Estimated Maintenance Cost Savings from a Geothermal Heat Pump Energy Savings Performance Contract at Fort Polk, Louisiana

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ABSTRACT

At Fort Polk, Louisiana, the space-conditioning systems of an entire city (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 hot water outlets, and attic insulation, were installed. These retrofits were performed by an energy services company at no up-front cost to the Army. The company has also assumed responsibility for maintenance of all the equipment installed. In return, it receives a percentage of the energy and maintenance savings realized by the Army. In developing the energy savings performance contract, the Army estimated its pre-retrofit maintenance costs from bids received on a request for proposals. In this paper, a more rigorous cost estimate is developed, based on a survey of maintenance records for the pre-retrofit HVAC equipment. The reliability of the equipment is also estimated using an actuarial method to determine the number of units requiring replacement each year and the effect of these replacements on annual maintenance costs.

INTRODUCTION

With the sponsorship of the U.S. Department of Defense (DOD) and the U.S. Department of Energy (DOE), a national laboratory is carrying out an evaluation of a large-scale energy savings performance contract at Fort Polk, Louisiana. Details of the evaluation methodology have been presented in Hughes and Shonder (1996) and Shonder and Hughes (1997). The energy savings performance contract 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 4,003 housing units with geothermal (or ground source) heat pumps (GHPs). Given the scale of the retrofit, the energy savings performance contract represents a unique opportunity to obtain statistically valid data to establish the energy, demand, and maintenance savings associated with comprehensive retrofit projects for energy efficiency anchored by GHPs.

Until 1994, the heating, ventilating, and air-conditioning equipment in Ft. Polk's family housing was maintained by a series of private service contractors. For the most part, the experience with these contracts was less than satisfactory. According to Army personnel, some contractors tended to underestimate the manpower required to maintain equipment in the 4,003 housing units, resulting in poor service to the residents. Costs were also underestimated, resulting in financial difficulties for some contractors. The performance contract (the shared savings type in this case) was seen as one way to resolve these problems.

For the next 20 years, an energy service company will be responsible for maintenance of the HVAC equipment in Ft. Polk's entire stock of family housing. At the beginning of the contract period, the energy service company drew down approximately $18 million of private financing in order to acquire and install a comprehensive package of energy-efficiency measures, including GHPs, compact fluorescent lighting, attic insulation, low-flow hot water outlets, and window treatments to reduce solar gain. The Army will pay the company a percentage of the energy and maintenance savings it realizes each month throughout the 20-year contract period. The monthly energy savings will be determined by subtracting measured energy consumption from a weather-normalized baseline estimate of what energy consumption would have been in the absence of the performance contract. Because the company will be entirely responsible for maintaining the HVAC equipment during the contract period, the maintenance savings are equal to the estimated baseline maintenance costs.

Because historical baseline maintenance costs for Ft. Polk's family housing could not be separated from the total cost of facility maintenance, the Army developed an estimate of the maintenance costs 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

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TABLE 1
Fraction of Maintenance Savings to be Paid to ESCO in Each Month

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1	0	0	0	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
2	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
3	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
4	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
5	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
6	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
7	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
8	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
9	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
10	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
11	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
12	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
13	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
14	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
15	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
16	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
17	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
18	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
19	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
20	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65

foot per year for the approximately 5.6 million square feet of family housing. As previously mentioned, from the Army's point of view, this entire amount will be saved each year because the company assumes responsibility for all family housing HVAC equipment. According to the shared savings contract, the Army will then pay the company a percentage of this savings each month, according to the schedule in Table 1.

Through the energy savings performance contract, the Army has effectively capped its future expenditures for family housing HVAC maintenance at a percentage of the estimated baseline maintenance costs. Averaged over the 20 years, the Army will be paying the company about 78% of the baseline maintenance costs, or $261.95 per housing unit per year, or approximately 18.1 cents per square foot per year.

For comparison with the Army's baseline, the *ASHRAE Handbook* (ASHRAE 1995) lists a mean cost for HVAC system maintenance of 32 cents per square foot per year, with a median cost of 24 cents per square foot, in 1983 dollars. Data from a 1994 survey of commercial buildings, performed by the Building Owners and Managers Association (BOMA 1994), shows an average HVAC maintenance cost of 29 cents per square foot per year for federal, state, and local government buildings. Thus, the Army's estimate of the baseline maintenance costs for Ft. Polk's family housing is on the low side of these values. The objective of this paper is to develop an independent estimate of the baseline maintenance costs and to estimate the Army's maintenance cost savings, the net of the company's payments, over the 20-year life of the contract.

EXPECTED NUMBER OF ANNUAL OUTDOOR UNIT REPLACEMENTS

In order to develop an estimate for maintenance costs, the authors began by estimating the number of compressor-bearing outdoor units of air-source heat pumps (ASHPs) and central air conditioners (CACs) that would require replacement each year. Because no historical maintenance data were available, a survey was made of the existing ASHP and CAC outdoor units to determine their age. The dates of manufacture of the outdoor units at 3,879 of the 4,003 residences were recorded from the nameplate on each unit (a full census was not possible because some housing was connected to a "solar farm" and had no outdoor units, and some outdoor units could not be accessed, due, for example, to a fenced yard with a dog). The age distribution as determined by the survey is shown in Figure 1. The average age of the outdoor units was determined to be 13.4 years.

Comparison of the residence's construction date with the date of manufacture of its ASHP or CAC outdoor unit allowed the authors to determine whether the outdoor unit was original equipment or had been replaced. The data showed that 679 of the units, or 17.5%, had been replaced at least once since the residence was constructed. Given some key assumptions, the dates of manufacture of the 679 replacement units can be used to

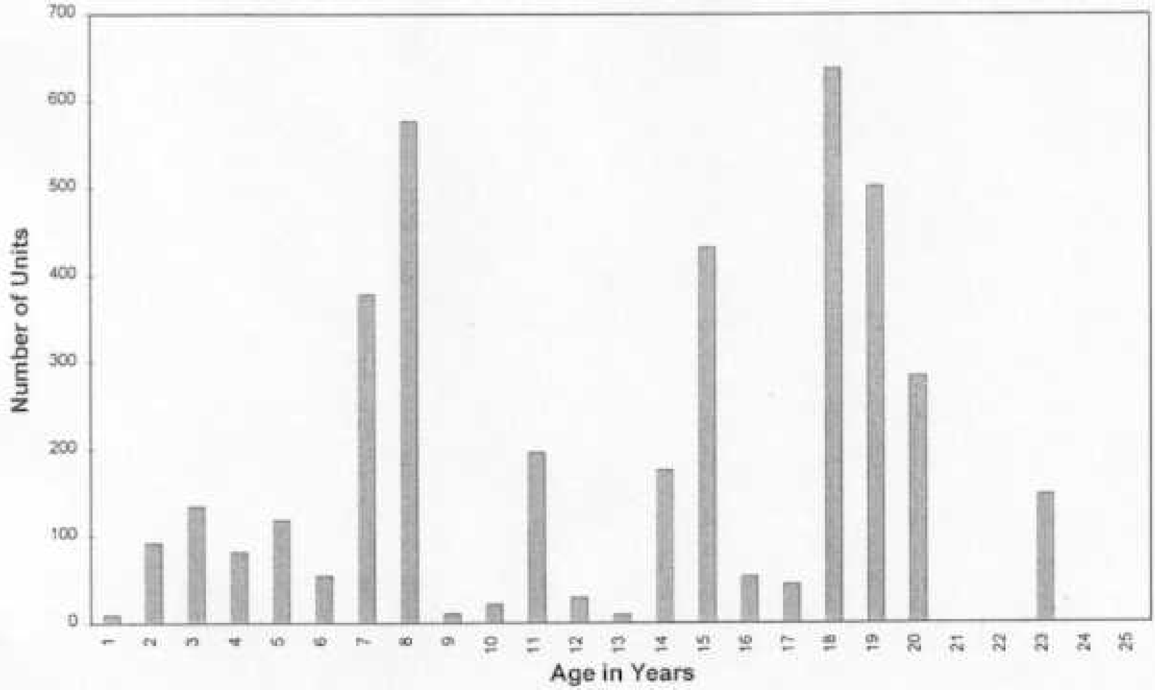

Figure 1 *Age of pre-retrofit outdoor units in family housing.*

derive statistics on the reliability of the compressor-bearing outdoor units. These assumptions are:

- *The 679 outdoor units that had been replaced had been replaced only once since the residence was constructed.* In general, this is not likely to be true. In fact, it might be assumed that as many as 119 of the units, or 17.5%, had been replaced twice. Of these, approximately 21 may have been replaced three times. However, in the absence of data on the history of replacements at each residence, the authors accepted this assumption, recognizing that it might produce a service life estimate somewhat higher than the true service life of the population.
- *The year of manufacture of the current outdoor unit is the year in which the unit was installed and the year in which the original unit failed.* The validity of this assumption depends on whether the replacement heat pumps were new equipment manufactured during the year in which they were installed or had been purchased previously and held in inventory. At most, this assumption should introduce an error of only one to two years. Note that this will tend to make the service life estimate somewhat lower than the true service life of the population.

Given these assumptions, for each observed replacement occurrence, the authors estimated the age at replacement of the original outdoor unit as the difference between the year of manufacture of the replacement unit and the year of construction of the residence. The distribution of the age at replacement for the 679 outdoor units is shown in Figure 2.

Because the outdoor units were installed in various construction phases between 1972 and 1988, an actuarial method (Nelson 1982) was used to determine the reliability of the outdoor units. This method has been used by EPRI (1990) and others (Bucher et al. 1990; Pientka 1987; Lovvorn 1985) to determine the reliability of refrigerant vapor compressors and complete compressor-bearing outdoor units. Figure 3 shows the fraction of original outdoor units remaining in service as determined by this method. The curve is assumed to follow a Weibull distribution, with

$$R(t) = \exp[-(t/\alpha)^{\beta}] \qquad (1)$$

where $R(t)$ is the fraction remaining in service. Taking the natural logarithm of both sides of the equation gives:

$$\ln(R) = -(t/\alpha)^{\beta} \qquad (2)$$

and taking the natural logarithm again gives:

$$\ln(-\ln(R)) = \beta \ln t - \beta \ln \alpha \qquad (3)$$

If a plot of $\ln(-\ln(R))$ vs. $\ln t$ forms a straight line — the portion of interest being the long-term data — then the distribution can be modeled by a Weibull function and the parameters α and β can be determined. Such a plot is shown in Figure 4. It is seen that the last five points fit quite well to a straight line, and a linear fit to these points gives $\alpha = 33.237$, $\beta = 2.686$. From these values, the mean service life of the outdoor units at Ft. Polk is calculated at 29 years. That this is somewhat longer than the 20-year mean life determined by Lovvorn for air-source heat pumps (Lovvorn 1985) is due possibly to the error introduced by the assumptions outlined above and the fact that the outdoor units in

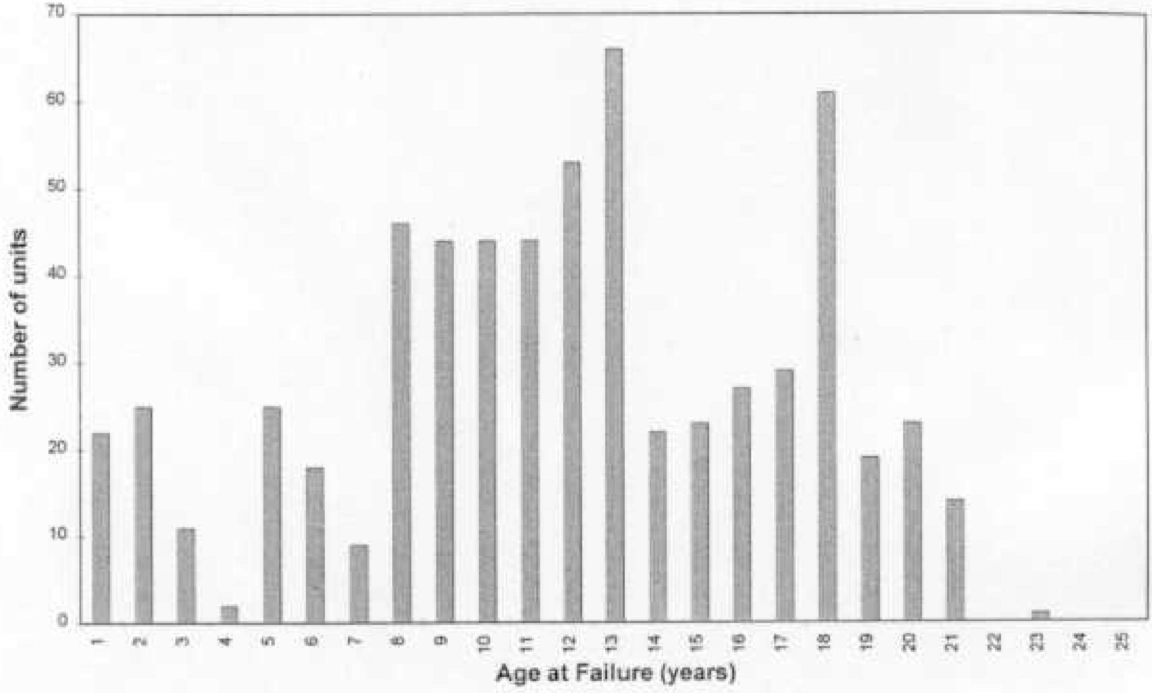

Figure 2 Age of outdoor units at failure.

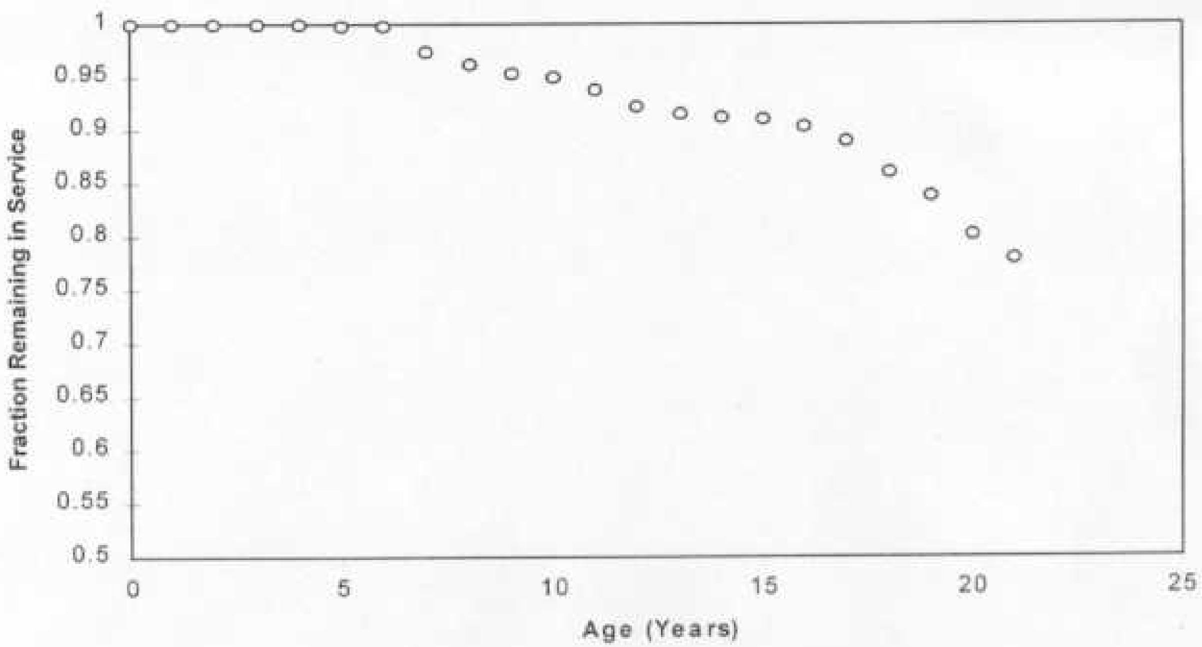

Figure 3 Fraction of outdoor units remaining in service vs. age.

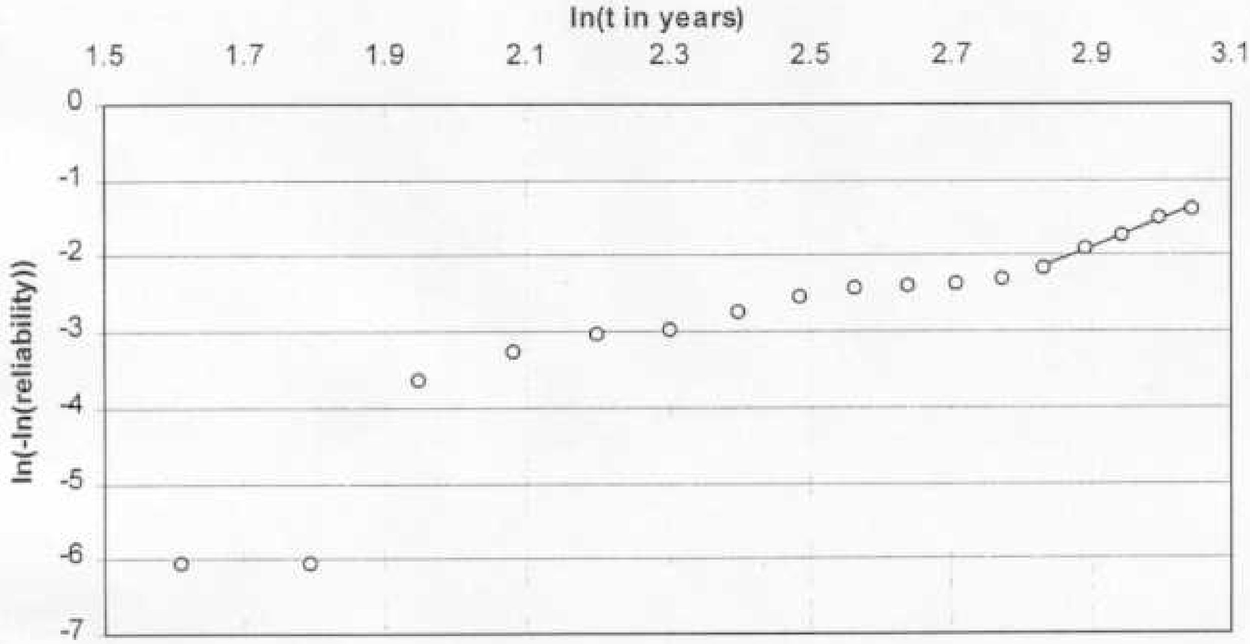

Figure 4 *Weibull plot of outdoor unit reliability vs. time.*

our sample are of more recent manufacture and about 20% of them are central air conditioners. Climate may be another factor in the longer service life calculated for these heat pumps because they rarely run in the heating mode and require fewer defrost cycles.

Once the parameters of the Weibull distribution were determined, a spreadsheet model was developed to determine the likely number of replacements during each year. The spreadsheet begins in year zero with the distribution of heat pumps as determined from the survey. The expected number of failures in each age class is determined from the Weibull distribution, and the failed units are assumed to be replaced at mid-year with new ones. In the following year, the new units have age 1 and the remaining units in each age class are one year older. As an example, suppose that in year 0 the entire population consists of 100 outdoor units of age 10. If the expected number of failures is 20, then in year 1 the population will consist of 20 units of age 1 and 80 units of age 11.

Figure 5 shows the expected number of outdoor unit replacements as calculated by the spreadsheet, given the initial age distribution. In the first year, 61 outdoor units are expected to be replaced. Because the population is aging, the number of expected replacements grows to 90 by year 12. As failed units are replaced with new ones, the average age of the population decreases, and by year 20 the expected number of replacements per year decreases to 85.

ESTIMATE OF MAINTENANCE COSTS

The energy services company assumed responsibility for maintenance of Ft. Polk's family housing HVAC equipment in April 1994, and records have been kept of all maintenance activities since that time. In order to develop a model for the baseline costs to maintain the equipment, an audit was made of these records for a random sample of 175 residences from May 1994 through April 1995. The performance contract retrofit construction, including HVAC conversions to GHPs, did not start until July 1995, so all maintenance performed by the company during this period was on the pre-existing ASHPs and gas furnace/CAC combinations. Data were collected on the type of service performed on each call and the date on which the call was made. In order to determine manpower requirements, data from the sample were scaled up to the 4,003 units in the family housing area. Figure 6 shows the expected number of service calls per day by month for the entire area. As expected, the highest number of service calls occur during the summer months, but the maintenance staff remains busy during the entire period from May through November. Based on this data, each residence requires an average of 3.2 service calls per year. While this seem rather high, it should be remembered that residents of military family housing are discouraged from performing the normal minor repairs that homeowners would perform on their own equipment.s

Table 2 lists the percentage of service calls by activity for the survey sample. Also listed in this table is an estimate of the man-hours for each type of activity and an estimate of material

TABLE 2
Maintenance Activities, Duration, and Associated Material Costs

Activity	Frequency	MH/ Call	Mat'l Cost
Flush condensate pan/drain line	16.4%	0.50	$
Charge system with refrigerant	13.1	2.00	25
Clean indoor coil	11.3	1.00	
Check system/no apparent problem	10.2	0.50	
Light gas furnace pilot	6.5	0.50	
Replace outdoor fan motor	5.1	1.50	125
Repair/replace compressor wiring	4.7	1.50	10
Repair/adjust indoor thermostat/wiring	4.7	1.00	
Repair refrigerant leak/charge system	3.3	1.50	25
Reset circuit breaker	2.9	0.50	
Repair/replace outdoor fan motor wiring	2.5	1.00	10
Replace indoor thermostat	2.5	1.00	75
Clean outdoor coil	1.8	1.00	
Clean furnace heat exchanger	1.8	2.00	
Repair defrost cycle	1.8	2.00	10
Repair/replace wiring to auxiliary heater	1.5	2.00	15
Replace indoor fan motor	1.5	2.00	150
Repair/replace indoor fan motor wiring	1.5	1.00	10
Replace 1.5-2.00 refrigeration-ton compressor	1.5	6.00	550
Replace outdoor unit	0.0	4.00	1600
Repair furnace pilot assembly	1.1	1.00	50
Repair indoor fan	1.1	1.00	10
Replace outdoor coil	0.7	4.00	400
Replace gas furnace	0.7	6.00	500
Replace furnace heat exchanger	0.4	2.00	300
Repair outdoor fan motor	0.4	1.00	10
Replace indoor coil	0.4	4.00	400
Replace furnace gas valve	0.4	2.00	100
Repair gas leak	0.4	1.00	10
Weighted Average		**1.23**	**$34**

costs for each activity. These estimates were provided by a local HVAC service contractor (Butler 1996). The weighted average of service times is 1.23 hours per call, with an average of $34 in material costs per call. An overhead of 25% on service time for travel and administrative tasks brings the average service time per call to 1.54 hours.

It was determined that a staff of 12 regular service technicians would be required to perform the required maintenance and to make one preventive maintenance call per year to each residence. During the months of May, June, July, and August three additional technicians would be hired on a temporary basis to handle the increased number of calls. This averages to 13 full-time employees, in addition to office staff. Data from Means (1992) were used to develop an estimate of the total cost per year of performing the maintenance on the 4,003 residences. The total cost per year was estimated at $1,373,290. Details of the estimate are presented in Table 3.

This "first year of the energy savings performance contract" baseline maintenance cost estimate is based on the distribution of maintenance activities actually performed by the service company from May 1994 through April 1995. However, as shown in Figure 5, the maintenance requirements of the population of outdoor units would change with time. But note that in the maintenance records examined, no outdoor units were replaced. Because the ASHPs and furnace/CACs were being maintained only until they could be replaced by GHP units, the service company did not replace entire outdoor units, choosing instead to replace components as required.

In order to adjust the "first year" estimate to account for this behavior, some further assumptions must be made. Note that 1.5% of the service calls were for compressor replacement. An average of 3.22 calls per residence per year means that approximately 193 compressors were replaced. Because the data of Figure 5 indicate that 61 entire outdoor units would have been replaced during this year, the authors assume that in 32% of the cases (61/193), the entire outdoor unit would have been replaced had the company not been planning to replace everything with GHPs in the near future. Thus, the activity "outdoor unit replacement" was added to the list of Table 2. The time for replacement of an entire outdoor unit is estimated to be four hours at a cost of $1600 for the typical 2-ton unit. Adding this task does not affect the manpower requirements but raises the average cost per service call. With these new material costs, the total "first year" baseline maintenance cost becomes $1,450,054.

The baseline maintenance costs in subsequent years are estimated by allowing the frequency of "outdoor unit replacements" to change according to the expected number of outdoor unit replacements per year from Figure 5. The resulting estimated baseline maintenance costs in each year of the contract are as listed in Table 4. Also listed are costs per unit per year, for comparison with the Army's baseline. The average of the 20 values is $369.05 per housing unit per year, or 26.0 cents per square foot per year. The difference of 9.9% between this average and the Army's calculated baseline seems to be within the accuracy of the model, given its assumptions.

Given the values in Table 4, the life-cycle cost to the Army of maintaining the family housing HVAC equipment over 20 years is $15,609,989 on a present value basis, using the standard 7% discount rate specified by the U.S. Department of Commerce (1982). With the contracted baseline and the schedule of payments

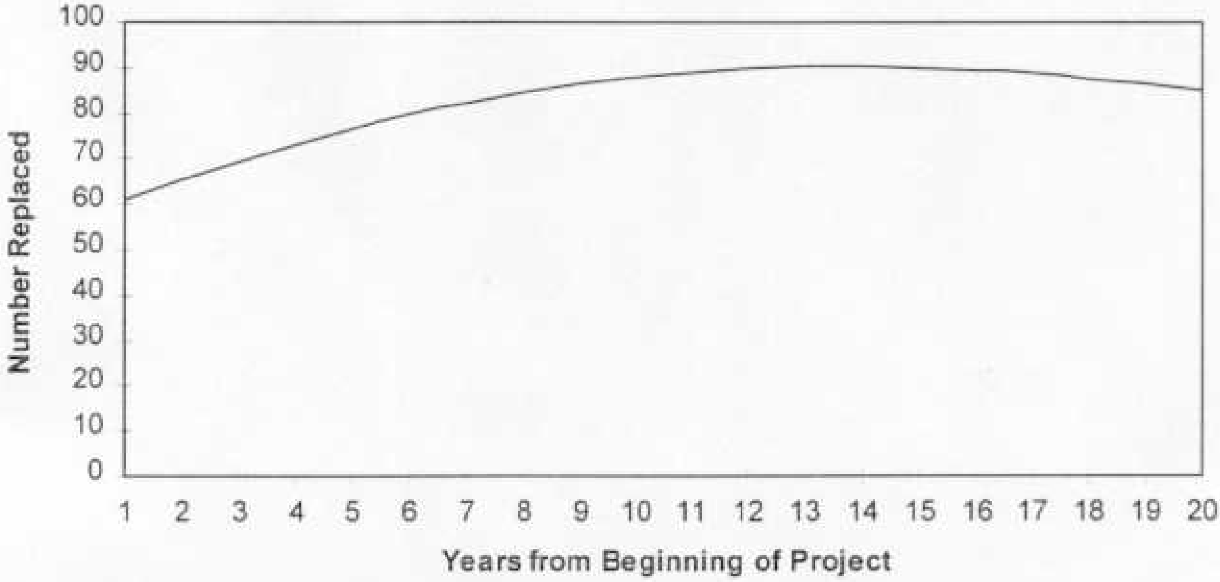

Figure 5 *Expected number of outdoor units replaced per year.*

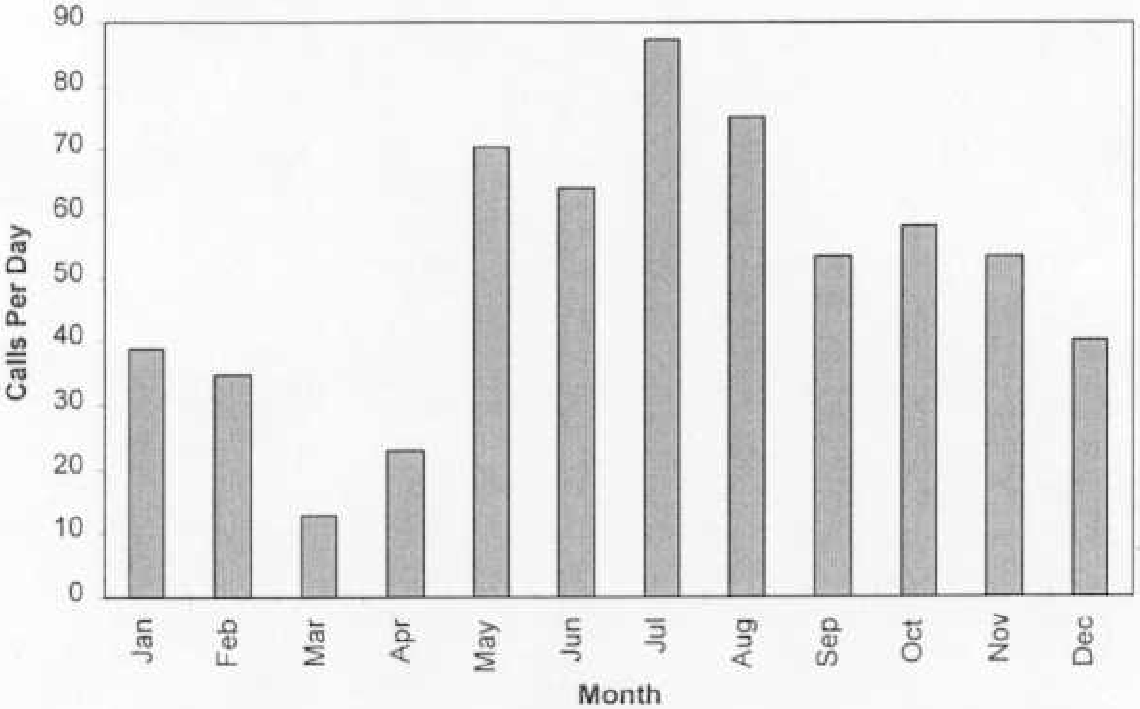

Figure 6 *Average number of service calls per day, pre-retrofit, in family housing.*

TABLE 3
Baseline Maintenance Cost Estimate for Year

Labor Costs		
a	Base Hourly Rate	$17.00
b	Fringe Benefits	5.0%
c	Workers Comp. Ins.	6.1%
d	Fixed Overhead	14.6%
e	Operating Overhead	28.5%
f	Hourly Rate with OH	$26.21
g	Number of Men	13
h	Hours/year	2080
i	**Annual Labor Cost**	**$708,597**
Material Costs		
j	Service Calls/unit/yr	3.22
k	Number of Units	4003
l	Mat'l Cost per Call	$33.98
m	Bare Mat'l Cost/year	$437,980
n	Sales Tax	5.0%
o	**Total Material Costs**	**$459,879**
Total Costs		
p	Labor and Materials	$1,168,475
p	Insurance Costs	7.5%
r	Profit	10.0%
s	**Total**	**$1,372,959**
	Cost, ¢/sq. ft.	**24.6**
Operating Overhead		
t	Manager's Salary	$60,000
U	Fringe Benefits	5.0%
v	Fixed Overhead	14.6%
w	Worker's Comp. Ins.	10.0%
x	**Manager with OH**	**$77,760**
y	**Building**	**$24,000**
z	**Vehicles**	**$41,600**
aa	**Utilities**	**$2,000**
ab	**Telephones**	**$3,000**
ac	**Office Equipment**	**$10,000**
ad	Sec'y 1	$15,000
ae	Sec'y 2	$20,000
af	Fringe Benefits	5.0%
ag	Fixed Overhead	14.6%
ah	Worker's Comp. Ins.	4.0%
ai	**Sec'ys with OH**	**$43,260**
aj	**Total Operating OH**	**$201,620**
ak	**Overhead Rate**	**28.5%**

Notes:
i = a·g·h·(1+b+c+d+e)
o = j·k·l·(1+n)
z = g·.32·10,000
x = t·(1+u+v+w)
ai = (ad+ae)·(1+af+ag+ah)
aj = x+y+z+aa+ab+ac+ai
ak = aj/i
p = o+i
s = p·(1=q+r)

TABLE 4
Maintenance Cost Estimates by Year

Years from Start of Project	Annual Maintenance Cost	Annual Cost per Housing Unit
1	$1,450,054	$362.24
2	1,455,088	363.50
3	1,460,122	364.76
4	1,465,155	366.01
5	1,468,931	366.96
6	1,473,964	368.21
7	1,476,481	368.84
8	1,480,256	369.79
9	1,482,773	370.42
10	1,484,032	370.73
11	1,485,290	371.04
12	1,486,549	371.36
13	1,486,549	371.36
14	1,486,549	371.36
15	1,486,549	371.36
16	1,485,290	371.04
17	1,485,290	371.04
18	1,484,032	370.73
19	1,482,773	370.42
20	1,480,256	369.79

in Table 1, the life-cycle cost of the payments the Army will make to the company is $11,076,395 on a present value basis. This represents a net present value life-cycle cost savings of $4,533594 over the life of the contract.

CONCLUSIONS

The U.S. Army has entered into a shared savings contract with an energy services company at Ft. Polk, Louisiana, under which the company assumes all responsibility for the maintenance of HVAC equipment in family housing. The contract enables the Army to effectively cap its future expenditures for family housing HVAC maintenance at about 78% of the Army's estimated 20-year average baseline maintenance costs of $335.83 per housing unit per year, or approximately 18.1 cents per square foot per year.

This paper developed a 20-year average baseline maintenance cost estimate of $369.05 per housing unit per year, which is about 10% higher than the Army's estimate of $335.83. Given the assumptions inherent in the model, our estimate agrees well with the Army's value. Using the numbers developed in this paper, the net present value life-cycle cost savings to the Army due to maintenance over the life of the contract is estimated to be about $4.5 million.

Preliminary analysis of the measured pre- and post-retrofit energy consumption of the housing units at Ft. Polk shows that the geothermal heat pumps and other energy-efficiency measures are saving approximately 32% of total electrical energy and an even higher percentage of peak electrical demand (Shonder and Hughes 1997). The cost savings associated with these measured energy and demand savings, when combined with the maintenance cost savings estimates developed in this paper, will provide the Army with independent verification of its total cost savings under the energy savings performance contract. It should be noted that the 32% energy savings figure represents the "apparent" savings seen in the monitored data; this does not correspond to the "contracted" energy savings, which may require adjustments for such things as changes in indoor temperature performance criteria, additions of ceiling fans, and other factors.

The figure of 18.1 cents per square foot per year that Fort Polk will pay for equipment maintenance in family housing is in agreement with other estimates for maintenance of GHPs. For example, The Geothermal Heat Pump Consortium (1996) gives a range of 11 to 22 cents per square foot per year for commercial geothermal systems. Mancini et. al. (1995) reported a figure of 10 cents per square foot per year for a commercial system in southern Ontario. Note, however, that at Fort Polk the company's cost includes maintenance of other equipment (desuperheaters, compact fluorescent lights, low-flow hot water outlets, etc.) in addition to the GHPs.

ACKNOWLEDGMENTS

The opportunity for the authors 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

Hugh Henderson, Principal, CDH Energy Corp., Cazenovia, N.Y.: How much impact would assuming a mean equipment life of 15-20 years have on your estimate of maintenance cost savings?

John A. Shonder: Since a relatively small number of units are being replaced per year, the maintenance costs estimates are not very sensitive to the equipment life. Using the mean service life of 29 years that we calculated from the data, we determine that an average of 83 units per year would be replaced over the 20-year life of the contract, resulting in an annual maintenance cost of $369 per housing unit. If the mean service life is assumed to be 17 years, about 115 units per year would require replacement. The annual maintenance costs rise by about 3% to $379 per year.

Harvey M. Sachs, Technical Director, Geothermal Heat Pump Consortium: Work recently completed by Cane et al. established very low O&M costs for 25 GHP buildings averaging five years old. Costs are running very low, generally below $0.10 per square foot per year.

Shonder: This is very encouraging. Note that in this paper we did not attempt to estimate the maintenance costs for the geothermal heat pumps. However, the fact that the energy services contractor was willing to accept 18.1 cents per square foot shows that their own estimates of maintenance costs for the GHPs must be somewhat lower than 18.1 cents per square foot.