet of each bore is not part of the heat exchanger, the total installed vertical heat exchanger bore length is 1,810,628 for an average of 275 feet of bore per ton. A total of 3,621,256 feet of 1-inch SDR-11 high-density polyethylene pipe 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

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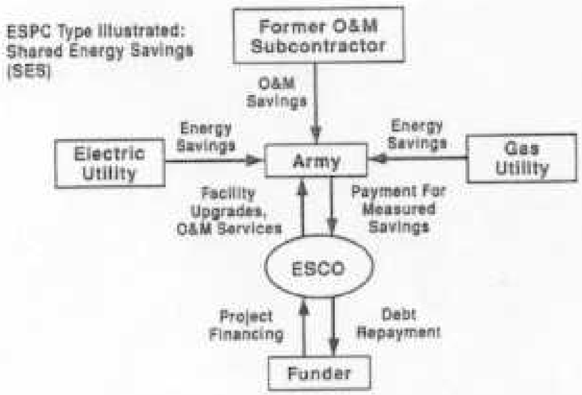

Figure 1 *Structure of Fort Polk energy savings performance contract.*

the GHP when it is operating for heating or cooling. Additional energy conservation measures included low-flow shower heads and compact fluorescent lighting (all indoor and outdoor fixtures attached to the 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 were not installed at the time this paper was written.

The entire up-front cost of the retrofits and working capital to develop the project—approximately $18.9 million ($2867/ton)—was borne by the energy services company, which also assumed responsibility for maintenance of the installed equipment for the duration of the contract. In return, the Army has contracted to pay the company a percentage of the energy and maintenance savings realized each month. The structure of the energy savings performance contract is shown in Figure 1. Electrical energy savings are determined by subtracting actual kWh consumption from the assumed baseline consumption, which is a function of the heating and cooling degree-days that occurred during the month. The baseline is derived from a quadratic regression of historical data on monthly electrical consumption in the family housing vs. total degree-days (i.e., the sum of heating and cooling degree-days base 65°F) in each period. Similarly, natural gas savings are determined by subtracting actual gas consumption in therms from a weather-corrected baseline consumption, derived from a regression of the post's previous monthly natural gas consumption vs. heating degree-days. Dollar savings are then determined by multiplying the electrical and gas savings by that month's base-wide average energy prices per kWh and per therm, as determined from utility bills. Over the life of the contract, the energy services company will receive about 77% of the savings achieved.

Because the company assumes full responsibility for maintaining the equipment installed, the Army's savings are its entire previous cost of HVAC equipment maintenance in family housing. This is specified in the contract as $335.83 per residence per year (with minor cash flow adjustment stipulations and a consumer price index [CPI] escalator). For the 4,003 residences, this comes to approximately $0.24 per square foot per year. As with the energy savings, the company will receive about 77% of the maintenance savings over the life of the contract.

EVALUATION APPROACH

The objectives of the evaluation were to (1) determine statistically valid energy, demand, and operation and maintenance impacts of GHPs applied to military family housing at Fort Polk and (2) improve the capability to evaluate, design, install, operate, and maintain GHPs in military family housing. The evaluation approach (Hughes and Shonder 1996), shown schematically in Figure 2, 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 15-minute intervals from submeters on 14 of the 16 electrical feeders that supply electricity to the family housing areas of the Fort (the original intent 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 are also collected at 15-minute intervals at four different locations within the family housing area. Level 1 data allow comparison of pre- and post-retrofit energy usage patterns on the aggregate of all loads served by each feeder. A schematic of the level 1 data collection, pre- and post-retrofit, is presented in Figure 3.

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 15-minute intervals. Level 2 data allow the determination of the coefficient of variation of savings across buildings and apartments. A schematic of the pre-retrofit level 2 data collection is presented in Figure 4; Figure 5 presents the schematic for post-retrofit data collection.

At 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, 15-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 vs. base loads and supports analysis to determine the

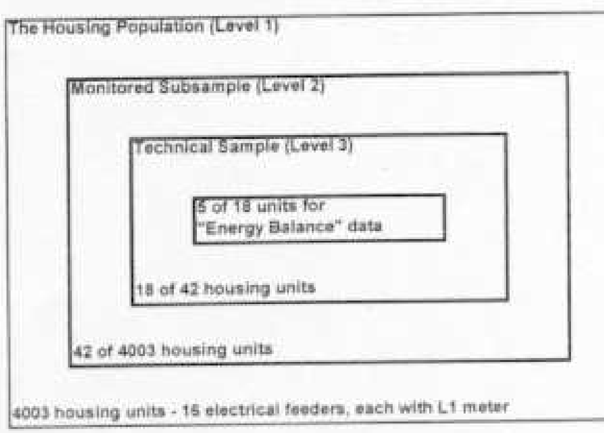

Figure 2 *Project evaluation approach.*

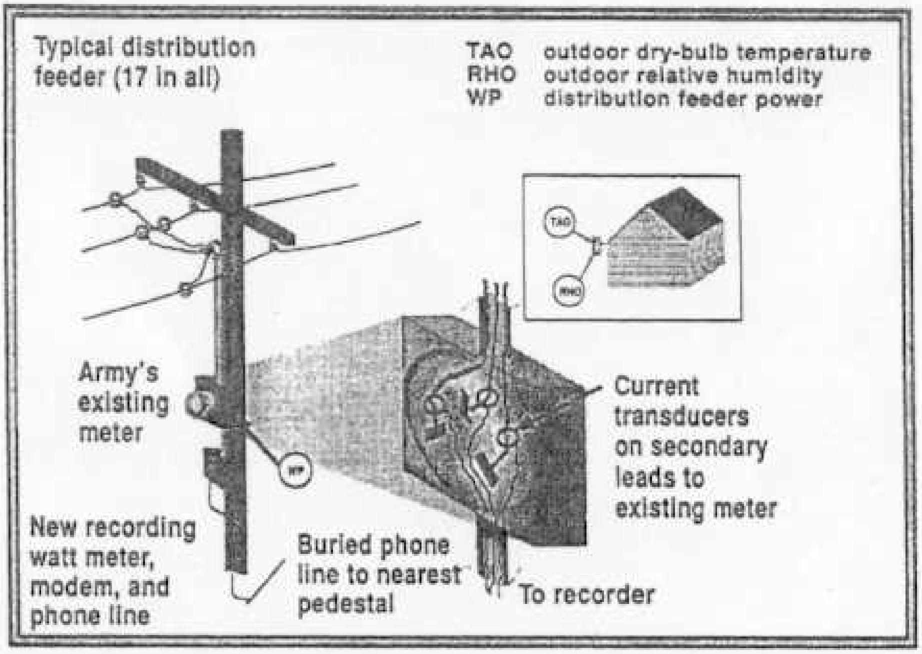

Figure 3 *Level 1 pre-/post-retrofit data collection.*

savings attributable to the various conservation measures. Pre- and post-retrofit data collection is similar to that of level 2, presented in Figures 4 and 5.

ENERGY CONSUMPTION BASELINE

At Fort Polk, electrical energy is provided to family housing through 16 individual feeders that are separately metered and read manually on a monthly basis. In its request for proposal (RFP), the Army supplied historical data on total electrical consumption from these feeders for a period of 55 months from August 1988 through February 1993. Prior to the award of contracts, the energy services company used the data from August 1988 through March 1992 to develop a formula to determine the baseline (pre-retrofit) energy consumption in family housing for each month; the electrical savings in each post-retrofit month is determined by subtracting actual electrical consumption from the weather-corrected baseline. The baseline formula is specified as

$$kWh/month = (-6.40743 \cdot X^2 + 13095.7 \cdot X + 2899270) \cdot (n/30) \quad (1)$$

where X is the total number of heating plus cooling degree-days (both base 65°F) occurring during the month at the base airstrip and n is the number of days in the month. The minimum and maximum values of X over the historical data period were 120 and 690, respectively.

The historical data supplied in the RFP are plotted in Figure 6. It is clear from this figure that not all of the variation in monthly electrical consumption is dependent on weather; in fact, when compared to the historical data, the root-mean squared error (RMSE) of Equation 1 is 1,236,125 kWh, or about 18.5% of the average monthly consumption. Other causes of variation include differences in occupancy, number of holiday and weekend days, and streetlight operating hours from month to month. However, some of the remaining variation in Figure 6 is still weather-related. Because all living units are cooled with electric vapor compression devices, but only 81% of the units are heated that way (and these have supplemental resistance heat), one would not expect a simple total degree-day correlation to remove all variation due to weather.

It should be noted that Equation 1 is not a least squares fit to the data of Figure 6. It was developed from a subset of the historical data and is only valid for values of total degree-days from 120 to 690, and the engineering judgments made during the development of the expression, in hindsight, may have been no better than straight regression. An actual least-squares quadratic regression of the historical data gives

$$kWh/month = (2.3693 \cdot X^2 + 5139.9 \cdot X + 4357719) \cdot (n/30) \quad (2)$$

The RMSE of this equation is 1,184,313 kWh, only slightly less than that of Equation 1. The historical data and the monthly consumption predicted by Equations 1 and 2 are presented in Table 1. Because both equations predict the historical consumption to about the same degree of accuracy, the use of Equation 1 will not affect savings calculations appreciably, with the possible exception of months with total degree-days near the high or low extremes. One possible advantage of straight regression is that the constant term in Equation 2 can be interpreted as an estimate of the monthly nonweather-dependent consumption. Understanding the relative importance of weather-dependent and nonweather-dependent consumption in the baseline period improves the accuracy of energy savings estimates.

In the course of analyzing our own 15-minute-interval level 1 data for the evaluation, the authors developed models of pre-retrofit electri-

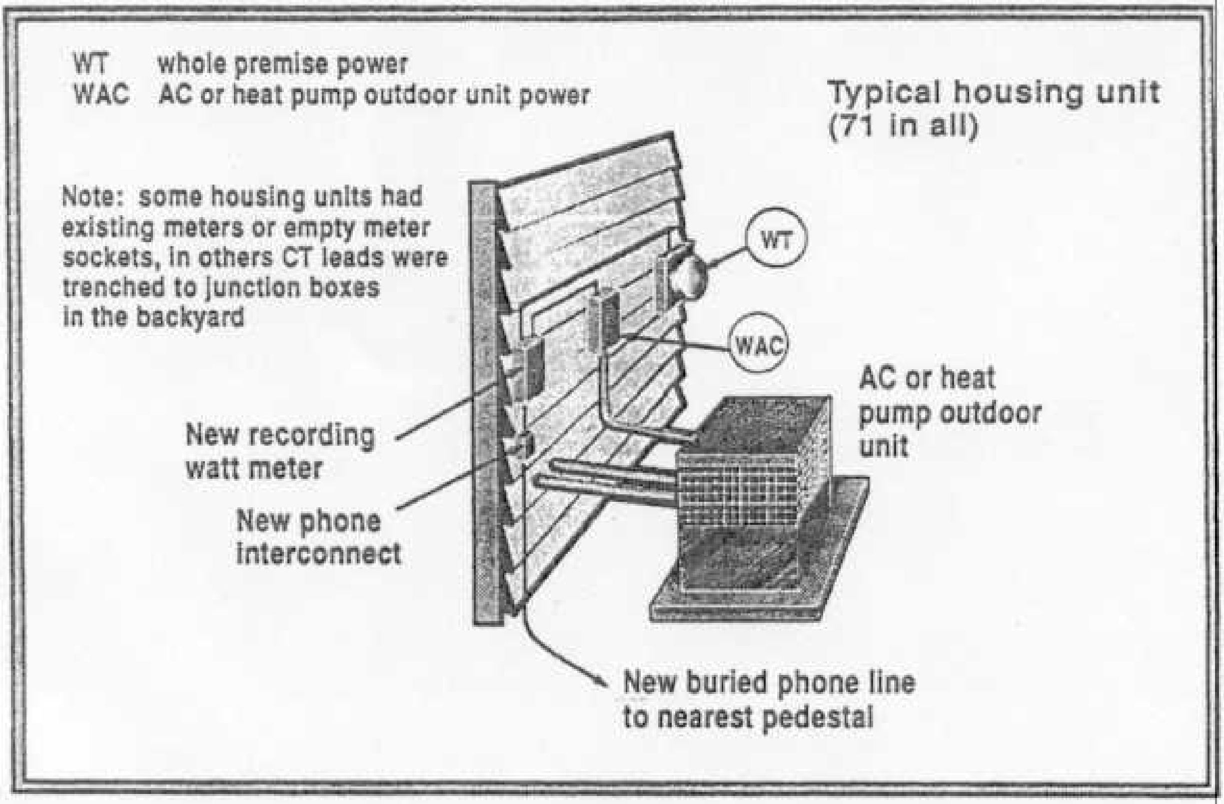

Figure 4 Level 2 pre-retrofit data collection.

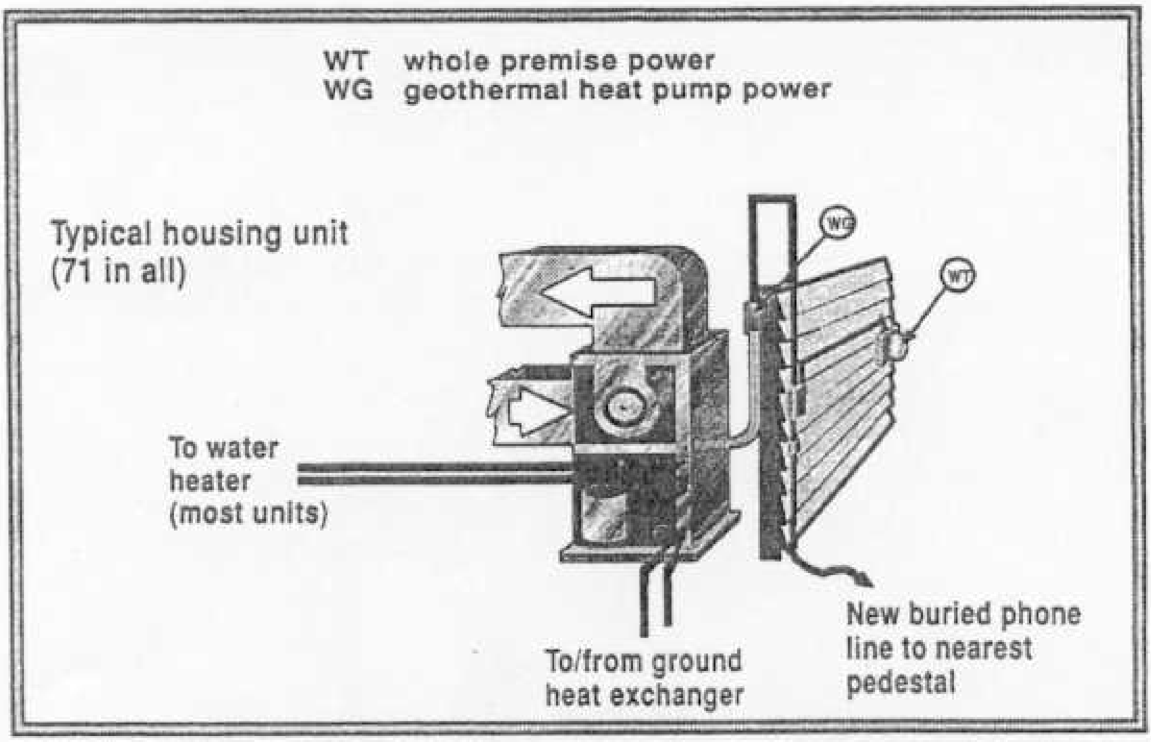

Figure 5 Level 2 post-retrofit data collection.

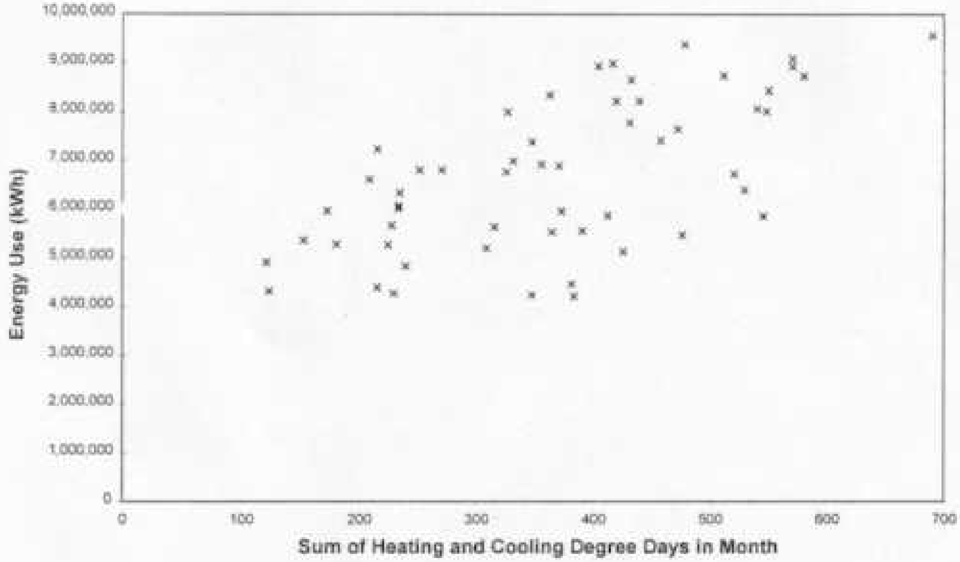

***Figure 6** Historical kWh consumption data used to develop contract baseline.*

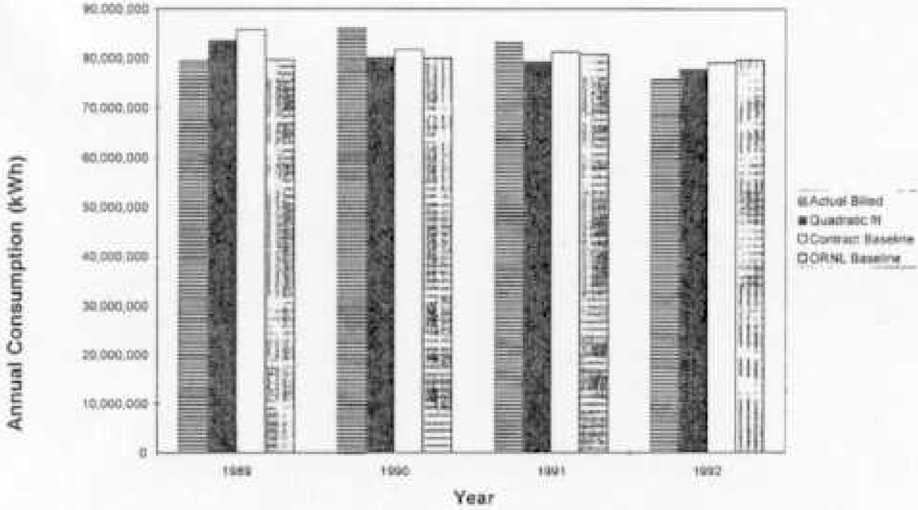

***Figure 7** Annual consumption in family housing as predicted by three methods.*

cal consumption for each of the 16 feeders that serve family housing. Details of these models, which predict daily energy use for the housing on each feeder based on average daily temperature, are presented in a companion paper (Shonder and Hughes 1997b). Pre-retrofit daily electrical use in all family housing was found to fit the following five-parameter model:

$$kWh/day = \begin{cases} -6940.54 \cdot (T - 56.46) & T < 56.45°F \\ 171031 & 56.45 \le T \le 68.06 \\ 6571.15 \cdot (T - 68.06) & T > 68.06 \end{cases} \quad (3)$$

When used to predict total energy consumption for the 55 months of baseline data, our model shows an RMSE of 1,072,624, or 16.1% of the average monthly consumption. This slight increase in accuracy indicates that in the case of Fort Polk—and most likely for other facilities where family housing is the primary electrical load—accurate baseline models can be derived with only 9 to 12 months of daily energy consumption data. Such a model appears to be as accurate as a model developed with 4.5 years of historical data. On an annual basis, all of the models are able to predict annual consumption for the 1989-1992 period within about 7%; this is shown in Figure 7.

Nevertheless, the baseline consumption formula is only as good as the data used to develop it. Some questionable figures have, in fact, been discovered in Fort Polk's historical electrical consumption records (Gordon 1997). For example, during some months, certain meters were not read and zeroes were entered for their electrical use until a recording of cumulative consumption was made in a subsequent month. In other cases, the figure from the previous month was entered. All of these data, interpreted and refined as necessary, were used in developing the contract baseline. Because the authors' correlation—

TABLE 1
Historical Monthly kWh Consumption; Consumption Predicted by Contract Formula and by Quadratic Fit to Historical Data

Month	Days	TDD	Billed kWH	Contract Formula	Quadtratic Fit
8/88	31	570	8,923,463	8,282,045	8,057,243
9/88	30	419	8,210,955	7,261,473	6,927,288
10/88	31	121	4,912,730	4,390,039	5,014,333
11/88	30	227	5,666,276	5,541,825	5,646,559
12/88	31	425	5,131,935	7,307,600	6,970,126
1/89	31	347	4,241,419	6,671,966	6,426,544
2/89	28	472	7,643,689	7,652,968	7,311,589
3/89	31	364	5,533,180	6,817,146	6,542,560
4/89	30	233	6,014,599	5,602,715	5,683,938
5/89	31	390	5,556,626	7,032,023	6,722,645
6/89	30	431	7,771,847	7,353,266	7,013,134
7/89	31	545	5,863,189	8,133,260	7,862,701
8/89	31	540	8,061,724	8,102,541	7,824,148
9/89	30	362	8,336,714	6,800,258	6,528,840
10/89	31	229	4,268,093	5,562,173	5,659,000
11/89	30	270	6,803,709	5,968,007	5,918,209
12/89	31	690	9,563,168	8,884,726	9,032,272
1/90	31	347	7,375,510	6,671,966	6,426,544
2/90	28	215	7,234,432	5,418,662	5,572,314
3/90	31	233	6,072,062	5,602,715	5,683,938
4/90	30	215	4,396,293	5,418,622	5,572,314
5/90	31	326	7,992,310	6,487,512	6,285,121
6/90	30	570	9,087,096	8,282,045	8,057,243
7/90	31	550	8,429,413	8,163,657	7,901,373
8/90	31	580	8,728,277	8,339,317	8,135,890
9/90	30	439	8,209,439	7,413,436	7,070,744
10/90	31	234	6,338,288	5,612,819	5,690,184
11/90	30	224	5,270,235	5,551,208	5,627,934
12/90	31	457	7,410,335	7,545,820	7,201,474
1/91	31	548	8,010,802	8,151,537	7,885,890
2/91	28	308	5,203,056	6,324,911	6,165,564
3/91	31	239	4,833,345	5,663,143	5,721,487
4/91	30	172	5,969,510	4,962,173	5,311,871
5/91	31	331	6,989,741	6,531,942	6,318,603
6/91	30	432	8,652,750	7,360,832	7,020,319
7/91	31	511	8,735,052	7,918,058	7,602,877

TABLE 1 (Continued)
Historical Monthly kWh Consumption; Consumption Predicted by Contract Formula and by Quadratic Fit to Historical Data

8/91	31	416	8,982,246	7,238,237	6,905,933
9/91	30	325	6,768,723	6,478,588	6,278,438
10/91	31	208	6,605,673	5,345,965	5,529,319
11/91	30	412	5,869,661	7,207,076	6,877,527
12/91	31	370	6,889,434	6,867,502	6,583,834
1/92	31	520	6,723,727	7,976,465	7,671,121
2/92	29	315	5,641,550	6,388,638	6,211,876
3/92	31	180	5,288,075	5,048,895	5,359,662
4/92	30	152	5,370,286	4,741,779	5,193,720
5/92	31	251	6,799,793	5,782,616	5,797,097
6/92	30	478	9,372,041	7,695,019	7,355,933
7/92	31	529	6,398,563	8,033,834	7,739,749
8/92	31	404	8,931,932	7,144,138	6,820,941
9/92	30	355	6,918,744	6,740,747	6,480,969
10/92	31	123	4,319,349	4,413,103	5,025,769
11/92	30	372	5,960,913	6,884,185	6,597,629
12/92	31	383	4,216,910	6,975,024	6,673,845
1/93	31	476	5,476,258	7,681,053	7,341,133
2/93	28	381	4,464,657	6,958,623	6,659,945

developed from independently monitored data—is able to predict monthly consumption for the period 1989-1993 with about the same accuracy as the contract baseline, the effect of the erroneous values in the electrical consumption does not seem to be large. However, in future projects where electrical energy is provided by a number of feeders, it may be more prudent to develop baseline models for each individual feeder and to sum these models to obtain total energy consumption. Using total degree-days to weather-normalize monthly feeder readings will never remove all of the variation caused by weather, but more of it can be removed if one avoids the mixing of space-conditioning equipment types and vintages.

Some project partners may also prefer to collect and archive 9 to 12 months of 15-minute-interval pre-retrofit feeder-level electrical consumption to use as a check on existing records. This can be done without interfering with existing feeder meters or their calibration, yet allows newly calibrated independent recordings. The project's meters were installed by applying current transducers to the secondary leads of existing meters. The current transducers were then interfaced to newly calibrated watt-hour transducers and recorders independent of the existing meters. A diagram of a typical installation is presented in Figure 3.

MONITORING AND VERIFICATION OF ENERGY SAVINGS

Post-retrofit electrical energy consumption was monitored through meter readings from the 16 feeders serving the family housing area in order to determine energy savings. Using the terminology of the North American Energy Measurement and Verification Protocol (DOE 1996a) and the more specific Measurement and Verification Guidelines for Federal Energy Projects (DOE 1996b), this is an "Option C" monitoring and verification plan, whereby savings are determined from actual facility meter readings. (As an aside, ASHRAE Guideline Project Committee 14P is also developing "Guidelines for Measurement of Energy and Demand Savings," a document expected to strengthen the technical foundation of monitoring and verification.)

Given the results to date, the "Option C" approach to monitoring and verification of savings appears to have several advantages over other options for large housing projects. As described above, weather normalization is straightforward, depending only upon heating and cooling degree-day information, which is collected at most National Weather Service stations. Because feeder-level meters monitor the entire population, savings calculations are more accurate than a system whereby a sample of buildings is monitored. Also, as opposed to stipulated savings agreements, the use of actual energy consumption data maintains motivation for an energy services company to sustain the energy-efficiency improvements over the life of the contract.

Nevertheless, there are some disadvantages to using feeder-level data for monitoring and verification in housing projects. First of all, the feeders may include nonhousing loads such as street lighting, sewage treatment plants, sewage lift stations, supply water pumping, and fire stations. An accurate, up-to-date electrical distribution diagram is required to identify these loads, as well as to determine which housing units are served by which feeders. If these loads are significant and are likely to change over the course of the project, it may be advisable to meter them separately and subtract the nonhousing loads from the total.

Another problem with collecting feeder-level data is that the configuration of the electrical distribution system may change. For example, at Fort Polk the system can be reconfigured temporarily to perform maintenance or to supply power during outages. For this reason, it may be advisable to install meters even on normally closed connections to capture energy use during temporary reconfigurations. At Fort Polk, there is reason to believe that some permanent changes were made in the distribution system during the time when retrofits were being installed.

"Plug load creep" is another issue that may affect service companies with feeder-level monitoring and verification. As new appliances are introduced and adopted by the public, overall electrical consumption tends to increase. Because savings are determined by comparison with the 1989-1993 electrical use, savings in future years may appear smaller than they actually are (i.e., the increase in nonweather-dependent loads would have occurred with or without the energy savings performance contract). One way to correct for this would be to continue to use the manually recorded monthly feeder-level electrical consumption data, producing new correlations periodically to determine the nonweather-dependent consumption and adjusting the baseline accordingly.

As an example, in Equation 2 above, historical monthly energy use in Fort Polk's family housing was correlated to a quadratic function of total degree-days. The constant term in this equation, 4,357,719 kWh, is an estimate of the monthly non-weather-dependent consumption in family housing or among any other loads connected to the feeder, such as street lighting. In order to check this result, the authors analyzed pre-retrofit data from 13 of their level 3 all-electric apartments to determine non-HVAC electrical consumption. The figures are presented in Table 2. Weighted by apartment size, the average base

TABLE 2
Base Electrical Consumption from 13 Level 3 Sites

Site	Number of units	Total ft^2	Pre-retrofit base load ($kWh/ft^2/dy$)
211	1	1794	0.0281
213	4	4632	0.0218
214	2	3456	0.0178
215	4	4292	0.0363
216	2	3396	0.0243
Weighted average:			**0.0257**
Family Housing-wide, kWh/month:			**4356895**

load is 0.0257 (kWh/ft^2)/day. Multiplying by the total square feet of family housing at Fort Polk (5,576,612) and by 30 days per month gives a base load of 4,299,568 kWh/month, leaving 58,151 kWh/month (about 1.3%) for street lighting and other loads. The level of agreement between the two numbers is surprising and perhaps misleading given the small sample size for the apartment data. Nevertheless, it does appear that analysis of monthly feeder-level data is a valid method of estimating the base (nonweather-dependent) electrical loads. For comparison, the average consumption of the six lowest months (inspection of Figure 6 justified averaging six months; monthly billed values were then obtained from Table 1) in the historical record is 4,317,797 kWh/month.

In cases where historical data do not exist, it may be possible to determine the nonweather-dependent loads from 9 to 12 months of 15-minute-interval pre-retrofit data collected from the feeders. Our five-parameter fit of 12 months of this data (Equation 3) predicts a base load in family housing of 171,031 kWh/day, or 5,199,342 kWh/month. This indicates that for Fort Polk, the nonweather-dependent electrical load is about 84% of the load seen on days with mild temperatures, the rest being HVAC. This should be a good rule of thumb for other facilities where housing is the primary load.

Table 3 compares the actual kWh in family housing (from manually collected meter readings) with the weather-corrected baseline predicted by our model (developed from 12 months of 15-minute-interval data) and by the contract model. The table also shows the payments the company receives for 77% of the kWh savings compared to the two baselines, assuming an electrical energy price of $0.06 per kWh. The agreement between the two over the six-month period (a difference of less than 1%) indicates that a baseline developed from 12 months of 15-minute-interval data may be just as accurate as one developed from about 4.5 years of historical data.

At Fort Polk, there is another method of monitoring energy consumption in family housing. While, in general, the U.S. military does not monitor electrical use from individual residences, watt-hour

TABLE 3
Comparison of Energy Payments to ESCO using ORNL Baseline and Contract Baseline

Month	Days/ Month	Metered kWh	TDD	ORNL Baseline		Contract Baseline	
				kWH	Payment	kWH	Payment
07/96	31	5954810	607	8041738	$96,416	8770467	$130,083
08/96	31	5531792	508	7455011	88,853	8161637	121,499
09/96	30	4245368	351	7210381	136,984	6706459	113,702
10/96	31	4290899	194	6115453	84,294	5371975	49,946
11/96	30	3478709	237	5978498	115,490	5643052	99,993
12/96	31	4733698	379	7143831	111,348	7173576	112,722
Total		**28235276**			**633,385**		**627,945**

meters were installed on a group of 130 apartments at Fort Polk at the time of their construction. The energy services company has been collecting monthly readings from these meters for more than two years. As shown in a companion paper (Shonder and Hughes 1997b), when scaled up to the entire facility, these monthly readings predict energy savings within 2% to 3% of the value derived from feeder-level data. The meter readings have also been used in negotiating baseline adjustments. While the cost of reading the meters is very low, they provide valuable information that can be used to supplement the information derived from feeder-level meter readings. In future housing projects where meters are already installed, it may be worthwhile to collect such readings from a group of residences.

MAINTENANCE SAVINGS

Although reduced maintenance costs represent a significant portion of the Army's savings in this contract, the original cost of maintaining HVAC equipment in family housing was difficult to obtain. This is often the case in environments where maintenance is unfunded or deferred from year to year. Published values for HVAC maintenance (ASHRAE 1995; BOMA 1995; Mancini et al. 1996) often provide only a range of figures. Because the historical cost of maintenance of the HVAC equipment in Ft. Polk's family housing could not be separated from the total facility maintenance costs, the Army developed an estimate based on bids received on a request for proposals (Aldridge 1995). The baseline maintenance cost was determined to be $335.83 per housing unit per year, or about 24.1 cents per square foot per year.

Although the Army's maintenance records were incomplete, the energy services company assumed responsibility for maintaining existing family housing HVAC equipment approximately one year prior to the beginning of retrofit construction; the company's records allowed the authors to develop an independent estimate of the Army's baseline maintenance costs (Shonder and Hughes 1997a). Examining the maintenance records for a random sample of 175 of the 4,003 residences, the authors tabulated the frequency of maintenance activities observed for each residence (e.g., charge system with refrigerant, clean indoor coil, replace outdoor fan motor, etc.) and obtained estimates of the time and materials required for each activity from an HVAC service technician.

This information, along with labor and overhead costs, provided an estimate of what it was costing the company to maintain existing equipment. However, it was reasoned that this maintenance was not typical; because the company was planning to replace the equipment with geothermal heat pumps in the near future, no instances of complete outdoor unit replacement were observed. In order to correct for this, the authors surveyed 3,879 of the outdoor units to determine their year of manufacture. Comparison of the date of manufacture of the outdoor unit with the year in which the residence was constructed allowed the authors to determine whether the original outdoor unit had been replaced and, if so, its approximate age at replacement. From this the authors derived a figure for the reliability of the aggregate of the outdoor units and determined how many would require replacement each year.

Based on this analysis, the authors developed a 20-year-average maintenance cost of $369.05, or 26.5 cents per year per square foot, which agrees well with the Army's figure. This indicates that the Army's method of estimating costs using bids on a maintenance RFP was valid. However, in future projects, such bids may not be available, and facility owners may have to rely on their own records or published figures to develop cost estimates.

ENGINEERING THE PROJECT

Developing models of energy consumption for 4,003 residences, engineering the retrofits for each one, and estimating overall energy savings represented a major undertaking on the part of the company. However, unlike most private housing, military family housing is centrally managed, and existing technical records and plan vaults enable economies of scale in the engineering of retrofit projects. The archived information enables the identification of a relatively small group (64 in this case) of unique "building block" housing units that describe the entire housing population. All housing units represented by the same "building block" are identical from the point of view of heating and cooling design load calculations (same floor plan, same wall/roof/floor/window/door constructions, same wall/roof/floor/window/door exposures to outside air) except for compass orientation. Precalculation of design loads for each building block and orientation creates the equivalent of a spreadsheet-based lookup table for any of the 4,003 units.

The housing characteristics of the "building block" are determined by carefully overlaying the construction contract history determined from the technical records and plan vaults. The starting point is the construction documents for each phase of the original construction (as mentioned above, family housing at Fort Polk was built in nine different phases). Older housing often has already had energy-related retrofits since the original construction (attic insulation, window upgrades, etc.). When creating characteristics files for each "building block" housing unit, the objective is to establish the currently existing characteristics first and then make any modifications related to energy conservation measures that will be installed along with the geothermal heat pumps (in this case, lighting upgrades to compact fluorescent lights affected heating/cooling load calculations in all cases and attic insulation and window treatments sometimes).

The characteristics are documented in the form of input files to the heating/cooling design load calculations used to size the geothermal heat pumps. The design load calculation tool outputs are documented in the spreadsheet-based lookup table for each building block and orientation. The spreadsheet defines each of the 4,003 apartments by building block and orientation, design loads, geothermal heat pump size, building number, and the serving electric feeder (in the normal electric distribution configuration).

The design team did everything that is normally recommended for ground heat exchanger design and came face to face with the limitations of the state of the art of ground heat exchanger design as of 1993-94. On-site short-term tests were conducted on ground heat exchangers installed at three locations (north, middle, and south fort housing), specifically to determine the conductivity of the soil formation. The soil properties indicated by these tests were similar to what ASHRAE lists for heavy damp soil, and heavy damp soil was used as a design input. The designer was also aware of the diversity of sizes that available ground heat exchanger sizing methods recommend and had utilized several different methods. The decision was made to install the larger of the recommended sizes because of the severe consequences of undersizing (potentially 4,003 separate ground heat exchangers needing add-ons).

Nevertheless, this evaluation indicates that the ground heat exchangers were somewhat oversized (Thornton et al. 1997). Data collected during the evaluation were used to calibrate an engineering model of the residential vertical geothermal heat pump system. As part of model calibration, the properties of the soil formation that enabled the ground heat exchanger component model to track data were determined to be similar to what ASHRAE lists for heavy saturated soil. Using heavy saturated soil and a variety of practical ground heat exchanger sizing methods, one still obtains a diversity of recommended sizes, but they are shorter than for heavy damp soil (Thornton et al. 1997). Assuming the soil properties at the test apartment, and the apartment itself, are representative of the entire housing, feet of vertical bore could have been decreased by about 20%, from 1,834,652 to 1,467,722 feet (from 275 to 220 bore feet per ton excluding bore within 3 feet of the ground surface).

The design team also did everything that is normally recommended for energy estimating, although in hindsight some of the steps might have been carried out differently. Using pre-retrofit housing characteristics, engineering models of the building block apartments were assembled and weighted to create a model of all housing that was calibrated to the available baseline monthly electric consumption data. Savings were estimated by changing the inputs to the engineering models to reflect all of the energy conservation measures to be installed.

This approach might have been more effective if done feeder by feeder, so that all-electric and gas/electric feeders and feeders built at different times could have been isolated and calibrated separately. Also, with an hourly building energy model and a modest amount of daily feeder data (derived from 15-minute-interval data), rather than a monthly bin model and monthly feeder data, a better calibration to base loads on days with little or no heating and cooling could have been performed (no month at Fort Polk has little or no space conditioning). Isolating feeders and fully using the available data results in better estimates of pre-retrofit base loads relative to heating/cooling. This is important in projects of this type because the most important energy conservation measure (geothermal) primarily impacts heating/cooling—if pre-retrofit heating/cooling is overestimated, savings will be overestimated. The authors found the models available to estimate water-heating savings due to desuperheaters to be crude or to require far more input data than is typically available to a design team. This problem is being addressed with ongoing work.

The design team also performed short-term monitoring on a small sample of apartment installations both before and after the retrofits. However, true power measurements were not taken (amps were measured rather than watts), no weather data were collected, the pre/post data collection period was modest, the sample size and apartment selection technique could not support a direct savings estimate for the housing population, and the data set was ill-suited for calibration of engineering models. The data did provide a concrete (relative to models) demonstration of savings sufficient to secure construction funds for the project from a private investor, when considered along with the creditworthiness of the customer (the Army) and the experience of the energy services company.

For future projects, some project partners may prefer a small pilot test of the comprehensive set of retrofits first. Data collection and analysis should be designed to determine the soil properties as described elsewhere (Thornton et al. 1997) to enable economical yet safe and reliable ground heat exchanger sizing. The same pilot provides data that supplements the monthly baseline data on feeders, so that a better job of calibrating engineering models and estimating energy savings can be done. Although pilot tests could be conducted to estimate housing population energy savings directly, the cost of the required sample size and duration would likely be prohibitive if it must be funded as part of the project investment.

The nature of the site data collection during project development that some project partners may prefer is summarized here because it is significantly different from what was done by the developers of the Fort Polk project or by the project evaluators. First, the feeder-level data are discussed.

The three years or so of manually recorded monthly electric consumption by feeder is still desired. However, it may be desirable to have these same data recorded at 15-minute intervals for a period of 9 to 12 months before retrofit construction and perhaps during and after construction (27 to 36 months) using the nonobtrusive interface described above and presented in Figure 3. This 15-minute-interval data serves several purposes. First, the pre-retrofit period provides ambient temperature and power data in convenient electronic form for calibrating engineering models of housing population energy consumption during the pre-retrofit period in a way that properly determines the relative importance of base loads and space conditioning. Then the calibrated model provides one means of estimating savings of the energy conservation measures across the housing population. Second, the pre-retrofit data support development of pre-retrofit electric consumption models by feeder that reference daily averages of kWh and ambient temperature and provide a more reliable means of estimating savings in the early days of the project than monthly readings (30 data points each month rather than one). Third, the post-retrofit data support the development of the same sort of consumption model for the post-retrofit period.

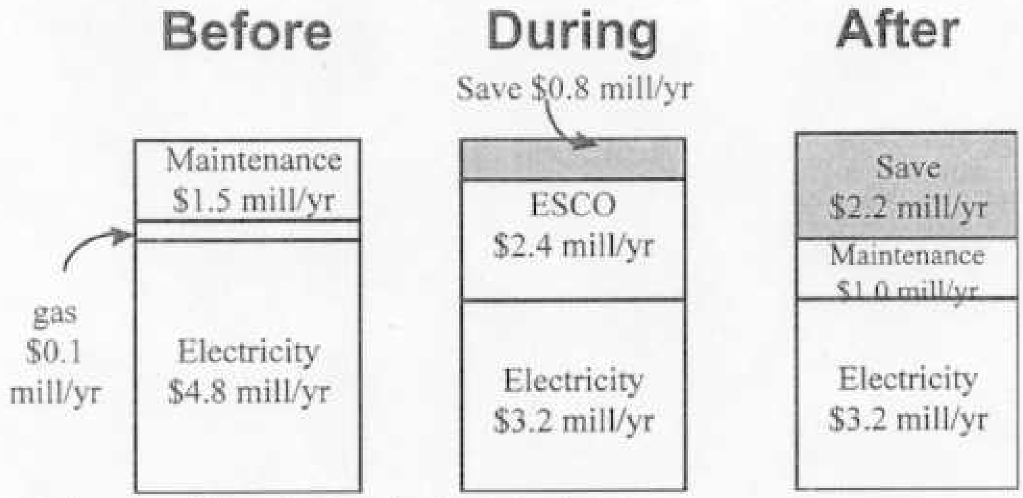

Figure 8 *Financial structure of the project from the Army's standpoint.*

Having both the pre- and post-retrofit daily average models archived may also be useful in the event of future disputes. For example, as mentioned above, if savings decline over time, reinstalling 15-minute data collection equipment for a short period might indicate a significant rise in post-retrofit kWh consumption on mild (baseload) days, which could lead to an amicable agreement on a baseline adjustment for plug load creep. Such data could also help the parties agree on the impacts of changes in occupancy rates and total occupancy, or indoor temperature setpoints, if these become issues over the term of the contract. If no disputes arise during the contract, the need to record 15-minute data after the initial 27- to 36-month period will never arise.

In addition to the feeder data, some project partners may prefer that pre/post data be collected on a small sample of apartments receiving installations of the comprehensive package of energy conservation measures. If collected properly, these data will provide a better indication of soil properties than the currently available short-term on-site tests. These data also provide an opportunity to calibrate engineering models to detailed data on a few apartments. Building energy analysis engineering models have many inputs; some are best calibrated to global (feeder) data as described above and others are best calibrated to detailed data from individual apartments (Thornton et al. 1997). Having both "pre" feeder data and "pre/post" apartment data during the project development phase will significantly increase the reliability of prior estimates of energy savings. If periodic corrections for plug load creep are to be made, the apartment-level data can also be used to provide a check on baseload calculations derived from the feeder-level data. Perhaps after a few more projects, customers and project developers and funders will be confident enough to pursue these mega-projects without any pilot testing. Some may have that level of confidence now.

POTENTIAL ECONOMIC IMPACTS OF LESSONS LEARNED

The lessons learned in this evaluation can be used to improve the economics of future energy savings performance contracts. To illustrate this, the authors examined how the economics of a contract like the one at Fort Polk can change under various scenarios. It should be noted that the numbers presented here are based on energy savings for a typical meteorological year as determined from the pre- and post retrofit models developed in the course of the evaluation. Maintenance costs and savings are based on authors' estimates as well, and energy prices are average values. The figures presented here are for illustrative purposes only and do not correspond to the actual costs and payments in the Fort Polk contract, which vary by year according to weather and other factors stipulated in the contract and its amendments.

The financial structure of the energy savings performance contract from the standpoint of the Army is presented graphically in Figure 8. Before the contract, with energy prices of $0.06 per kWh of electricity and $0.50 per therm of natural gas, the Army's total energy cost for family housing in a typical year was about $4.9 million ($1,223 per year per living unit). Maintenance costs were about $1.5 million per year ($369 per year per housing unit). Over the 20-year life of the contract, the Army will pay about $2.4 million per year to the energy services company and $3.2 million for electricity, saving $0.8 million per year. After the contract expires, the Army will realize a savings of about $2.2 million per year, assuming it is able to extend a maintenance contract at the same cost as its maintenance payments to the company during the 20-year performance contract. Using a standard 7% annual discount rate over the 20-year life of the contract (DOC 1982), the net present value of the contract to the Army is about $9.1 million dollars. This figure does not include the salvage value of the geothermal heat pumps at the end of the 20-year period. Upon termination of the contract, the Army will own the 4,003 heat pumps and ground loops. At 20 years, the heat pumps may be approaching the end of their useful service life, but the ground loops will likely outlive several more heat pumps. This will reduce the Army's cost of installing new GHPs, should it desire to do so.

While the figures above are representative of the contract as originally signed, negotiations are currently under way to adjust the baseline energy consumption formula. The original RFP specified heating and cooling setpoints of 68°F/78°F in all of the housing units, but as a result of tenant complaints, these setpoints are now controlled by the occupants. Because the Army was unable to operate the family housing according to the agreement, this change may result in an addition of 8 million kWh per year to the baseline formula. This would bring the Army's annual savings down to about $0.4 million. With this adjustment, the net present value of the contract to the Army would fall to $4.5 million—again, exclusive of the equipment's salvage value.

From the standpoint of the energy services company, the financial picture is somewhat different. Exclusive of costs to maintain equipment in family housing, their primary liability is debt service on the $18.9 million borrowed to purchase and install the energy conservation measures and recover the working capital required to develop the project. At 9% interest compounded monthly, this is approximately $2.0 million per year. Payments from the Army will total $2.4 million per year, leaving $0.4 million per year to perform maintenance on the GHPs and other equipment installed in the 4,003 housing units. Assuming zero operation and maintenance phase profit and ignoring the CPI escalator on the maintenance payment, this comes to about $100 per housing unit per year, or $0.07 per square foot per year for maintenance. With the baseline adjustment, payments to the company increase to $2.8 million per year, leaving $200 per housing unit per year (about $0.14 per square foot per year) for maintenance. Because published figures for maintenance costs of GHP equipment (Geothermal Heat Pump Consortium 1996) are in the range of $0.10 to $0.22 per square foot per year, the figure of $0.14 per square foot per year for maintenance leaves little room for profit on the part of the company unless it takes further action. One option would be for the company to refinance its debt at a more favorable interest rate. At 8% interest, the annual debt service drops to $1.9 million, leaving $0.16 per year per square foot for maintenance.

Research has also shown that the ground heat exchangers were oversized in this project, possibly by as much as 20%. At $3.50 per bore foot, the up-front cost of the project could have been reduced by about $1,300,000. In future efforts of this kind, some project partners may wish to perform the measurements required to develop more accurate estimates of soil properties to support refined loop sizing. A rough estimate for the data collection required is $100,000. Assuming the remaining savings deduct from principal, at 8% interest the annual debt service drops to $1.765 million, leaving $0.185 per square foot per year for maintenance. Other ground heat exchanger design refinements, such as thermally enhanced grout, may also improve the economics of future projects.

Several other minor design refinements will be possible in future projects. The next smaller ground loop pump would have been ample for the application. This pump costs $20 less and draws 40 less watts. Because each GHP runs about 2,500 hours annually, this change costs $80,000 less and saves about $24,000 annually in electricity costs. Even with the smaller pump, 0.75-inch rather than 1.0-inch circuit pipe in the bores would have provided adequate water flow to the heat pumps. It would also have cost less, even though slightly more vertical bore is required than for 1.0 inch pipe, and would have had negligible performance impact. Experienced industry participants could likely identify a number of other cost-effective design refinements.

While the economics of the Fort Polk energy savings performance contract are somewhat different from the representative figures presented here, they show that the energy services company has a strong incentive to seek out other opportunities for energy savings in family housing. Examples include hot water tank wraps and weather stripping (both of which were identified as potential energy conservation measures in the contract but have not yet been carried out), duct leak repairs, and educational programs for family housing residents. According to the contract, the company will receive 77% of the energy dollar savings it manages to achieve.

CONCLUSIONS

When carried out properly, the feeder-level approach to monitoring and verification of energy savings is practical for large housing projects of this type. However, manual monthly readings over the baseline period of three years or so, during retrofit construction, and throughout the term of the contract may not be enough to ensure project success for all combinations of customer, project developer (energy services company), and funders. Where the three-year baseline data do not exist, 15-minute-interval recordings over a 9- to 12-month period can be used to establish a baseline. Even where historical data exist, some project partners may prefer to supplement monthly manual readings with 15-minute electronic recordings over a 9- to 12-month period before retrofit construction. This will improve the prior estimates of energy savings and is relatively inexpensive because the housing population is captured by only a few feeder meters. Other project partners may elect to continue 15-minute data through retrofit construction and for 9 to 12 months after construction is complete. This additional 18 to 24 months of data (for a total of 27 to 36 months) has modest cost and several benefits. At the beginning of the project, savings are known sooner and with greater confidence than with only monthly pre-/post-retrofit data, and the archived 15-minute data can support the amicable resolution of several types of savings measurement disputes that may occur in the future. Last, existing inexpensive data sources should be utilized to their fullest. If some apartments have existing meters, it costs almost nothing to record the readings and obtain an indication of savings sooner than is possible with any type of feeder-level monitoring.

Some project partners may also wish to include more rigorous pilot tests in their project development phase than were done at Fort Polk. This involves installing the comprehensive package of energy conservation measures in a small sample of apartments three or so months after initiating 15-minute end-use metering on them but six to nine months prior to initiation of general construction. This metering can occur simultaneously with the 9- to 12-month period of feeder-level pre-retrofit data collection described above. Done properly, this pilot test will determine soil properties for fine-tuning of ground heat exchanger sizing. The pilot test will also improve prior estimates of energy savings and help secure project financing.

Probably all project partners will want to benefit from site measurements of soil properties so that ground heat exchangers can be sized as economically as possible. Short-term tests on installed ground loops, conducted from a portable trailer, were not up to this challenge during the development of the Fort Polk project. However, active programs to improve these methods may bear fruit in the near term. Until that happens, calibration of detailed ground heat exchanger models against data from operating pilot test heat pump units remains an alternative.

Design teams should also revisit the basic application design parameters in every large project. Choices that should be reconsidered include conventional or thermally enhanced grout, circuit pipe size, and loop pump size.

Establishing the HVAC maintenance expenditure baseline and estimating savings relative to that baseline remain difficult but are essential for geothermal heat pump projects to demonstrate themselves to be self-funding (i.e., to have positive cash flow). This is important for U.S. federal sector projects because the statutory authority allowing federal agencies to enter into energy savings performance contracts requires them to be self-funding from energy-related operating accounts. Historical maintenance expenditure records kept by federal facilities generally are not adequate to establish a baseline, particularly in a budget environment where maintenance may be unfunded and deferred from year to year. Fort Polk was no exception. The approach to establishing a maintenance baseline taken by the evaluation team, which relies on service incidence histories and nameplate data, may be as good as any. It resulted in a baseline of 26.5 cents per square foot per year, similar to the 24.1 cents per square foot per year estimated by the Army while developing the project. As for what it will actually cost the energy services company to maintain the systems over the 20-year contract life, only time will tell. However, the relevant price to the Army is what the company agreed to do it for, which was 18.1 cents per square foot per year. HVAC maintenance for geothermal heat pump systems in schools has been reported to be 13 cents per square foot per year (Mancini et al. 1996).

ACKNOWLEDGMENTS

The opportunity to evaluate the energy savings performance contract at Fort Polk was created by the efforts of numerous organizations. Personnel at Fort Polk championed the contract and continue to administer it. The Huntsville Division of the Army Corps of Engineers was instrumental in determining the feasibility of the contract, developing the request for proposal, and awarding the contract. The selected energy services company, Co-Energy Group (CEG), was responsible for designing, financing, and building the energy conservation retrofits in return for a share of the energy savings and is responsible for maintaining the installed equipment for the duration of the 20-year contract. Applied Energy Management Techniques, under subcontract to CEG, was responsible for surveying the family housing, developing the energy consumption baseline from historical data, and developing the retrofit designs and prior cost and savings estimates. Oak Ridge National Laboratory (ORNL) carried out an independent evaluation of the contract with sponsorship from the U.S. Department of Defense (DOD), the U.S. Department of Energy (DOE), and Climate Master, Inc. Under subcontract to ORNL, field data collection was provided by Science Applications International Corporation, and TRNSYS modeling was provided by Thermal Energy Systems Specialists.

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DISCUSSION

Donald M. Brandage, Engineer, Southern Company Service, Atlanta, Ga.: You mentioned that the drillers of the water loop ran behind schedule. What were the reasons for this: poor estimates by drilling contractors, unexpected soil conditions, etc.?

Patrick J. Hughes: The function of the drilling contractors on this project was to drill 4.125 inch bores to depths of 190 to 250 ft., withdraw the drill stem, insert U-tubes of nominal 1 inch diameter SDR11 high density polyethylene pipe, and backfill and the bore from bottom to top with bentonite-based grout. Several of the contractors were not experienced at drilling in the local conditions and their rigs were not optimally configured. Also, several contractors were not experienced at installing U-tube ground heat exchangers. The outside dimension of the U-bend at the bottom of the U-tube was about 3.8 inches leaving modest clearance in the 4.125 inch bore. The expansive clays encountered sometimes made it difficult to insert the U-tubes after the drill stem was removed.