Geothermal Heat Pumps at Ft. Polk: Early Results

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At Fort Polk, LA an entire city (4003 military family housing units) is being converted to geothermal heat pumps (GHP) under a performance contract. At the same time other efficiency measures such as compact fluorescent lights (CFLs), low-flow water outlets, and attic insulation are being installed. If these contracts and this technology are to be used widely in U.S. Department of Defense (DoD) facilities and other public buildings, better data from actual projects is the key.

Being the first GHP project of this type and size, Fort Polk proved to be very challenging for all concerned. To get from RFP to start of construction took several years. This hard work by others created a once-in-a-lifetime opportunity to address many of the due diligence issues that delayed the Fort Polk project. So that future projects can move faster, an evaluation has been undertaken to address the following barriers:

- Absence of a documented large-scale demonstration of GHP energy, demand, and maintenance savings (a barrier to acceptance by federal customers, performance contractors, and investors),
- Newness of large-scale facility capital renewal procurements at federal facilities under energy savings performance contracts (ESPCs) or traditional appropriations (lack of case studies), and
- Variability in current GHP design tools (increases risks and costs for federal customers, performance contractors, investors and designers).

This paper presents early energy and demand savings results based on data collection through January 1996.

INTRODUCTION

Background

With sponsorship by the U.S. Department of Defense (DoD) and the U.S. Department of Energy (DOE), the Oak Ridge National Laboratory (ORNL) is carrying out an evaluation of a large-scale energy savings performance contract (ESPC) at Fort Polk, Louisiana. The ESPC implements a number of measures in Ft. Polk's family housing to save energy and maintenance costs, the most important of which is the retrofit of the heating and cooling systems in each of the facility's 4003 housing units with geothermal heat pumps (GHPs). Given the scale of the retrofit, the ESPC represents a unique opportunity to obtain statistically valid data to establish the energy, demand, and maintenance savings associated with comprehensive energy efficiency retrofits anchored by GHPs. Also, since the housing rehabilitation is being carried out at no up-front cost to DoD by means of a shared savings performance contract, the results of the evaluation will be of value both to DoD and to performance contracting energy services contractors (PC/ESCOs) in the development of future comprehensive energy efficiency projects.

Scope

The Fort Polk Joint Readiness Training Center is located in west-central Louisiana just outside of Leesville. The 300-square-mile facility contains military offices, training centers, equipment and storage warehouses, and a hospital. Family housing is located in two distinct areas called the North Fort and South Fort. The housing stock consists of 4003 units in 1296 buildings constructed in nine phases between 1972 and 1988. About 80 percent of the units have air-source heat pumps and electric water heaters. The remainder use central air conditioning, and are heated by a natural gas forced-air furnace. These units have natural gas water heaters as well.

In January 1994, the U.S. Army awarded a 20-year shared energy savings contract to Co-Energy Group (CEG), a Santa Monica, CA-based PC/ESCO. Under the terms of the contract, CEG will replace the space conditioning systems in all of Ft. Polk's family housing units with GHPs. The ground heat exchangers associated with the GHPs are of the vertical u-tube type. The gas-fired water heaters will also be replaced with electric water heaters. Approximately 75% of the new GHPs will include desuperheaters to supplement domestic hot water heating with energy recovered from the GHP when it is operating for heating and cooling. Other conservation measures such as compact fluorescent lights, domestic hot water tank wraps, low-flow hot water outlets, and attic insulation will also be implemented on an as-needed basis. Over $18 million in private capital is being invested to rehabilitate the housing at Fort Polk. Further details of the project have been presented by Aldridge (1995).

Retrofit construction started in July 1995. As of January 1996, over 50 percent of the vertical ground heat exchangers had been installed and over 25 percent of the housing units had been entirely completed.

METHODOLOGY

Evaluation Approach

As shown in Figure 1, ORNL's evaluation approach to determine energy and demand savings includes three interrelated levels of field data collection (Levels 1, 2, and 3). The fourth level of field data collection (Energy Balance data) supports the advancement of GHP system design and energy estimating methods and is not discussed here further.

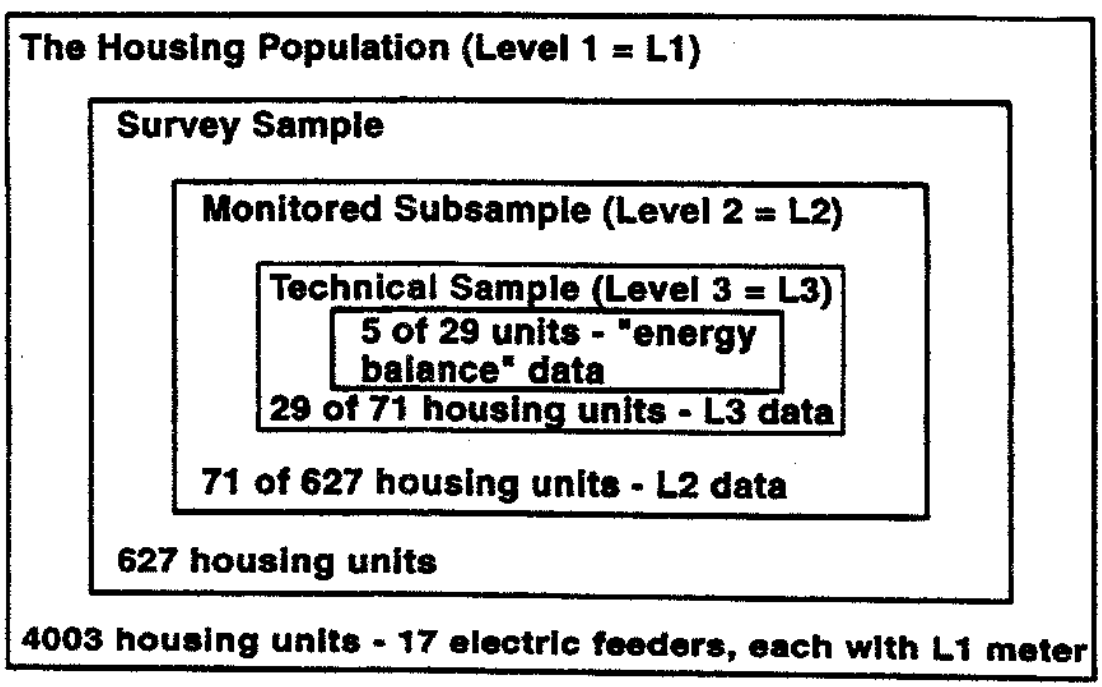
Level 1 addresses the project as a whole: data on electrical demand and consumption are collected at fifteen minute intervals from submeters on the seventeen electrical feeders that supply electricity to the family housing areas of the Fort. Temperature and humidity data are also collected at fifteen-minute intervals at four different sites. Level 1 data allows us to compare the pre- and post-retrofit energy usage patterns in the entire family housing stock and of the housing served by individual feeders, which roughly correspond to construction vintage.

Level 2 data collection focuses on a sample of 71 individual housing units in 24 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) are collected at fifteen-minute intervals. In addition to premise-level and heating/cooling-level pre- and post-retrofit energy consumption and demand comparisons, the Level 2 data will also be used to determine the effect of the retrofits on heat pump coincidence factors across the sample, and to study variations in impacts by construction vintage, floorspace, and other characteristics.

In Level 3, more detailed energy use data are collected on a subsample of 29 of the 71 Level 2 units (8 of the 24 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.

A key step in the development of comprehensive energy efficiency mega-projects is the piloting of the comprehensive retrofits in order to tighten project designs; improve esti-

Figure 1. *Data Collection and Evaluation Approach*



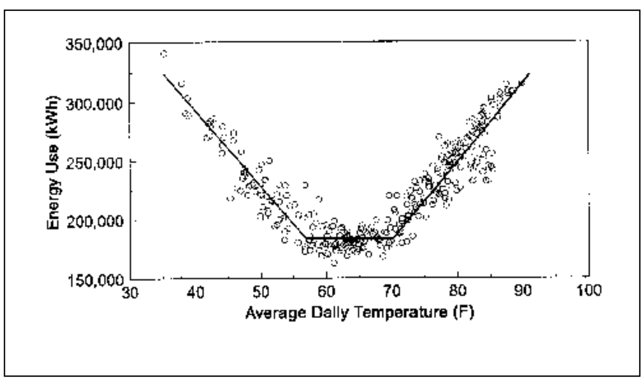
mates of project financial value; and lower risks for customers, ESCOs, and funders. Our Level 2 and 3 data are analogous to a pilot test on a sample of buildings, and our level 1 data capture the total project impact. The combined information will be used to develop guidance on the issues of designing pilot tests for mega-projects, using the results to improve retrofit designs, and estimating total project financial value from pilot test results (for example, the Energy Balance data enables fine-tuning of borehole length, which can save hundreds of thousands of dollars in mega-project construction costs).

Of course pilot tests of this nature only support estimates of project-wide energy and demand savings. Also needed are the translation of these savings into dollar savings, and an estimate of project-wide maintenance savings. The ORNL evaluation fully addresses these issues with the use of other data being collected at the site, including utility tariffs and monthly Fort-wide utility bills; nameplate data from the outdoor units and compressors of pre-existing heat pumps and air conditioners; and construction management and maintenance databases being maintained by the PC/ESCO.

Availability of Post-Retrofit Data

Retrofit construction began at Fort Polk in July 1995, and is proceeding neighborhood by neighborhood according to a sequence agreed upon by the Army, the residents, and the PC/ESCO. As of January 1996, five of our 24 sampled buildings (21 of 71 housing units) have been completed: four units at site 210, completed on 8/2/95; four units at site 213, completed on 8/11/95; four units at site 218, completed on 10/13/95; four units at site 219, completed on 10/11/95; and five units at site 220, completed on 9/18/95. Thus the post-retrofit data for sites 218 and 219 cover the heating season only, while sites 210 and 213 cover both the heating and cooling seasons. Site 220 was not used for this analysis because installation of Energy Balance instrumentation at that site was delayed and very little post-retrofit data was available.

Figure 2. *Total Daily Electrical Use for Family Housing*



Consequently this paper is based on data from sites 210, 213, 218 and 219. All 16 housing units in these four buildings were all-electric in the pre-retrofit condition, and employed air-source heat pumps for heating and cooling. Ample pre-retrofit data are available for all of the Level 2 and Level 3 sampled buildings. The feeder-level data could not be used for this preliminary analysis of pre-/post-retrofit savings, because retrofit construction had not been entirely completed on any of the 17 feeders.

PRELIMINARY RESULTS

Housing-Wide Pre-Retrofit Electrical Consumption

In order to develop a model for total pre-retrofit electrical consumption in family housing, the fifteen-minute interval data for the period 8/94 through 7/95 was summed across the seventeen feeders for each day, and an average temperature for that day was calculated. As shown in Figure 2, total daily electrical consumption for the family housing units correlates well with daily average temperature. Since relative humidity is also collected, it was possible to correlate the daily energy use with average daily moist air enthalpy. This however did not reduce the scatter of the data. Likewise there does not appear to be a significant difference in energy consumption between weekdays and weekends. In the pre-retrofit condition, the total daily energy use for Fort Polk's family housing can be predicted within $\pm$25MWh (about 15% of the base load) by considering average daily temperature alone.

Although retrofit construction has not progressed sufficiently for a feeder-level analysis to be performed, Figure 2 demonstrates the value of using daily average temperature as a normalizing parameter.

Building-Level Pre-/Post-Retrofit Electrical Consumption

As with the feeder data, electrical energy consumption was summed for each day, and daily energy consumption was plotted vs. daily average temperature. While data for individual housing units shows a high degree of scatter, some of this scatter was eliminated by summing the energy consumption for all the housing units in a given building. Figures 3, 4, 5 and 6 present daily energy consumption vs. daily average temperature for sites 210, 213, 218 and 219, respectively (post-retrofit data was not available for apartment d of site 219).

It is apparent from the data in all four cases that the retrofits have resulted in significant reductions in daily energy use. The EMODEL software from the Energy Systems Labora-

Figure 3. *Site 210 Daily Energy Consumption*

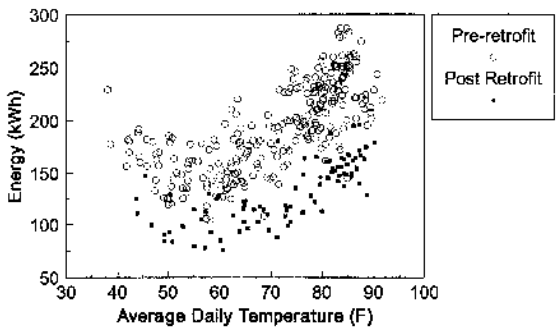


Figure 4. *Site 213 Daily Energy Consumption*

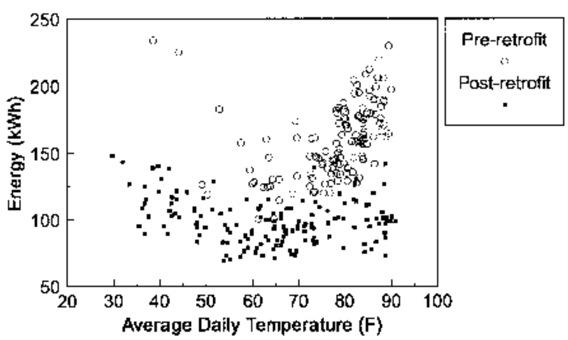
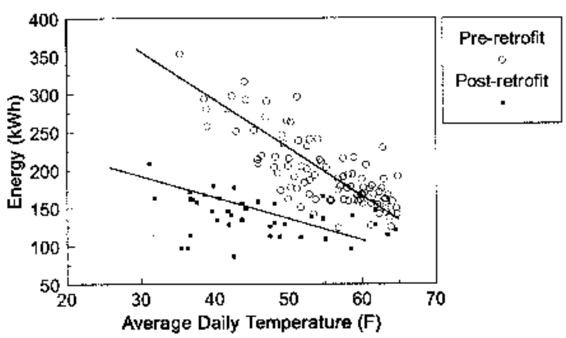


Figure 5. *Site 218 Daily Energy Consumption*



tory of Texas A&M University (Kissock, 1994) was used to develop regression models of daily energy use vs. average temperature. For sites 218 and 219, the models were linear; data for sites 210 and 213 were fitted to four-parameter change point models (3). Table 1 presents the correlation

Figure 6. *Site 219 (units a, b, c) Daily Energy Consumption*

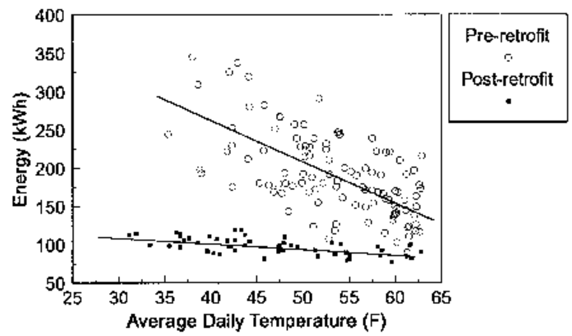


Table 1. *Correlation Coefficient (r^2) and Root-Mean-Square Error (RMSE) of Regression Models for Daily Energy Use vs. Daily Average Temperature, Sites 210, 213, 218 and 219.*

	Pre-Retrofit		Post-Retrofit	
Site	r^2	RMSE	r^2	RMSE
210	0.62	26.13	0.65	17.77
213	0.45	21.32	0.31	14.17
218	0.60	29.91	0.14	24.92
219	0.38	41.92	0.35	8.73

coefficient and the root-mean-square error of the models for each site in the pre- and post-retrofit conditions.

At all four buildings, there is only about one-third of the data available for the post-retrofit condition as there is for the pre-retrofit condition. In general this results in smaller correlation coefficients for the post-retrofit data. Note, however, that the RMSE for the models is generally smaller for the post-retrofit cases. All things being equal, this indicates that there is less scatter in the data in the post-retrofit condition, a fact which is also apparent from Figures 3, 4, 5, and 6.

Although there are only a few months of post-retrofit data available in each case, it is possible to determine the energy savings due to the retrofit. The EMODEL software achieves this by comparing the post-retrofit *data* against a projected electric consumption baseline (i.e., the pre-retrofit model driven by post-retrofit daily average temperature). Thus the electrical consumption for the baseline is the electricity that the pre-retrofit housing would have consumed, given the average daily temperatures of the post-retrofit period. The post-retrofit electricity is the electricity which was actually consumed during that period.

The energy comparisons are presented in Table 2. The table shows that during the heating season, the housing units are consuming less than half of the electrical energy which was consumed prior to the comprehensive energy efficiency retrofits. When both heating and cooling seasons are sampled, the savings is in the neighborhood of 36%. Based as they are on only six months of post-retrofit data (four months in the case of sites 218 and 219), these numbers should be considered preliminary. Nevertheless, they indicate a very impressive energy savings associated with comprehensive energy efficiency retrofits anchored by geothermal heat pumps.

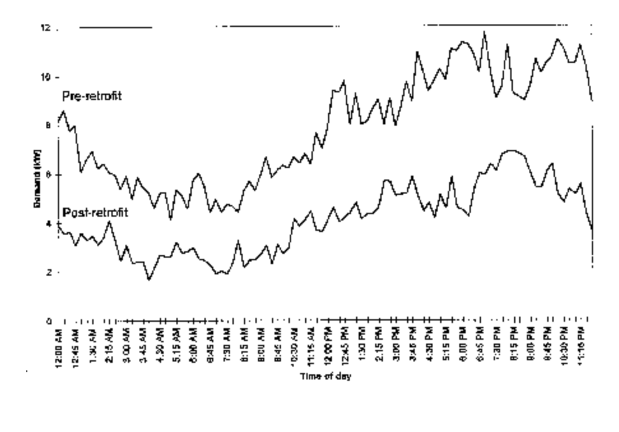
Building-Level Electrical Demand

In addition to energy use savings, preliminary data indicates that the GHP-anchored retrofits have also had a significant effect on peak electrical demand. Figure 7 shows electrical demand profiles for site 213, averaged over four peak cooling days both pre- and post-retrofit. The average of the four daily average temperatures were essentially identical for both sets. The peak electrical demand for cooling has been reduced from about 11.5 kW to 7 kW. Note also that the peak demand hour has shifted from about 7:00 PM to 8:15 PM. If the serving utility system peak occurs at 4:00 PM, coincident demand declines from about 10 kW to 5 kW, or 50 percent. Since each of the 4 housing units has a 1.5 ton GHP, the summer coincident demand savings is about 0.8 kW per ton of installed GHP capacity.

Table 2. *Comparison of Post-Retrofit Energy Consumption and Calculated Pre-Retrofit Consumption*

Site	Pre-Retrofit Energy Consumption (kWh)	Post-Retrofit Energy Consumption (kWh)	Savings, kWh (%)
210	18130	12040	6089 (34%)
213	24271	14988	9283 (38%)
218	9746	9746	4176 (57%)
219	11809	5203	6606 (56%)

Figure 7. *Site 213 Electrical Demand—Peak Cooling Day*



Electrical demand on peak heating days shows similar reductions. Figure 8 shows the average hourly demand at site 218 averaged over four peak heating days, before and after the retrofit. It is seen that peak electrical demand has dropped from 20 kW to 10 kW, a decrease of 50% or about 1.7 kW per ton of installed heat pump capacity.

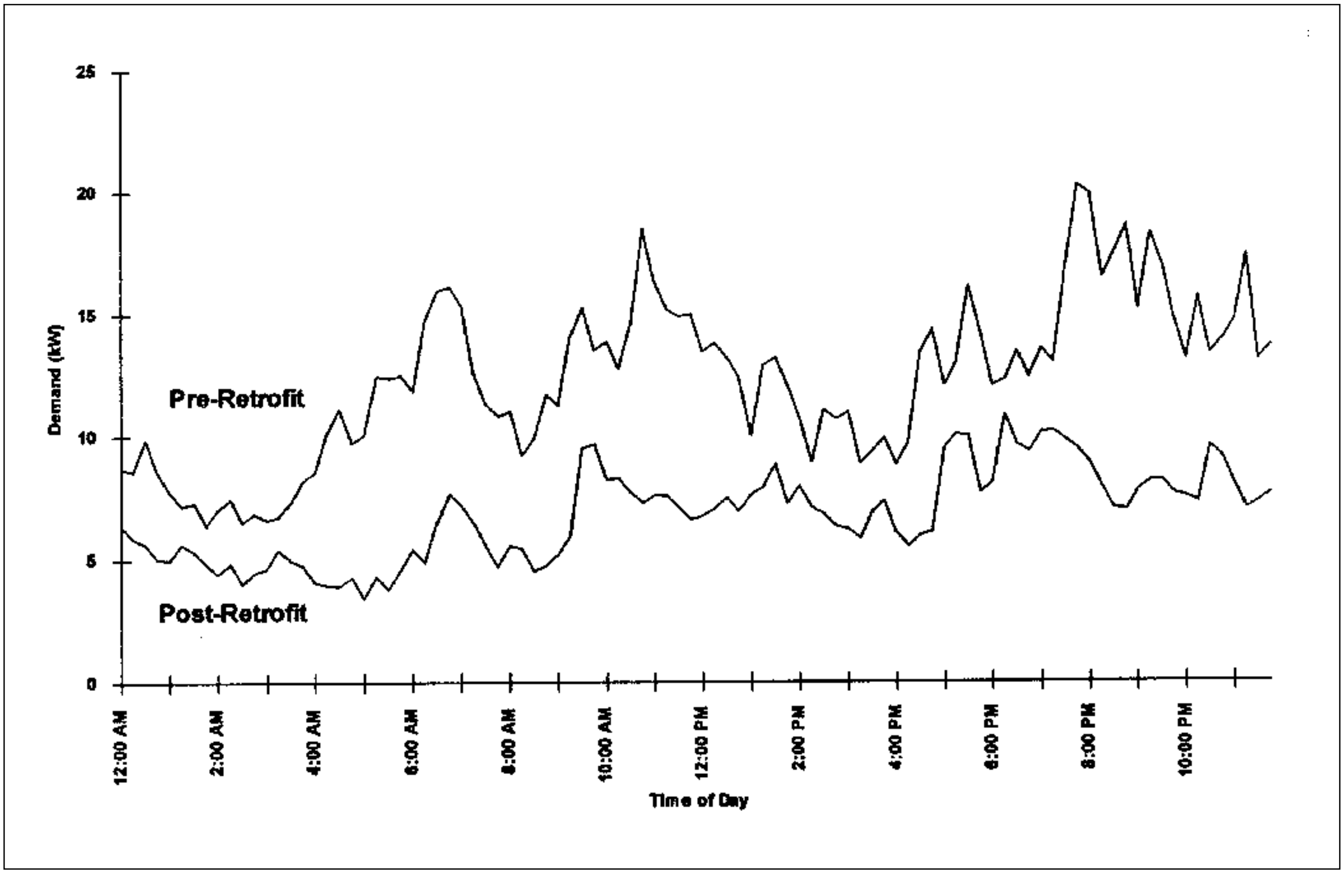
For site 218 the peak heating hour in the pre-retrofit condition was 7:45 PM. After the retrofit, the peak has moved to 6:15 PM. However, the peak demand hour for winter-peaking utilities normally occurs early in the morning around 6:00 AM. Assuming this is the case for Ft. Polk, the coincident demand reduction at the peak hour is about 10 kW for this site.

CONCLUSIONS

Retrofit of the family housing units at Fort Polk to GHPs began in July 1995, and was over 25% complete as of January 1996. More than a year of pre-retrofit data has been collected at most of the 71 sampled housing units (24 buildings). Although post-retrofit data has been collected for only a few sampled buildings to date, the preliminary indications are that GHP-anchored comprehensive energy efficiency retrofits have resulted in significant savings in electrical consumption and demand. Two buildings for which heating and cooling data are available show an average savings of 36% in total energy consumption, and two buildings for which heating data are available show an average savings of about 56% in total premise electricity consumption. Demand analysis of these two buildings show a 50% reduction in peak demand for both heating and cooling.

Although these results are impressive, it should be noted that they are based on preliminary data for the four sites which were available for analysis in February of 1996. Analysis of post-retrofit data from other sampled buildings will increase the confidence in these savings estimates, and analy-

Figure 8. Site 218 Electrical Demand—Peak Heating Day



sis of feeder-level data after retrofit construction is complete will put to rest any remaining questions.

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