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Geothermal Heat Pump ESPC at Ft. Polk: Lessons Learned

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GEOTHERMAL HEAT PUMP ENERGY SAVINGS PERFORMANCE CONTRACT AT FORT POLK, LA.: LESSONS LEARNED

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ABSTRACT

At Fort Polk, LA the space conditioning systems of 4,003 military family housing units have been converted to geothermal heat pumps (GHP) under an energy savings performance contract (ESPC). At the same time, other efficiency measures, such as compact fluorescent lights (CFLs), low-flow shower heads, and attic insulation, were installed. An independent evaluation of the Fort Polk ESPC 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 6,541 kW, which is 39.6% of the pre-retrofit peak demand. Natural gas savings are about 260,000 therms per year. In addition, the ESPC has allowed the Army to effectively cap its future expenditures for family housing HVAC maintenance at about 77 percent of its previous costs. Given these successful results, the Fort Polk ESPC can provide a model for other ESPCs in both the public and the private sectors. The purpose of this paper is to outline the method by which the ESPC was engineered and implemented, both from the standpoint of the facility owner (the U.S. Army) and the energy services company (ESCO) which is carrying out the contract. The lessons learned from this experience should be useful to other owners, ESCOs and investors in the implementation of future ESPCs. It should be noted that the energy savings presented in this document are the "apparent" energy savings observed in the monitored data, and are not to be confused with the "contracted" energy savings used as the basis for payments. To determine the "contracted" energy savings, the "apparent" energy savings may require adjustments for such things as changes in indoor temperature performance criteria, additions of ceiling fans, and other factors.

Keywords: Geothermal (or ground-source) heat pumps, energy savings performance contracts, electrical energy savings, maintenance savings

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ABSTRACT

At Fort Polk, LA the space conditioning systems of 4,003 military family housing units have been converted to geothermal heat pumps (GHP) under an energy savings performance contract (ESPC). At the same time, other efficiency measures, such as compact fluorescent lights (CFLs), low-flow shower heads, and attic insulation, were installed. An independent evaluation of the Fort Polk ESPC was carried out. Findings indicate that the project has resulted in a 26.1 million kWh savings in electrical energy use, or 32.7% 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 ESPC has allowed the Army to effectively cap its future expenditures for family housing HVAC maintenance at about 77 percent of its previous costs. Given these successful results, the Fort Polk ESPC can provide a model for other ESPCs in both the public and the private sectors. The purpose of this paper is to outline the method by which the ESPC was engineered and implemented, both from the standpoint of the facility owner (the U.S. Army) and the energy services company (ESCO) which is carrying out the contract. The lessons learned from this experience should be useful to other owners, ESCOs and investors in the implementation of future ESPCs.

1. BACKGROUND

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 ESPC.

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 which were constructed in nine phases between 1972 and 1988. Units range in size from 1,073 to 2,746 square feet, with an average area of 1,393 square feet. Prior to the implementation of the ESPC, 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 ESPC of the shared savings type to an ESCO. Under the terms of the contract, the ESCO replaced the space conditioning systems in all of Ft. Polk's family housing with GHPs. The total capacity of GHPs is 6,593 tons, installed in 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 (since 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, and 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 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 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 ESCO, 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 ESCO a percentage of the energy and maintenance savings realized each month. The structure of the ESPC is shown in Figure 1. Electrical energy savings is determined by subtracting actual kWh consumption from the assumed baseline consumption, which is a function of the heating and cooling degree days which 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 is 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 ESCO will receive about 77 percent of the savings achieved.

Since the ESCO assumes full responsibility for maintaining the equipment installed, the Army's savings is 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 ESCO will receive about 77 percent of the maintenance savings over the life of the contract.

2. EVALUATION APPROACH

The objectives of the evaluation were to: 1) determine statistically-valid energy, demand, and O&M 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 fifteen minute intervals from submeters on fourteen of the sixteen electrical feeders that supply electricity to the family housing areas of the Fort (the original intent 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 fifteen-minute intervals at four different locations within the family housing area. Level 1 data allows comparison of pre- and post-retrofit energy usage patterns on the aggregate of all loads served by each feeder. 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 fifteen-minute intervals. Level 2 data allows 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.

In Level 3, more detailed energy use data were collected on a subsample of 18 of the 42 Level 2 units (7 of the 16 buildings). In addition to total premise and space conditioning energy, fifteen-minute interval data are collected to isolate the energy use of the hot water heater, the air handling system, and the furnace in the pre-retrofit condition. Again the subsample includes buildings of varying floor areas, construction vintages, and other characteristics. This technical sample is useful for understanding the relative importance of the weather-sensitive end-uses versus base loads, and supports analysis to determine the savings attributable to the various conservation measures. Pre- and post-retrofit data collection is similar to that of level 2, presented in Figures 4 and 5.

3. ENERGY CONSUMPTION BASELINE

At Fort Polk, electrical energy is provided to family housing through sixteen 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 ESCO 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:

$$\text{kWh/month} = (-6.40743*X^2 + 13095.7*X + 2899270)*(n/30) \qquad (1)$$

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 is 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 street light operating hours from month-to-month. However, some of the remaining variation in Fig. 6 is still weather-related. Since all living units are cooled with electric vapor compression devices, but only 81 percent of 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 Eq. (1) is not a least squares fit to the data of Figure 6. It was developed from a subset of the historical data, 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:

$$\text{kWh/month} = (2.3693*X^2 + 5139.9*X + 4357719)*(n/30) \qquad (2)$$

The RMSE of this equation is 1,184,313 kWh, only slightly less than that of Eq. (1). The historical data, and the monthly consumption predicted by Eqs. (1) and (2), are presented in Table 1. Since both equations predict the historical consumption to about the same degree of accuracy, the use of Eq. (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 non-weather-dependent consumption. Understanding the relative importance of weather-dependent and non-weather-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, we developed models of pre-retrofit electrical consumption for each of the 16 feeders which 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, 1997). Pre-retrofit daily electrical use in all family housing was found to fit the following 5-parameter model:

$$\text{kWh/day} = \begin{cases} -6940.54*(T-56.46) & T<56.45\ ^\circ F \\ 171{,}031 & 56.45 \le T \le 68.06 \\ 6571.15*(T-68.06) & T>68.06 \end{cases} \qquad (3)$$

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 9-12 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 percent; 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 this data, interpreted and refined as necessary, was used in developing the contract baseline. Since our correlation - 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 9-12 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 calibrations, 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.

4. 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 (U.S. Department of Energy, 1996) and the more specific Measurement and Verification Guidelines for Federal Energy Projects (U.S. DOE Federal Energy Management Program, 1996), this is an "Option C" monitoring and verification plan, whereby savings are determined from actual facility meter readings. (As an aside, the ASHRAE Guideline Project Committee 14P is also developing "Guidelines for Measurement of Energy and Demand Savings", a documented expected to strengthen the technical foundation of M&V.)

Given the results to date, the "Option C" approach to monitoring and verification (M&V) 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. Since 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 the ESCO to sustain the energy efficiency improvements over the life of the contract.

Nevertheless there are some disadvantages to using feeder-level data for M&V in housing projects. First of all, the feeders may include non-housing 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 non-housing 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 retrofits were being installed.

"Plug load creep" is another issue that may affect ESPCs with feeder-level M&V: as new appliances are introduced and adopted by the public, overall electrical consumption tends to increase. Since 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 non-weather-dependent loads would have occurred with or without the ESPC). 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 non-weather-dependent consumption and adjusting the baseline accordingly.

As an example, in Eq. (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, we analyzed pre-retrofit data from 13 of our 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 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 percent) 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 (non-weather-dependent) electrical loads. For comparison, the average consumption of the 6 lowest months

(inspection of Fig. 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 does not exist, it may be possible to determine the non-weather-dependent loads from 9-12 months of 15-minute interval pre-retrofit data collected from the feeders. Our 5-parameter fit of 12 months of this data, Eq. (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 non-weather-dependent electrical load is about 84 percent 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 ESCO 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 percent) 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 meters were installed on a group of 130 apartments at Fort Polk at the time of their construction. The ESCO has been collecting monthly readings from these meters for more than two years. As shown in the companion paper (Shonder and Hughes, 1997), 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 which 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.

5. MAINTENANCE SAVINGS

Although reduced maintenance costs represent a significant portion of the Army's savings in this ESPC, 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 ESCO assumed responsibility for maintaining existing family housing HVAC equipment approximately one year prior to the beginning of retrofit construction; the ESCO's records allowed us to develop an independent estimate of the Army's baseline maintenance costs (Shonder and Hughes, 1997). Examining the maintenance records for a random sample of 175 of the 4003 residences, we 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 ESCO to maintain existing equipment. We reasoned however that this maintenance was not typical; since the ESCO was planning to replace the equipment with GHPs in the near future, no instances of complete outdoor unit replacement were observed. In order to correct for this, we 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 us to determine whether the original outdoor unit had been replaced, and if so, its approximate age at replacement. From this we 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 we 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.

6. 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 ESCO. 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. Pre-calculation 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 Ft. 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 CFLs 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, mid 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 percent, 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 (ECMs) 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 to 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 Ft. 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 ECM (geothermal) primarily impacts heating/cooling; if pre-retrofit heating/cooling is overestimated, savings will be overestimated. We 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 was 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. This 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 ESCO.

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 economic 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 Ft. Polk project, or by the project evaluators. First, the feeder level data is discussed.

The 3 or so year history of manually recorded monthly electric consumption by feeder is still desired. However it may be desirable to have this same data recorded at 15 minute intervals for a period of 9-12 months before retrofit construction, and perhaps during and after construction (27-36 months) using the non-obtrusive 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 ECMs across the housing population. Second, the pre-retrofit data supports 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 supports the development of the same sort of consumption model for the post-retrofit period.

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, re-installing 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 ESPC. If no disputes arise during the contract, the need to record 15 minute data after the initial 27-36 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 ECMs. If collected properly, this data will provide a better indication of soil properties than the currently available short-term on-site tests. This data also provides 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 base load 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.

7. POTENTIAL ECONOMIC IMPACTS OF LESSONS LEARNED

The lessons learned in this evaluation can be used to improve the economics of future ESPCs. To illustrate this, we examine below how the economics of an ESPC 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 we developed in the course of the evaluation. Maintenance costs and savings are based on our 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 ESPC, which vary by year according to weather and other factors stipulated in the contract and its amendments.

The financial structure of the ESPC from the standpoint of the Army is presented graphically in Figure 8. Before the ESPC, with energy prices of $0.06 per kWh 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/yr per living unit). Maintenance costs were about $1.5 million per year ($369/yr per housing unit). Over the 20 year life of the contract, the Army will pay about $2.4 million per year to the ESCO 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 ESCO during the 20 year ESPC. Using a standard 7 percent annual discount rate over the twenty year life of the contract (U.S. Department of Commerce, 1982) the net present value of the ESPC to the Army is about $9.1 million dollars. This figure does not include the salvage value of the GHPs 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 underway 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. Since the Army was unable to operate the family housing as per 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 ESPC to the Army would fall to $4.5 million - again, exclusive of the equipment's salvage value.

From the standpoint of the ESCO 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 ECMs and recover the working capital required to develop the project. At 9 percent 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 O&M 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 ft^2/year for maintenance. With the baseline adjustment, payments to the ESCO increase to $2.8 million per year, leaving $200 per housing unit per year (about $0.14 per ft^2/year) for maintenance. Since 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 ft^2/year for maintenance leaves little room for profit on the part of the ESCO unless the ESCO takes further action. One option would be for the ESCO to refinance their debt at a more favorable interest rate. At 8 percent interest the annual debt service drops to $1.9 million, leaving $0.16 per year per square foot for maintenance.

Our 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 percent 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. Since each GHP runs about 2500 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, cost less even though slightly more vertical bore is required than for 1.0-inch pipe, and 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 ESPC, as contracted, are somewhat different from the representative figures presented here, they show that the ESCO 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 ECMs in the contract, but which have not yet been carried out), duct leak repairs, and educational programs for family housing residents. According to the contract, the ESCO will receive 77 percent of the energy dollar savings it manages to achieve.

7. CONCLUSIONS

When carried out properly, the feeder-level approach to M&V of energy savings is practical for large housing projects of this type. However, manual monthly readings over the 3 or so year baseline period, during retrofit construction, and throughout the term of the contract may not be enough to assure project success for all combinations of customer, project developer (ESCO)

and funders. Where the 3-year baseline data does not exist, 15 minute interval recordings, over a 9-12 month period, can be used to establish a baseline. Even where historical data exists, some project partners may prefer to supplement monthly manual readings with 15 minute electronic recordings over a 9-12 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 9-12 months after construction is complete. This additional 18-24 months of data (for a total of 27-36 months) has modest cost and has 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. Lastly, 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 was done at Ft. Polk. This involves installing the comprehensive package of ECMs in a small sample of apartments three or so months after initiating 15 minute end-use metering on them, but 6-9 months prior to initiation of general construction. This metering can occur simultaneously with the 9-12 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 Ft. 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 remains difficult but essential for geothermal heat pump projects to demonstrate themselves to be self-funding (i.e., to be positive cash flow). This is important for U.S. federal sector projects because the statutory authority allowing federal agencies to enter into ESPCs 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. Ft. 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/ft^2/yr, similar to the 24.1 cents/ ft^2/yr estimated by the Army while developing the project. As for what it will actually cost the ESCO to maintain the systems over the 20 year contract life, only time will tell. However the relevant price to the Army is what the ESCO agreed to do it for, which was 18.1 cents/ ft^2/yr. 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).

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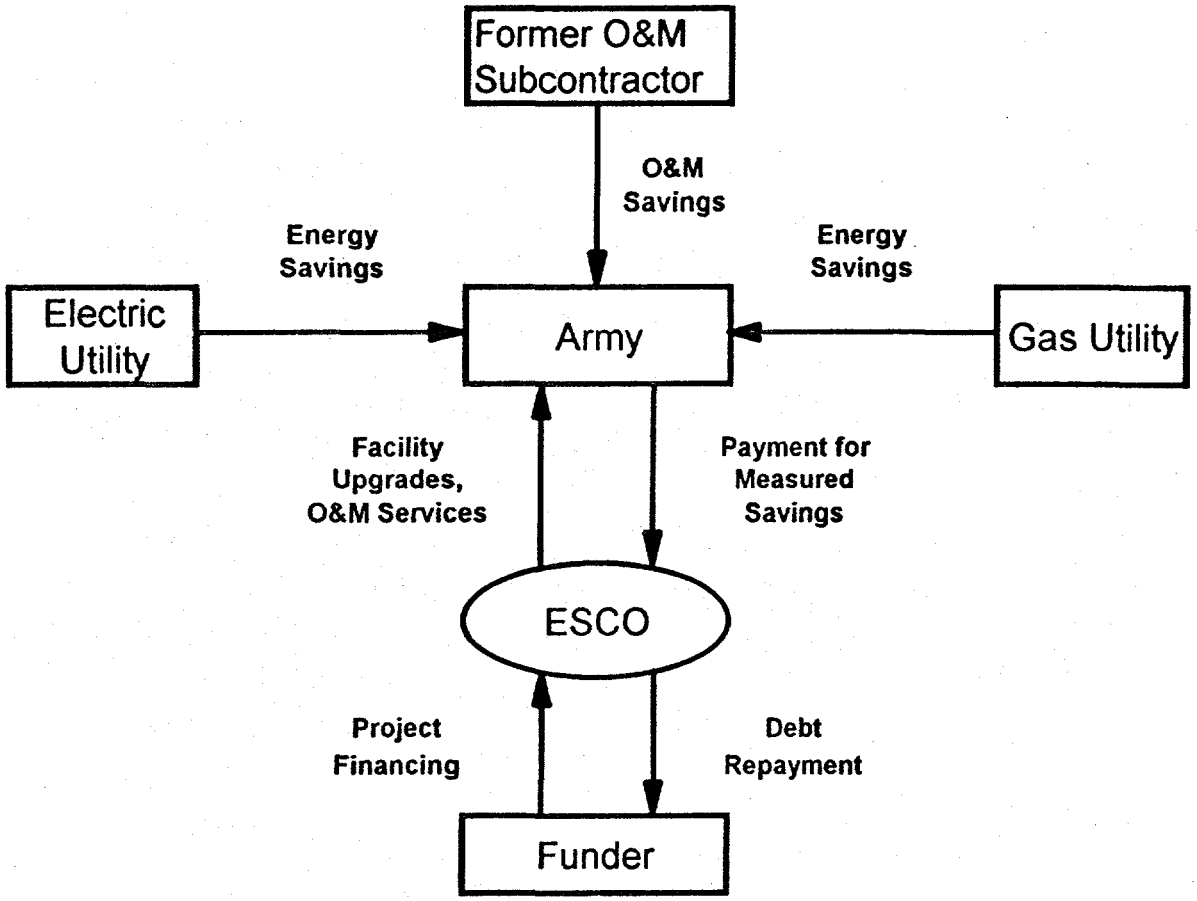

Figure 1: Structure of Fort Polk ESPC.

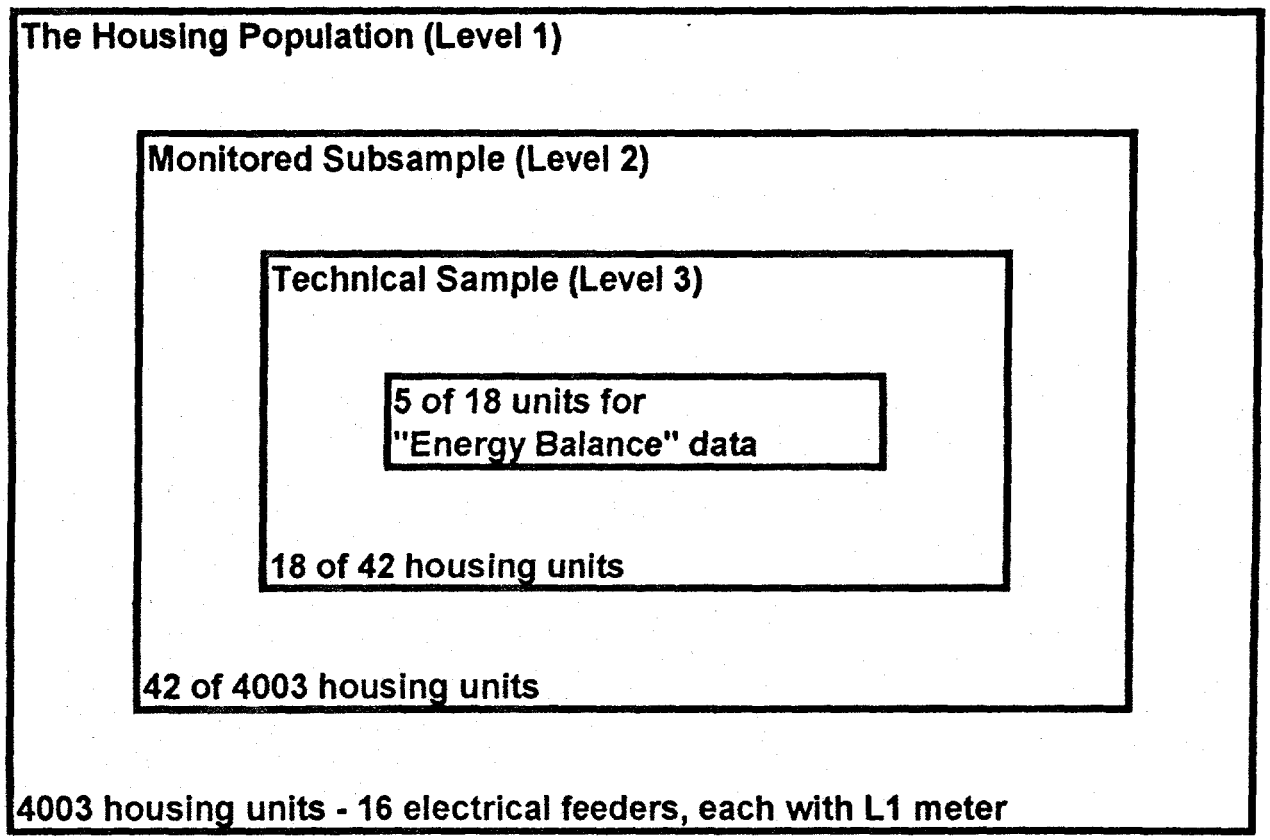

Figure 2: ORNL project evaluation approach

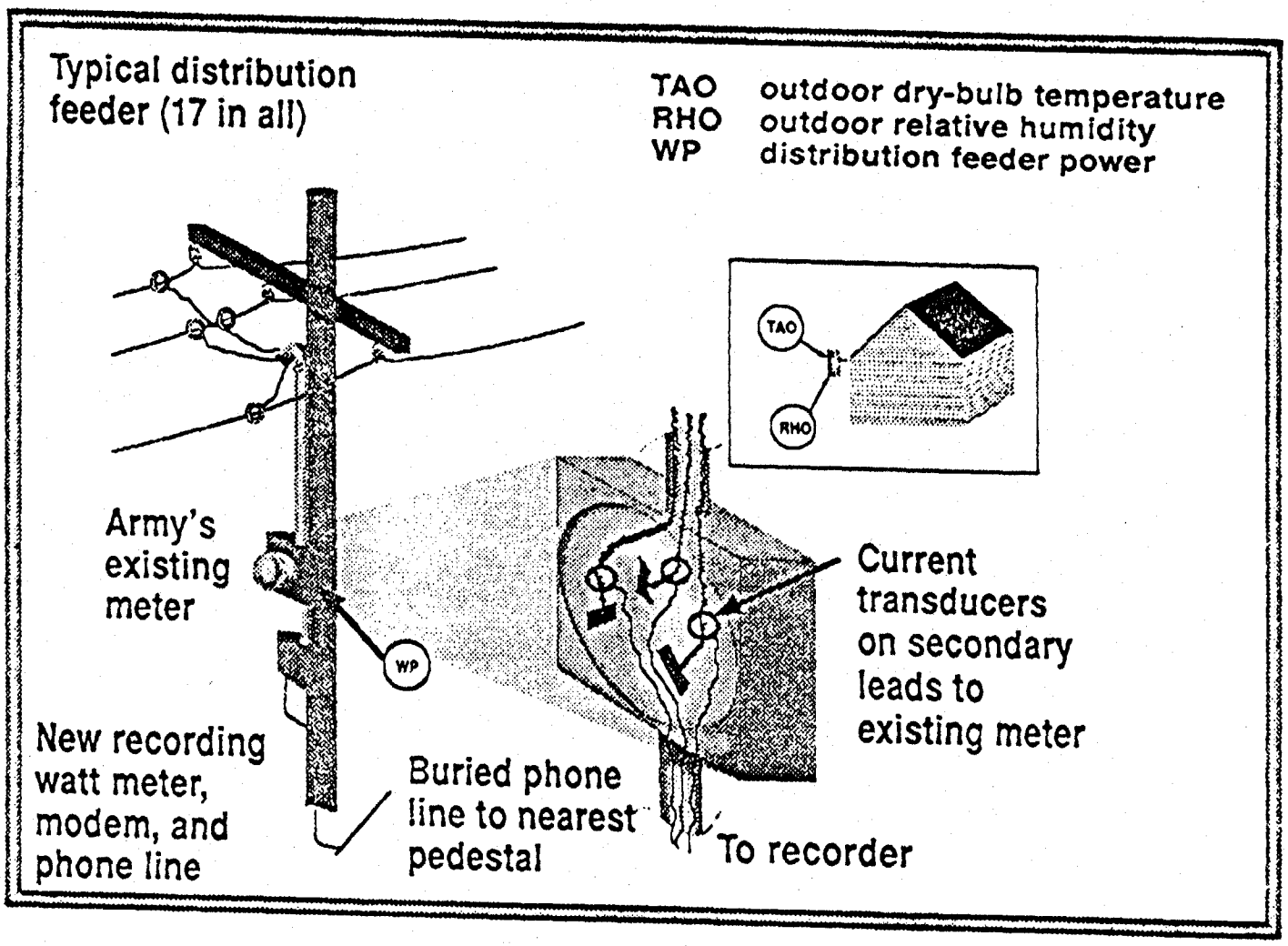

Figure 3: Level 1 pre-/post-retrofit data collection

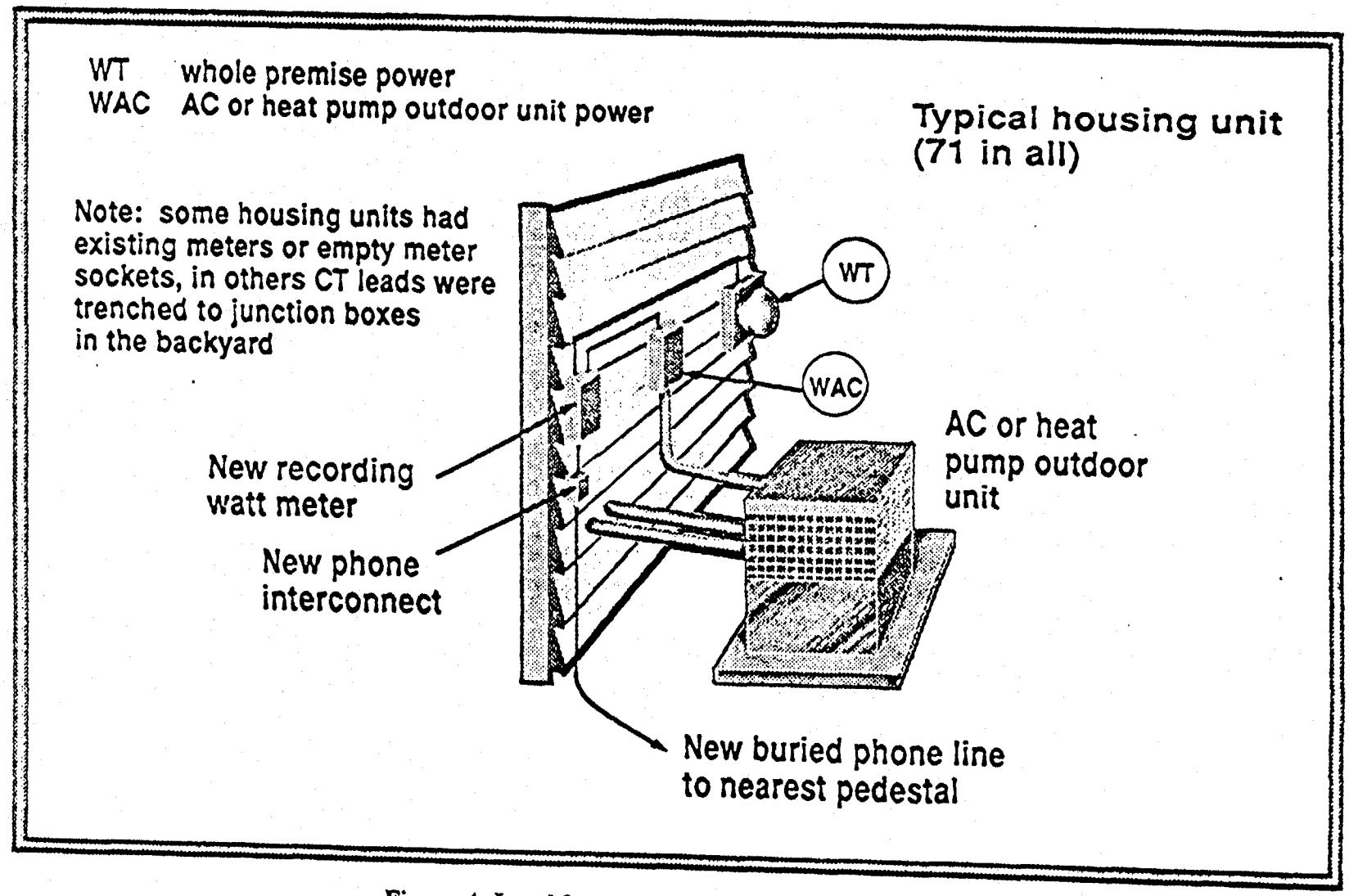

Figure 4: Level 2 pre-retrofit data collection

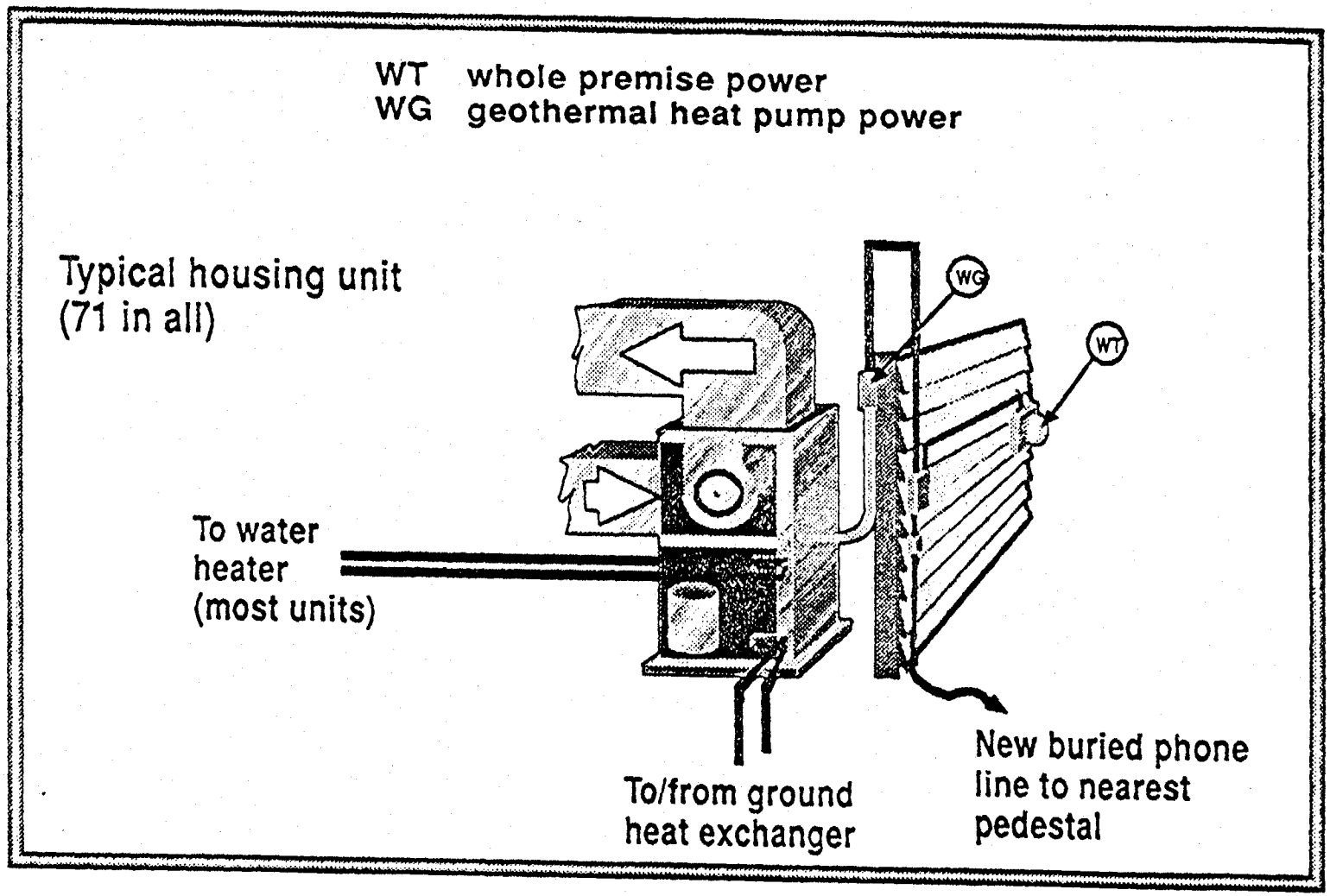

Figure 5: Level 2 post-retrofit data collection

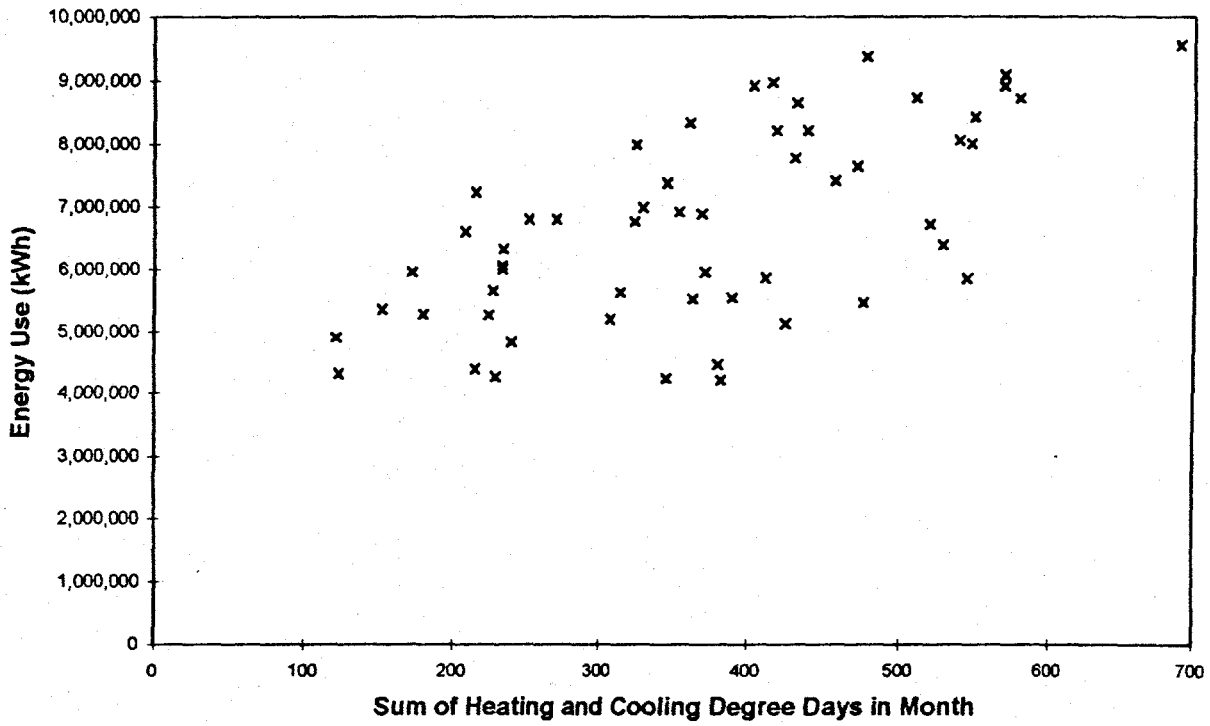

Figure 6: Historical kWh consumption data used to develop contract baseline.

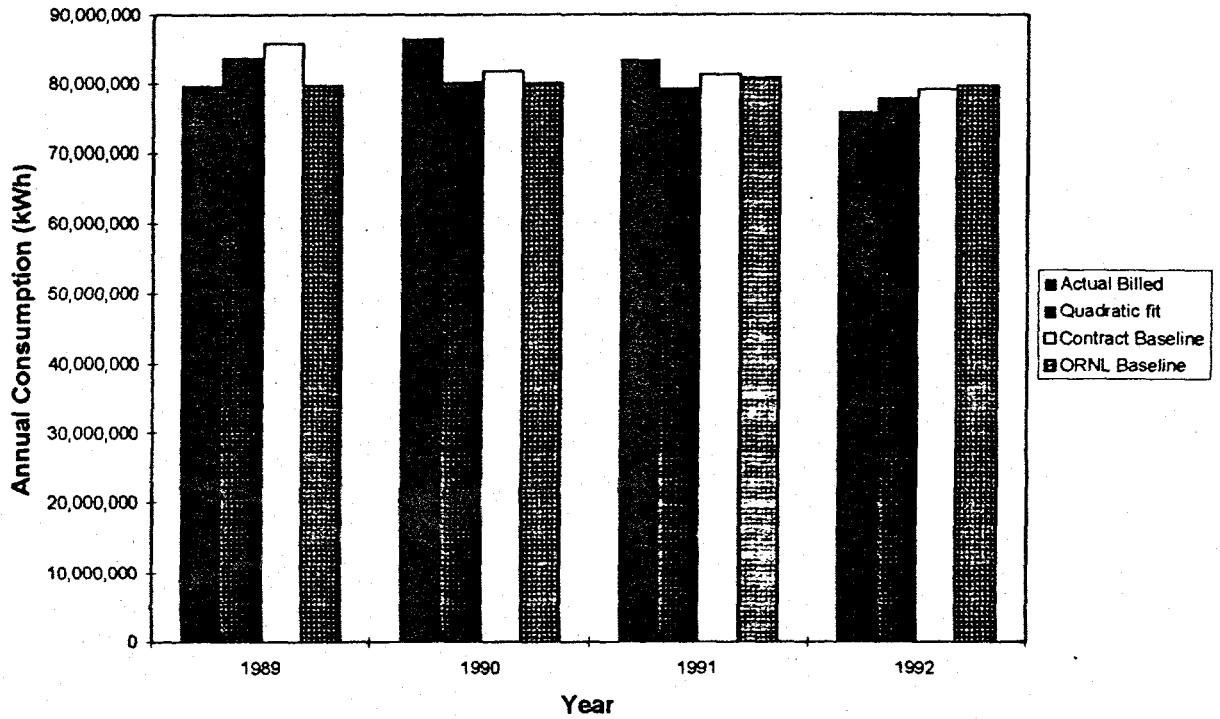

Figure 7: Annual consumption in family housing as predicted by three methods.

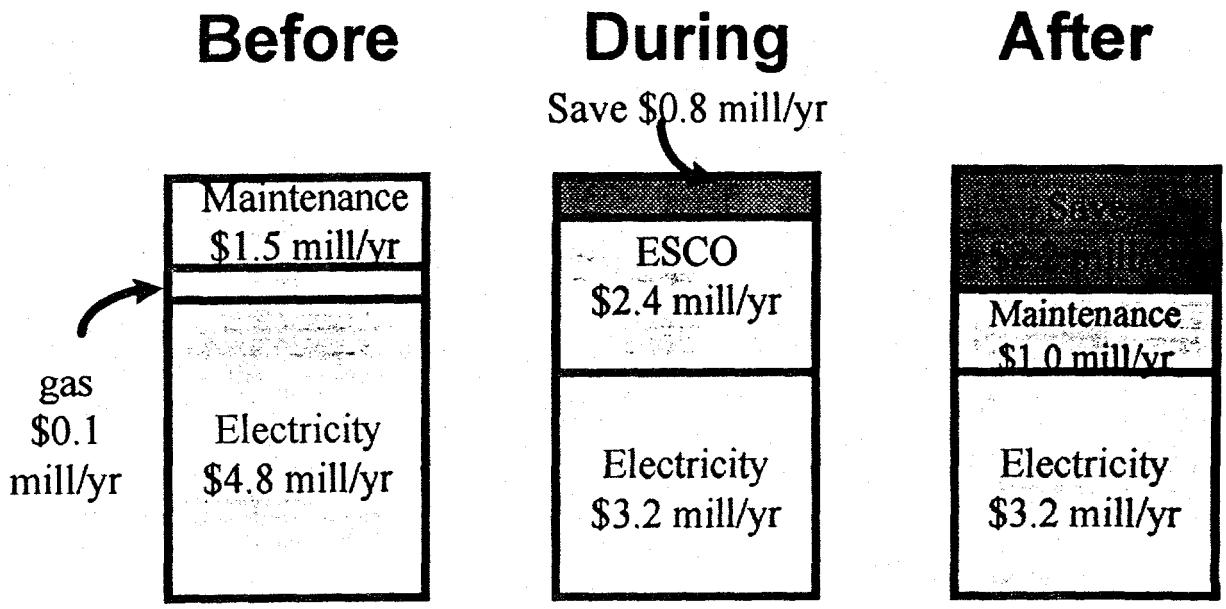

Figure 8: Financial structure of the project from the Army's standpoint.

Month	Days	TDD	Billed kWh	Contract Formula	Quadratic 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	5,418,662	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	5,511,208	5,627,934

Month	Days	TDD	Billed kWh	Contract Formula	Quadratic fit
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
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	4,216,970	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

Table 1: Historical monthly kWh consumption; consumption predicted by contract formula and by quadratic fit to historical data.

Site	Number of units	Total square feet	Pre-retrofit base load (kWh/sf/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**

Table 2: Base electrical consumption from 13 level 3 sites.

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**

Table 3: Comparison of energy payments to ESCO using ORNL baseline and contract baseline.

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