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Monitored Energy Use of Homes with Geothermal Heat Pumps: A Compilation and Analysis of Performance

Final Report

Jeff R. Stein and Alan Meier

Environmental Energy Technologies Division

December 1997

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MONITORED ENERGY USE OF HOMES WITH GEOTHERMAL HEAT PUMPS: A COMPILATION AND ANALYSIS OF PERFORMANCE

FINAL REPORT
December 19, 1997

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I. Summary

The performance of residential geothermal heat pumps (GHPs) was assessed by comparing monitored HVAC and whole house energy use of GHP houses and appropriate control houses. Actual energy savings were calculated and compared to expected savings (based on ARI ratings and industry literature) and predicted savings (based on COP measurements).

87 GHP houses in 10 states were compared to appropriate control houses that were either the GHP houses themselves before being retrofit with GHPs or houses of similar size, location, construction, etc. In order to make the comparisons as accurate as possible, we normalized for differences between the GHP and control houses in terms of heating degree days in the monitoring period, and floor area or total insulation value (total UA), as appropriate. The data was primarily supplied by utilities that responded to our requests. Therefore we may not have assembled a particularly representative sample. We also know very little about the circumstances of data collection in some cases or the appropriateness of some of the controls.

The predicted savings are consistently slightly below the expected savings but still within the range of performance commonly cited by the GHP industry. Average rated COP equals 3.4. Average measured COP equals 3.1. Based on measured COPs the GHP houses were predicted on average to save 66% of HVAC energy compared to electric resistance homes and 42% of HVAC energy compared to air-source heat pump houses.

The actual savings, however, were inconsistent and sometimes significantly below the predicted savings. For example, based on COP measurements, 15 GHP homes in Virginia were predicted to save 37% of HVAC energy compared to a set of air source heat pump (ASHP) homes but actually saved only 27%. HVAC savings ranged from -20% to 68% and whole house savings ranged from 4% to 36%. On average, the GHP homes performed as well as predicted compared to ASHP homes but worse than predicted compared to electric resistance homes. Compared to gas heated/AC cooled homes performance was mixed but the sample size is fairly small (see Figure 1).

We found no correlation between actual savings and actual energy use. For example, a group of 38 GHP homes in Montana had particularly low savings (21% of HVAC energy and 0% of total energy compared to a set of electric resistance homes) but also had lower energy use per house and per square foot than almost any other group of GHP houses. This suggests that other factors such as insulation and occupant behavior probably have greater impact on energy use than type of HVAC equipment. We also did not find a clear correlation between climate and actual savings or between climate and actual energy use. We did find, however, a trend between GHP installation date and savings. The newer units appear to have lower savings than some of the older units which is exactly opposite of what one would expect given the dramatic increase in rated efficiencies of GHPs in recent years.

There are a number of possible explanations for why actual savings are repeatedly below rated savings or predicted savings (COP measurements). Poor ground loop sizing or installation procedures could be an issue. Given that performance is good compared to ASHPs but poor compared to electric resistance homes, the shortfall in savings could be due to duct leakage. This is supported by the fact that savings were higher in houses that converted from electrical resistance *with ducts* than in houses that converted from electric resistance *without ducts*. The "takeback effect" could also be a reason for lower than expected savings. Occupants of heat pump homes are likely to heat more rooms and to use more air-conditioning than occupants of electric resistance homes, since electric resistance homes often are not centrally controlled and do not have air conditioning.

II. Background

Geothermal Heat Pumps, or Ground Source Heat Pumps, have gained a lot of attention and support in recent years. GHP proponents point to a number of advantages, including:

- **Energy Savings** - Evidence suggests that GHPs may save up to 60% on utility bills compared to more conventional HVAC equipment.
- **Peak Load Reduction** - GHPs can use considerably less power during peak heating and cooling periods.
- **Increased Comfort** - The supply air temperature in a GHP systems can be hotter in winter and colder in summer than some conventional systems (e.g. air source heat pump). This larger delta T allows for lower supply air speeds and less "draftiness". Lower air speeds can also provide more dehumidification in summer.
- **Desuperheating** - Desuperheating provides hot water by transferring some or all of the heat from the refrigerant loop to a hot water tank. This is especially useful in cooling mode when heat is essentially transferred from the living space to the hot water tank. During peak cooling periods a desuperheater can often satisfy the full water heating load.

In a 1993 study analyzing the efficiency and cost-effectiveness of HVAC systems, the EPA concluded that GHPs can reduce energy consumption by 23% to 44% over air source heat pumps and by 63% to 72% over electric resistance heating and standard air-conditioning equipment, depending on the location and climate conditions (EPA, 1993). Based on these savings, GHPs were determined to be highly cost-effective in all US regions as replacements for electric resistance and ASHP equipment and cost-effective in most climates when compared to natural gas/AC systems.

A. Rated Efficiency

The Air-Conditioning and Refrigeration Institute (ARI) certifies the efficiency of GHPs under one of three standards: ARI-320, ARI-325, and ARI-330. These ratings are widely accepted and quoted when calculating cost-effectiveness. The California Energy Commission, for example, lists on their web site 61 ground-coupled closed loop GHPs with ARI-certified Cooling EER ranging from 15 to 22.2 and Heating COP ranging from 3.2 to 4.1. They also list 103 closed loop water coupled GHPs with EER ranging from 12.5 to 15.4 and COP ranging from 4.0 to 5.4.

It is important to realize that the ARI ratings are single point ratings as compared to air source heat pump ratings, which are seasonal. According to ARI 330-93 "Ground Source Closed Loop Heat Pumps," cooling EER values are based on an inlet water temperature of 77°F and heating COP values are based on an inlet water temperature of 32°F. These values are characterizations of a northern climate. Actual performance can be better or worse depending on the actual water temperature produced by the ground coupling over the course of the year. Furthermore, ARI ratings do not account for quality of the ground coupling. Like air source heat pump ratings, losses in the air distribution are also not included.

GHP efficiency ratings have increased dramatically in recent years. Based on performance reported in the ARI directories for 1987 and 1994, typical EER increased 26 to 56 percent and COP increased 35 to 50 percent depending on the entering water temperature (Geo-Heat Center, 1995).

B. COP Measurements

COP is the ratio of the heating energy delivered by the system to the electric energy consumed. Energy delivered is typically measured by monitoring the temperature difference (across the fan and heat exchanger) and the run time of the heat pump system. Electric energy consumed is typically measured by submetering the GHP compressor, loop pump, and possibly the distribution fan or pump.

$$COP = \frac{Heating\ Energy\ Delivered}{Electric\ Energy\ Consumed} = \frac{m \times C_p \times \Delta T \times t}{kWh}$$

where

m	=	mass flow rate
C_p	=	specific heat
ΔT	=	temperature rise across fan and heat exchanger
t	=	runtime of heat pump system
kWh	=	electrical energy consumed by heat pump system

A number of isolated studies, mostly sponsored by electric utilities, have attempted to independently verify GHP efficiency claims, primarily by measuring COP/EER over extended periods of time. The Geo-Heat Center at the Oregon Institute of Technology compiled data from many such studies covering 184 houses. EER and/or COP was measured for 68 houses (using a variety of techniques and definitions of EER/COP). Values for COP ranged from 1.8 to 5.7, with most units in the 2 to 3 range. This is probably below the ARI rated COPs for those units, but still reasonably efficient. In most studies, annual energy savings were calculated by comparing the measured GHP efficiency with an assumed efficiency of a conventional alternative (see Table 1). Based on these annual savings and cost assumptions it was determined that GHPs have a payback of 4 years compared to electric resistance heat, 6 years versus air-source heat pumps and 12 years versus gas systems.

Table 1. HVAC Energy/Cost Savings for GHPs as Compiled by Geo-Heat Center

	Mean Annual Savings			
Conventional System	Houses*	Site Energy	Houses*	Dollars
Elec. Resist/AC	21	57%	18	54%
ASHP	33	31%	21	31%
Gas Furnace/AC	17	67%	21	18%
Oil Furnace/AC	6	71%	9	33%
Other (propane, unspecified)	7	46%	7	39%

Source: Geo-Heat Center, 1995
* Houses = number of houses reporting site energy savings or dollar savings.

C. Factors Affecting Performance

There are a number of factors that can cause actual energy savings to be different from what would be expected based on rated efficiency or COP measurements. These factors have been roughly divided into those factors that would be accounted for in a COP measurement and those factors not accounted for in a COP measurement.

Factors Affecting COP Measurement:

- **System Type** - Basic differences in GHP include ground-coupled versus water-coupled (lake or ground water), open loop versus closed loop.
- **Ground Coupling** - Coupling can be direct (DX) vs indirect, vertical vs horizontal, etc. Vertical loops often perform better than horizontal but cost more. The characteristics of the loop material and grouts can affect heat transfer mechanisms as well as circulating pump energy required.
- **Climate** - GHPs in climates with more extreme summer and winter temperatures will have lower annual COPs. (Air source heat pump COPs are more sensitive to climate severity.)

- **Soil Properties** - Density, moisture content, etc. will affect heat transfer properties. A GHP can have a long-term effect on surrounding soil temperature and moisture resulting in degraded GHP performance over a period of years. Other characteristics, such as snow cover, can also affect performance.
- **Equipment Efficiency** - According to ARI, performance of the equipment can vary by as much as 100% based on the quality of the heat pump purchased (Geo-Heat Center, 1995).
- **Equipment and Loop Sizing** - Under-sized systems may require considerable auxiliary resistance heat. Over-sized systems will have shorter run times and higher peak loads.
- **Installation** - The competence of the installer can be very important, especially for the ground loop.

<u>**Factors Not Accounted for in COP Measurement:**</u>

- **Definition of COP** - COP measurement equipment and calculation methods were not consistent across all the case studies in the Geo-Heat Center Compilation. Calculations may or may not include the energy used for electric resistance backup, the desuperheater, the fan, and the loop pump.
- **Component Efficiency** - Energy consumption is affected by peripheral system components not included in COP, which could include fan and auxiliary resistance heat.
- **Duct Losses** - GHP systems often have higher air flow rates through the distribution system than natural gas systems which can result in higher duct losses and thus reduced efficiency. Electric resistance heat, on the other hand, will not typically have any duct losses. High air flow rates can also lead to greater infiltration through the building envelope and thus larger heating and cooling loads.
- **Zoning** - GHP systems are typically centrally controlled and cannot be zone controlled in the same way as baseboard electric heaters. Thus efficiency gains can be eroded if occupants are forced to condition more space than with a conventional system.
- **Takeback Effect** - Faced with lower operating costs, occupants may choose a higher level of service with a GHP than with a conventional system (e.g., warmer winter setpoints and cooler summer setpoints) thereby eroding savings but enjoying greater comfort. This can be especially true if a conventional system without air conditioning is replaced by a GHP that includes air conditioning.
- **Non-Utility Fuel Use** - If a test or control house is using a non-utility fuel for space conditioning, such as a wood fireplace, then savings cannot easily be determined.
- **Desuperheater** - Efficiency of the desuperheater component can affect water heating energy and thus whole house savings.
- **Dehumidification in Summer** - Since GHPs have lower air flows across the evaporator than conventional AC they provide more dehumidification in the summer, i.e. a greater level of service that is not accounted for in energy comparisons. In other words, occupants may save energy by selecting higher thermostat settings which are just as comfortable because of increased dehumidification.

III. Methodology

A. Scope

It is not possible to directly measure GHP energy savings in an actual residential installation but there are a number of ways of estimating savings with varying levels of confidence. One method is computer simulation, which has the advantage of being able to remove uncertainty from occupant behavior and weather but cannot easily account for the role of installation quality, duct losses and other real world issues. A second method is to compare energy use of actual homes with GHPs to energy use of homes with conventional equipment. Our research focused exclusively on this second method. Drawing conclusions about heating system efficiency by comparing actual heating or whole house energy consumption can be like comparing apples and oranges if the houses have unaccounted for differences in insulation levels, occupancy, etc. But it is also the best way we know for getting an accurate picture of field performance and actual savings and seeing the impact on performance of the factors not accounted for in COP ratings or measurements or simulations. Thus we strove to find similar control houses (retrofits are usually the best) and to normalize for as many differences as possible.

Investigation was limited to residential systems in the US. Our analysis focused on energy savings and not on some of the other factors relevant to the success of GHPs such as capital cost, operation and maintenance, and peak load reduction.

B. Data Collection

We sought case studies where actual energy use data (either whole house and/or HVAC energy) was monitored for both GHP homes and appropriate control homes. Since we collected available data rather than conducting a controlled experiment, we do not claim to have assembled a statistically representative set of houses. In order to insure a fair comparison between test and control houses we sought as much information as possible about the circumstances of monitoring as well as house and occupant characteristics. For example, in most cases we were able to verify that the control houses were not using firewood for supplemental heating.

Little information on monitored residential GHP energy use has been published, especially for recent installations. Therefore, the primary method of data collection was networking. We solicited unpublished data from utilities, research organizations, etc. that have looked at this issue. One of our concerns with this sort of non-peer reviewed literature was getting an unbiased picture of field performance. In most cases, we know very little about the circumstances or methods under which data was collected.

Some contacts supplied us with data that was not complete enough to be included in our analysis. Other contacts may have data but we did not receive it before writing this report in late 1996. In several cases we decided that the control houses were too different from the GHP houses to make a fair comparison. For example, over 4,000 houses in Ft. Polk LA were retrofit with GHPs, which should make for an excellent pre/post comparison. However, a number of conservation measures (attic insulation, CFLs, low flow showerheads, etc.) were also implemented at the same time as the GHP installation. Thus not all of the energy savings can be attributed to the GHP. Ft Polk data is included in this report for comparative purposes but it is not included in the calculations for average results from all data collected.

Other contacts had information that they were unable to share for proprietary reason. A common response from utility contacts was, "We could have shared the information a year ago, but cannot share it now due to restructuring and competitive concerns." Appendix 1 contains a partial list of organizations and individuals we contacted or attempted to contact in the summer and fall of 1996 and the results in terms of what is or may be available.

C. Data

Case studies from 10 sources included monitored data for GHP and control homes that were similar enough to make fair comparisons (see Table 2). These case studies consisted of 87 GHP homes in 10 states. The control house data came from the same source as the test house data, except in the case of Montana, where we used a well known study of energy efficient houses in the Northwest for controls. In most cases the control houses were houses of similar size and construction but for 8 houses the controls were the GHP homes themselves before they were retrofit.

Different amounts of data were available for each case study (see detailed descriptions of each source in Appendix 2). In some cases, submetered HVAC energy data were available, in other cases only utility billing data were available. Similarly, only some studies measured COP.

In addition to the GHP houses for which we had suitable controls, data on an additional 526 GHP houses without controls was collected. In most of these cases the only data available is annual electricity consumption.

D. Analysis

There are a number of possible indicators of performance, each with its own merits and flaws. We chose to focus our analysis on actual energy savings (%) but also to look at predicted savings based on COP measurements and at actual energy use in terms of kWh/yr. and kWh/yr.-ft2. The advantage of measured savings is that it normalizes for differences in size, insulation, climate, etc. and allows for comparison among GHP houses with different sizes, climates, and insulation levels. One disadvantage of measured savings is that controls are never exact replicas, even after normalizing for these differences. Another disadvantage of actual savings is that it is generally not possible to normalize for differences in amenity or level of service, i.e. actual savings may be lower than expected because occupants of GHP have "taken back" some of the savings in higher levels of service.

The two types of measured savings we examined also have advantages and disadvantages. HVAC energy savings can give a better picture of HVAC performance because it removes differences in appliance use, but HVAC energy often does not include the energy savings due to de-superheating or the energy use of distribution fans or pumps. Whole house energy savings accounts for all GHP energy uses and contributions but can be clouded by appliance uses and occupant behavior.

Actual energy use can be a useful "second opinion" of system performance. A GHP house may have unexpectedly low actual savings but also have low absolute energy use. Thus, before concluding that a GHP is performing poorly, it is sometimes useful to look at actual energy use.

Each data set required different levels of analysis in order to calculate predicted and/or actual energy savings (see Appendix 2 for descriptions of each analysis). If measured GHP COP was available we calculated predicted HVAC savings and predicted total savings after establishing a baseline of non-HVAC energy use.

In some cases that did not have submetered data, we extrapolated HVAC energy use by assuming that the total energy consumed in the lowest consumption months was entirely non-HVAC energy and that non-HVAC energy use was constant.

For "similar" control houses, HVAC and whole house energy use were normalized by floor area or total UA value to account for differences between the GHP and control houses. In the Pontotoc MS case study, data was also normalized by number of occupants. Where possible, we accounted for the contribution of the GHP desuperheater to water heating by subtracting the GHP's contribution to water heating from the GHP HVAC (space heating) energy use.

For pre-retrofit control houses and for some "similar" controls, HVAC energy data was weather normalized to account for weather differences between the monitoring periods of the test and control houses.

In the Gas/AC cases, gas use was compared to electricity use by using a "source energy" conversion of 10,000 Btu = 1 kWh rather than a "site energy" conversion of 3,413 Btu = 1 kWh. This source energy conversion is commonly used to account for the fact that electricity is much more expensive than natural gas on a Btu basis. Thus source energy is a more accurate way of determining the cost or economic savings received by the consumer.

Actual savings were calculated according to the formula: 1 - (GHP energy use / Control energy use).

Average results are calculated on a project-weighted basis, with each individual "retrofit" house given equal weight as each group of "similar" houses. For example, the 26% average whole energy savings from the 8 Kentucky Utilities Gas/AC homes is given the same weight as the 18% savings from the one AL-Kavanagh Gas/AC house because the Kentucky houses used similar controls and the Alabama house was a retrofit (see Table 2). Retrofits are listed individually because building and occupant characteristics are assumed to be unchanged between control and test house and results are considered more accurate. Similarly-controlled houses are grouped by study because there are too many variables for individual house results to have much significance.

IV. Results

A. *Predicted Savings*

The Measured COPs were consistently between 2.5 and 4.0, which is slightly below the average ARI rating, but still implies a high level of efficiency. Based on these measured COPs, the predicted savings appear to be within the expected range (see Figures 1). For example, the average predicted HVAC savings compared to electric resistance is 66%, which is consistent with the EPA estimated savings of 63% - 72%. Similarly, the average predicted HVAC savings compared to ASHP is 42%, which is within the EPA range of 23% - 44%. Overall, the predicted HVAC savings is 57% and predicted total energy savings is 30%.

B. *Actual Savings*

Although the GHP houses consistently saved energy both on an HVAC and whole house basis, the actual savings are sometimes considerably below the predicted savings, especially when compared to electric resistance homes (see Figure 1). The electric resistance houses were predicted to save 66% on HVAC but only saved 41% according to energy measurements. On a whole house basis, they were predicted to save 38% but only achieved 27% savings on average[1]. It is interesting to note that the two houses with electric resistance furnaces (i.e. with duct distribution) had higher savings than the electric resistance houses that did not have ducts.

It is important to recognize that in most cases where the GHP had a desuperheater, we were not able to calculate the additional space heating (HVAC) energy savings that were "taken back" in the form of water heating. In one case where we were able to make this correction (the Montana case), the HVAC savings increased from 14% to 21%--a significant increase, but still considerably lower than the predicted HVAC savings of 60%. Of course, the total energy savings do account for the desuperheater contribution.

It is also worth noting that the GHP house occupants may have enjoyed a greater level of service because the electric resistance homes did not have air conditioning. For the Montana houses we calculated that the HVAC savings could be as high as 31% if we correct for air conditioning. However, this correction may be double counting HVAC savings because it is very possible that the time that the GHP unit is in cooling mode is also the time that the unit is in DHW mode and we have already subtracted the DHW mode energy from the GHP HVAC energy. The other cases where the electric resistance control houses

[1] It is not uncommon in building science research for actual savings to be less than predicted savings. Nadel and Keating (1991) analyzed 11 residential retrofit DSM programs (mostly weatherization programs) for which both engineering estimates and impact evaluation results were available. For most of the programs, impact evaluation results are substantially below the engineering estimates. Reasons for the discrepancies include use of secondary fuels and quality control problems in measure installation. However, in the one program where engineering estimates were done on a house-specific basis and where houses using secondary fuels were excluded from the program, engineering estimates were reasonably close to impact evaluation results.

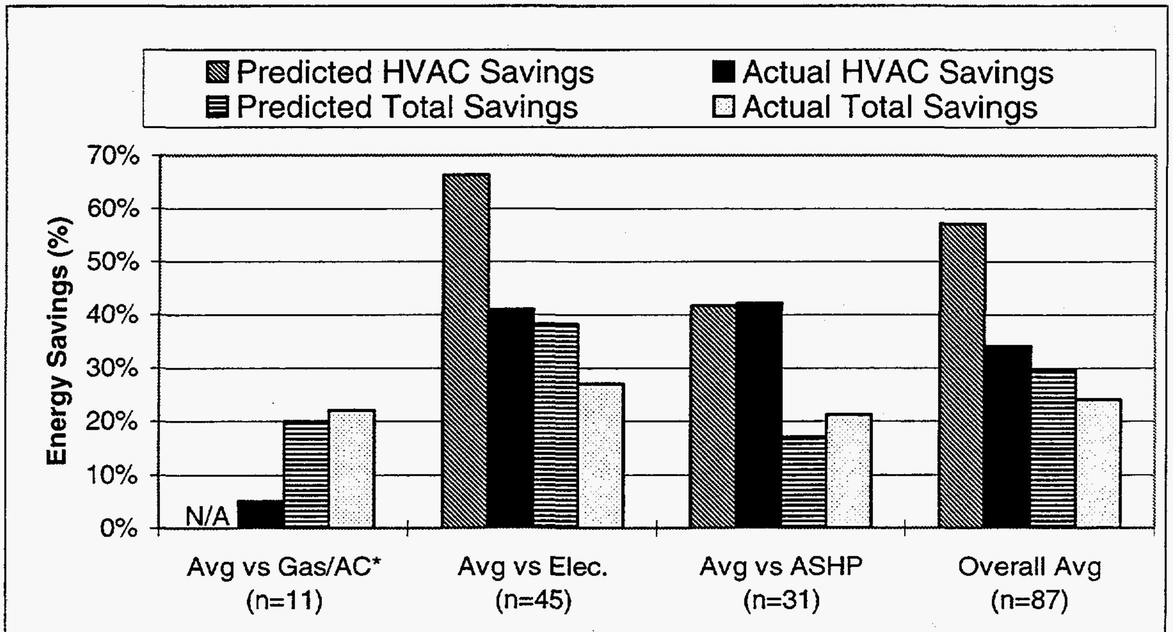
did not have air conditioning are the Alaska houses, where AC use is probably relatively small, and Oklahoma and Ithaca, which both happened to have surprisingly high HVAC savings without correcting for air conditioning. Thus, desuperheater energy for hot water and differences in air conditioning use probably explain some of the shortfall in savings compared to electric resistance house, but not the entire shortfall.

For the ASHP comparisons, on the other hand, the predicted and actual savings are quite close on average. Thus the GHPs appear to perform reasonably well in these cases. In fact, the GHPs saved about the same amount of HVAC energy versus ASHPs as they saved versus electric resistance.

The sample size is probably too small to discern a clear trend between GHPs and Gas/AC controls. For example, there were only two case studies for which we were able to calculate HVAC energy savings. One showed savings of 30% while the other showed negative 20% savings (Figure 2). Figure 1 does show a fairly high level of whole house savings versus Gas/AC (22%), but again it is based on only two data points, with uncertain data quality.

Overall, the GHP houses were predicted to save 57% of HVAC energy but actually saved only 34% and were predicted to save 30% of total energy but actually saved only 24%.

Figure 1. Summary of Predicted vs Actual HVAC and Whole House Energy Savings



* Natural gas is compared to electricity on a source (10,000 btu = 1 kwh) or local price basis

There was considerable variance in savings between studies and within studies (see Figures 2 and 3). For example, the 38 Montana GHP houses and the one Ithaca NY GHP house were both predicted to save about 60% of HVAC energy compared to electric resistance control houses based on actual COP measurements. The Montana houses actually saved 14% while the Ithaca house saved 68%. It is interesting to note, however, that the Ithaca house actually used more energy/ft2 (both HVAC and whole house energy) than the Montana houses (see Figures 4, 5, 6, and 7). One possible explanation for this seeming inconsistency is that the NY house is poorly insulated compared to the Montana houses. It is also possible that we have not adequately accounted for the differences between the Montana test and control houses and the true savings might be higher than shown in Figures 2 and 3.

Inadequate controls is certainly the case with the Alaska-Harmeling house. Figure 3 shows that the GHP house used 27% *more* total energy than the control (pre-retrofit) house, i.e. negative 27% savings. However, the control house used 5 cords of wood per winter, while the GHP house used none. Therefore, whole house energy savings does not reflect all fuels in this case. This house was not included in the average results.

Variance within studies is illustrated in the Pontotoc Mississippi study. Two of the three Pontotoc ASHP control homes used about the same energy as the four Pontotoc GHPs. However, the third control home used about three times the energy of any of the other test or control homes. Thus, on average the GHPs performed considerably better than the ASHPs but if we exclude this outlier there are no savings (see Table 8 in Appendix 2).

C. *Temporal Trends*

Despite the fact that GHP rated efficiencies have increased greatly in recent years, there was no demonstrated improvement over time in actual savings. In fact, it appears that the older installations performed better than the newer ones. This trend is clearest when comparing whole house energy savings versus ASHP houses (see Figure 3).

There are only two studies for which we have seasonal savings. In the Ft. Hood Texas case, two GHP houses saved 43% of HVAC energy versus Gas/AC control houses in the summer, but the GHP houses used so much more energy in the winter that the annual savings are negative 20%. In other words, the GHPs performed considerably better than the standard air conditioners in the summer but considerably worse than the natural gas furnaces in the winter. Thus the proportion of cooling load to heating load in a climate can determine how much energy a GHP will save when compared to a Gas/AC system. This conclusion seems to be supported by the Ft. Polk data, which showed significant annual savings versus Gas/AC in a cooling dominated climate (see Figure 3).

The other seasonal data is from the Virginia Power case study. 15 GHP houses that were compared to ASHP houses saved 7% of HVAC energy in the summer and 34% of HVAC energy in the winter for an annual savings of 27%.

Table 2. Summary of Results: HVAC and Whole House Energy Savings and Energy Use

Summary of Results: HVAC and Total Energy Savings & Energy Use															
Location	Year GHP Installed	Loop Type	Num. GHP homes	Control Type	Control System	desuperheater	Ratd GHP COP	Measured GHP COP/EER	Predicted HVAC Energy Savings	Actual HVAC Energy Savings	Predicted Total Energy Savings	Actual Total Energy Savings	GHP HVAC Energy (kwh/y)	GHP Total Energy (kwh/y)	GHP HVAC Energy Use/ft2	GHP Total Energy Use/ft2
KY - Ken. Util.	86-88		8	similar	Gas/AC							26%	7,553	19,009	3	7
AL - Kavanagh	1988	cls vrt	1	retrofit	Gas/AC	yes		3.3		30% a	20% b	18% c	4,341	13,672	3	9
TX - Ft. Hood	1995		2	similar	Gas/AC	no				-20% f			4,747			
OK - CREC	1989	closed	1	retrofit	elec. furn.							34%		29,280		11
AK - Harmeling	1992	cls hrz	1	retrofit	wood/elec	yes		3.89	75%		40%	-27% g	7,406	30,000	4	18
AK - Hills	1993	cls lake	1	retrofit	elec. resist.	yes		3.3 j	75%		40%	28%	12,510 i	24,000	8	15
NY - Ithaca	1993	cls vrt	1	retrofit	elec. furn.	yes	3.5 r	2.61 k	62%	68%	38%	42%	8,334	21,834	4	10
MT - Missoula	1994	cls vrt	38	similar	elec. resist.	yes	3.1	2.7 l	60%	21% a	35%	0%	4,969	16,700	3	9
MI - Selfridge	1995		3	similar	elec. resist.	no			60%	34% n		32% n				
KY - Ken. Util.	86-88		8	similar	ASHP					49%		36%	7,553	19,009	3	7
MS - Pontotoc	1992	closed	4	similar	ASHP							27%		22,037		11
OK - CREC	1993	closed	1	retrofit	ASHP							4%		27,516		16
NY - Ithaca	1993	cls vrt	1	retrofit	ASHP	yes	3.5 r	2.61 k	44%	48%	21%	24%	8,334	21,834	4	10
NY - Hyde Par	1993	cls vrt	1	retrofit	ASHP	yes	3.5 r	2.61 o	44%	45%	13%	14%	4,636	22,636	2	11
OK - CREC	1995	closed	1	retrofit	ASHP							22%		20,832		13
VA - VA Powe	1995		15	similar	ASHP			4.1	37%	27% p						
MO - Sac Osage			495											8,484		4
OH - Cinergy			31										12,684	28,303	4	9
Avg vs Gas/AC	(n=11)		11					3.3		5%	20%	22%	5,547	16,341	3	8
Avg vs Elec.	(n=45)		45					3.1	66%	41%	38%	27%	8,305	24,363	5	13
Avg vs ASHP	(n=31)		31					3.1	42%	42%	17%	21%	6,841	22,311	3	11
Overall Avg	(n=87)		87				3.4	3.1	57%	34%	30%	24%	7,552	21,676	4	11
LA - Ft. Polk	95-96	cls vrt	762	retrofit	Gas/AC	75%						30% t		12,885		10
LA - Ft. Polk	95-96	cls vrt	3241	retrofit	ASHP	75%						35% t		13,755		10

a: accounts for GHP contribution to DHW; b: 20% savings based on manufacturer's rating

c: These figures are for cost savings which are affected by local gas and electricity rates.

f: -20% annual savings, 43% savings in summer months (May - Sept)

g: -27% accounts only for (negative) electricity savings and not wood energy savings. Therefore this figure is omitted from the average

i: includes desuperheater energy use; j: COP = 3.3 with distribution fan energy, COP = 4.0 without distribution fan energy

k: heating season COP = 2.61, SEER = 12.8; l: range 2.5-3.8 n: Dec - March only o: heating COP = 2.61, SEER = 9.63

p: 7% savings in cooling season, 34% savings in heating season

q: only 4 or 495 houses reported floor area

r: rated heating COP = 2.7 - 3.2; rated cooling SEER = 14.

t: Other energy saving retrofits were also performed on many of the Ft. Polk houses (eg. CFLs, attic insulation). Therefore, these houses are not included in the averages. Therms converted to kwh using a "source energy" conversion of 10,000 Btu = 1 kWh

Figure 2. Comparison of HVAC Savings

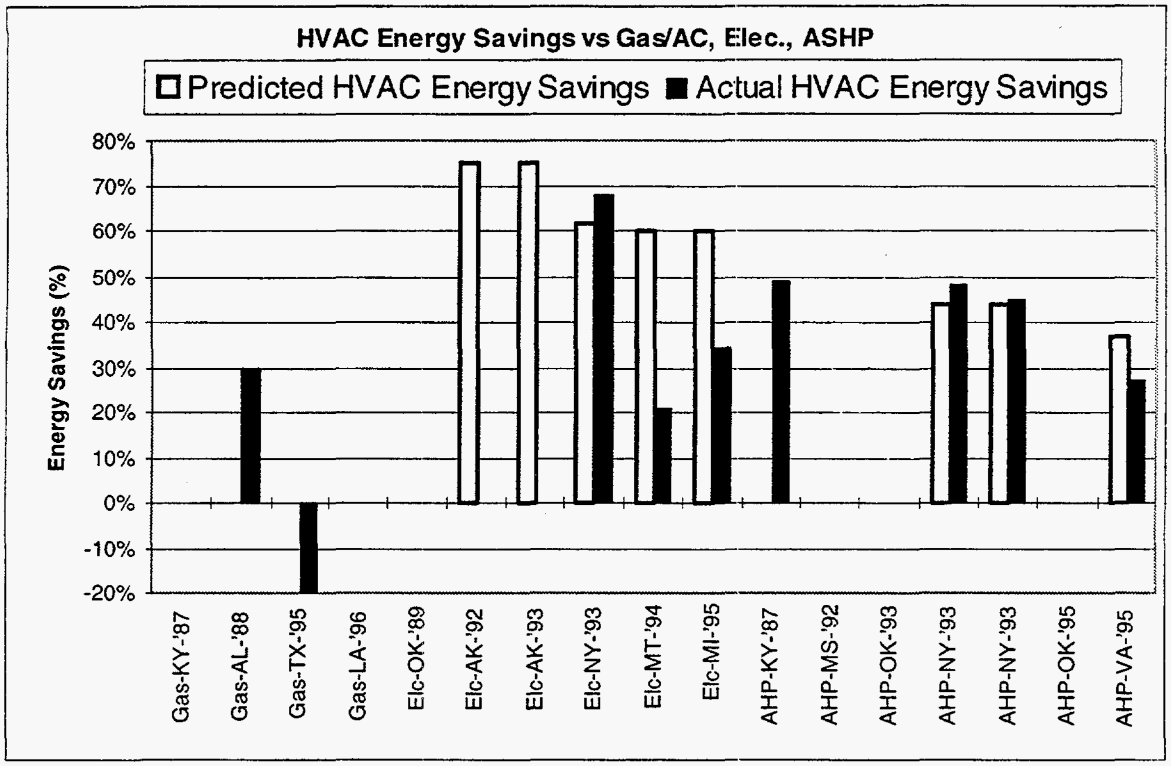


Figure 3. Comparison of Whole House Energy Savings

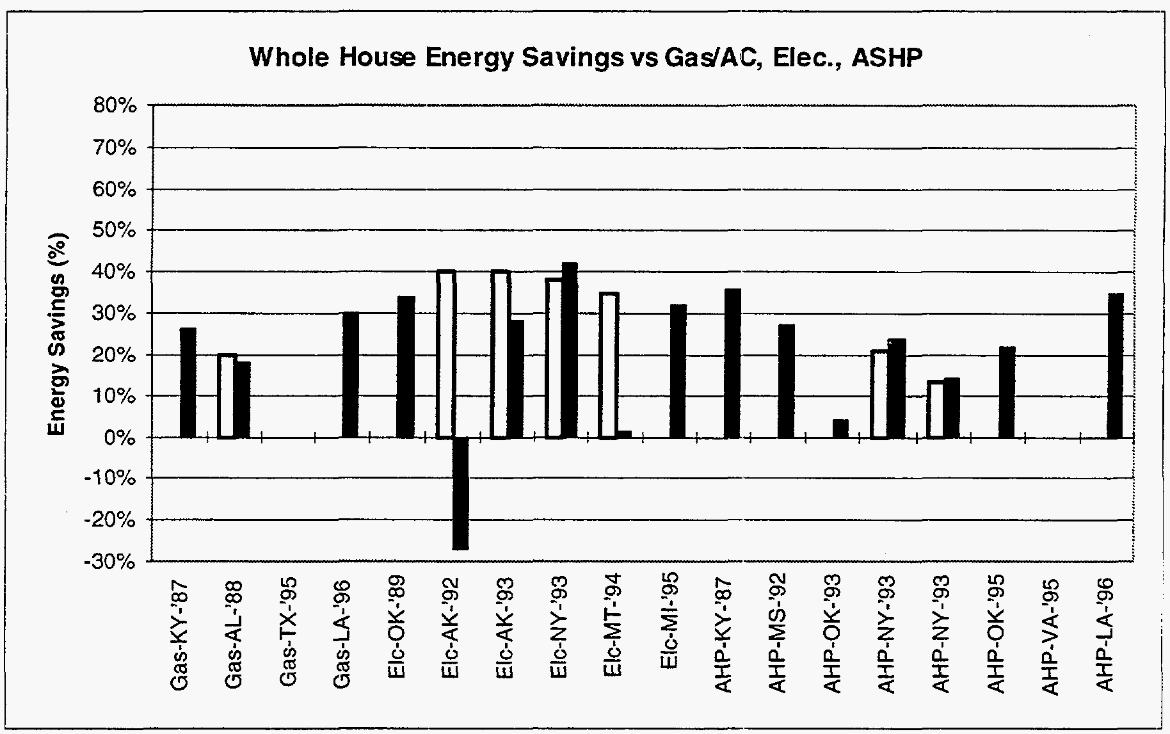


Figure 4. Comparison of HVAC Energy Use

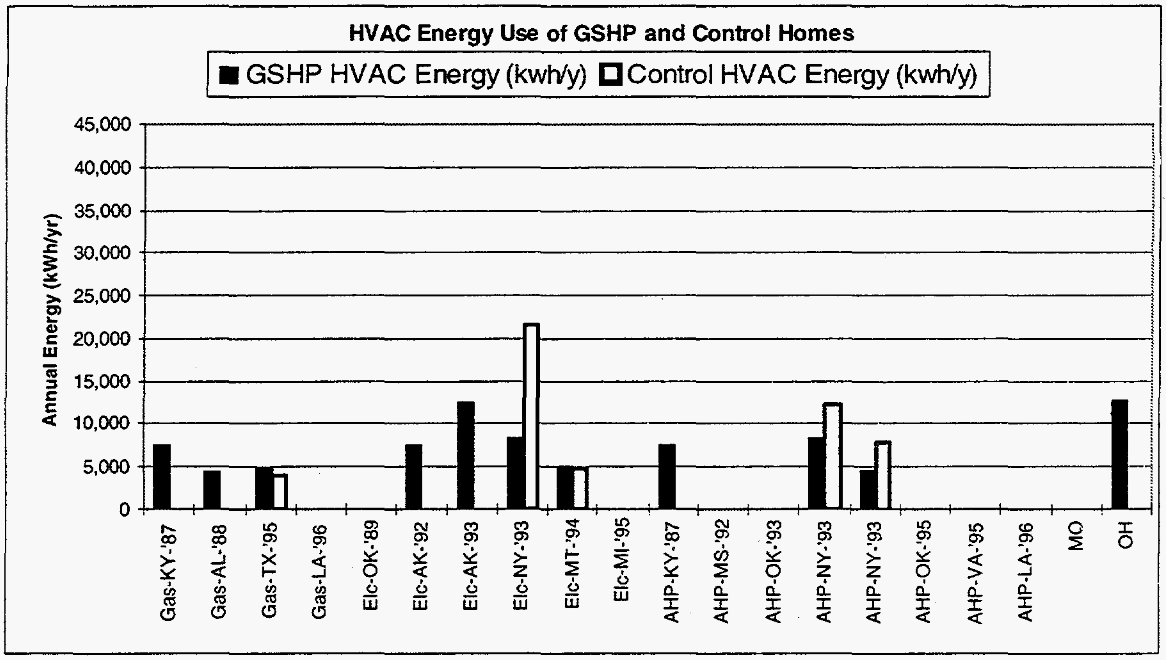


Figure 5 Comparison of Whole House Energy Use

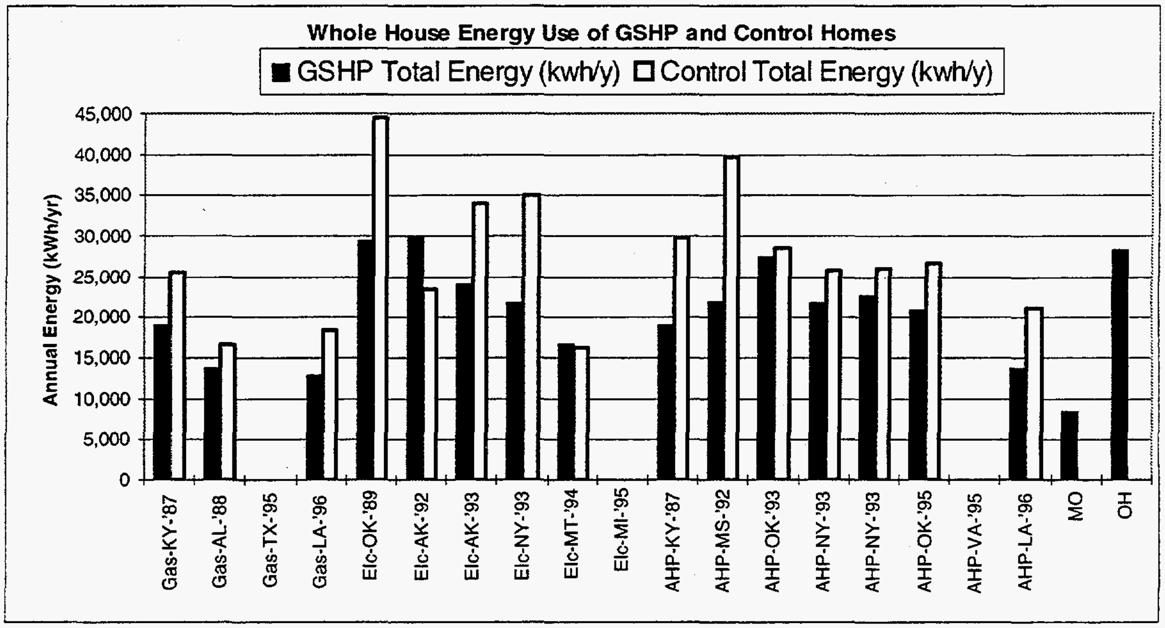


Figure 6. Comparison of HVAC Energy Use Per Square Foot

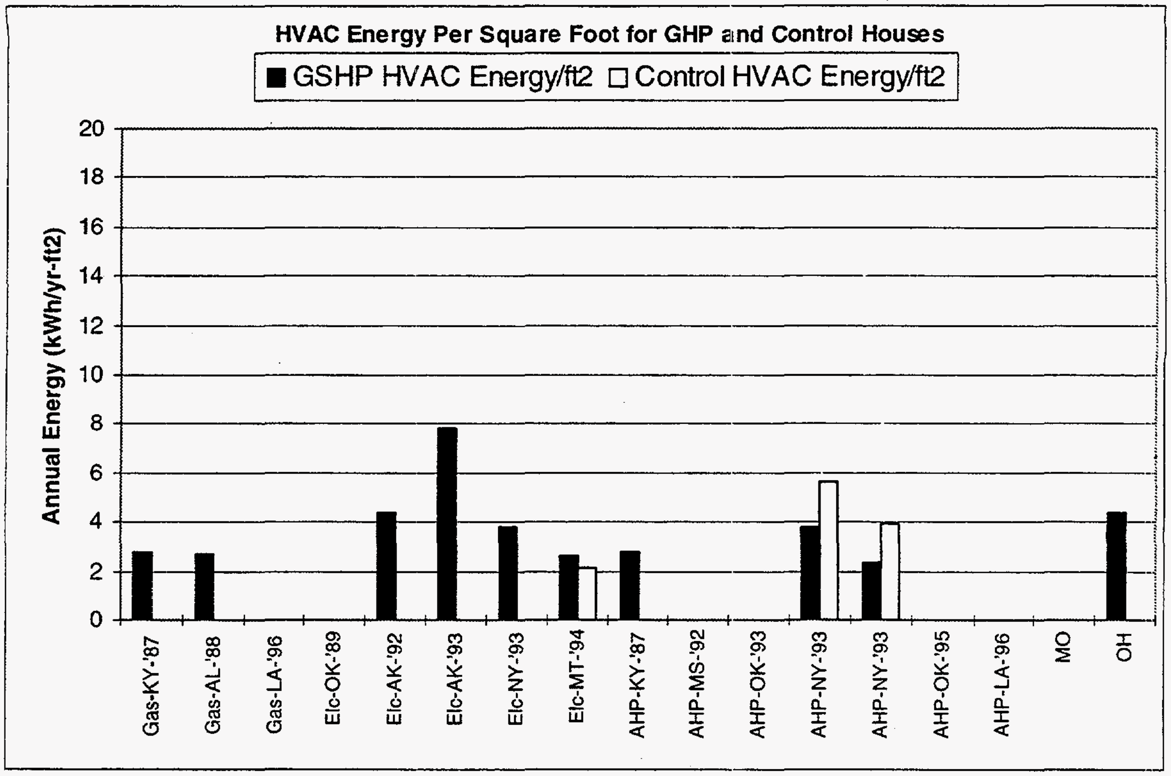
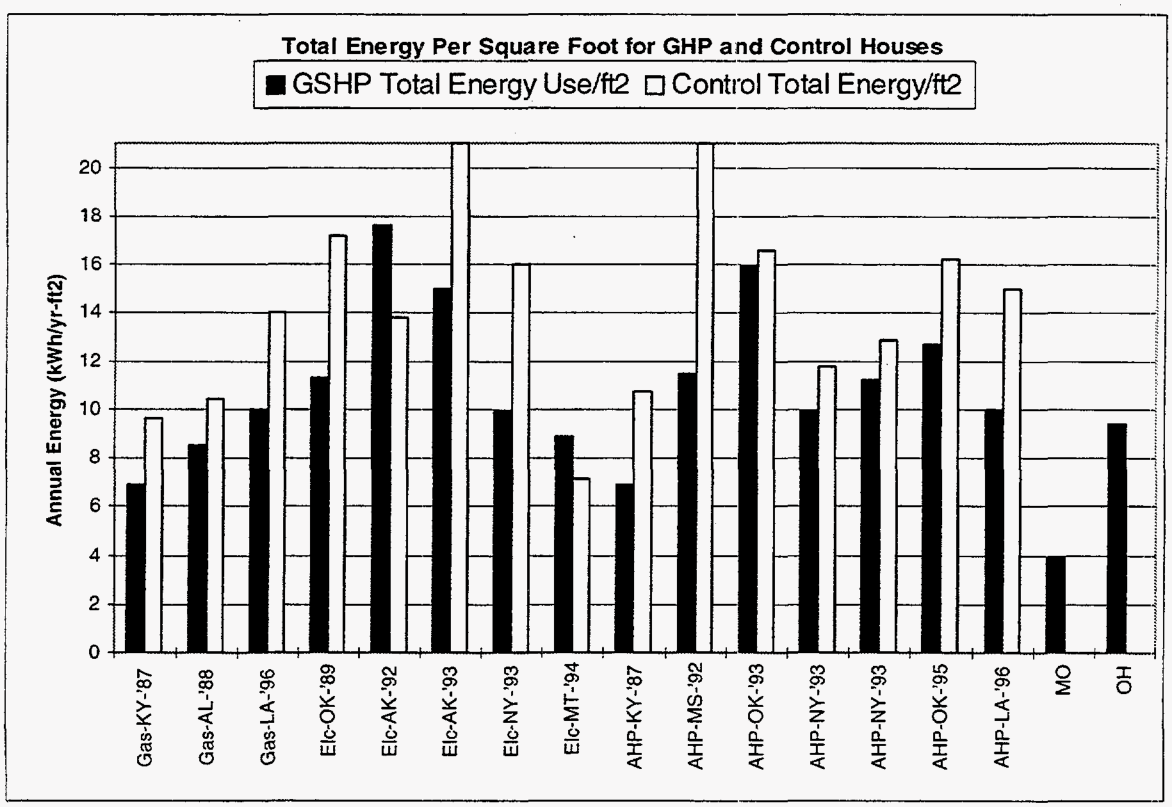


Figure 7. Comparison of Whole House Energy Use Per Square Foot



V. Conclusions

GHPs clearly save energy compared to conventional systems both on an HVAC energy basis and a whole house energy basis. Of the 16 case studies for which we computed HVAC energy savings and/or whole house energy savings (see Fig. 2, 3), only one case clearly showed negative savings (The negative savings shown for the AK-92 house does not account for the positive wood energy savings in that case).

However, in some cases the GHPs did not save as much energy as expected. Expectations are typically based on ARI COP ratings and are sometimes verified by measuring COP. The results also show that measured COP may not be a good indicator of actual energy use or savings. Savings are significantly less than expected when compared to electric resistance control houses. Predicted HVAC savings based on measured COPs were 6%, while actual HVAC savings were only 41%. On the other hand, savings versus ASHP systems were at or above predicted savings, on average.

Results are mixed in the Gas/AC cases, but sample size is small. One result does seem clear from the Gas/AC homes: the advantage of a GHP system vs a Gas/AC system comes in the summer time. Thus GHPs are more competitive with Gas/AC systems in cooling dominated climates rather than heating dominated climates.

Given that there is a significant shortfall in savings compared to electric resistance systems but not compared to ASHPs, the discrepancy could be related to the distribution systems or the level of service, as opposed to the GHP unit itself (compressor and ground loop). ASHPs and GHPs typically have the same type of forced air distribution system and the same type of centralized thermostat control. Both also have air conditioning. Electric resistance systems, on the other hand generally do not have a forced air distribution system and therefore are not subject to duct losses. The two electric resistance systems that had duct systems had higher savings than the ones that did not have ducts, thereby supporting the theory that duct distribution can erode savings. Electric resistance systems are often controlled very differently, with occupants only calling for heat in specific rooms at specific times. Finally, some of the electric resistance houses in cold climates examined here did not have air conditioning. Thus it is possible that expected savings are eroded as occupants increase the level of service by heating more rooms and/or by using air conditioning. There are, of course, other possible explanations for why the actual savings are often less than expected based on ARI ratings or COP measurements, including poor sizing or installation procedures.

In some cases, HVAC Savings may be distorted by the fact that some of the GHP's energy use is for water heating. Thus in the cases where we were not able to correct for the GHP's contribution to water heating, the HVAC savings may be understated. Of course, total energy savings are not affected by this possible distortion. In the case of the Montana homes, we were able to correct for desuperheating and for differences in air conditioning use and we still found that the HVAC and total savings were less than predicted. Thus, in addition to the air conditioning, other factors are also contributing to the erosion of savings. These could include distribution losses, poor sizing or installation, and other differences in the level of service (conditioning more rooms, more comfortable settings, etc.).

There are also some possible explanations for the fact that the energy savings appear to be smaller for newer GHPs rather than greater, as would be expected. Many of the earlier installations for which we have data were specifically installed as test installations. Therefore, more attention than usual may have been paid to proper loop sizing, installation, and maintenance. On the other hand, many of the newer installations analyzed were not installed or maintained as part of a special monitoring program but rather they were normal installations by typical contractors. Thus the newer equipment may indeed have higher laboratory efficiency but the installation and/or maintenance could be considerably worse. Another possible explanation is that the older systems may have been open loop systems which are more efficient but are now generally not used for environmental reasons. We know that all of the newer installations are closed loops, but we do not know the loop type for some of the older ones.

It is important not to over-interpret the results given the nature of the data gathered. For some of the cases we know very little about the houses being monitored such as the circumstances of how the HVAC systems were installed and how they were selected for monitoring. On the other hand, the results are least encouraging for some of the cases for which we have the most information and higher confidence in the data. For example, the Montana study is the largest (38 GHP houses) and the one for which we have the most extensive data. Yet these GHP houses still showed significantly less savings than expected when compared to electric resistance houses.

VI. Recommendations

Given the large variance in results and the questionable quality of some of the data, there is a clear need for additional research on the actual performance of residential GHPs. Additional research is needed in a number of areas:

- **Collect Case Studies** - This analysis has just begun to scratch the surface of what is potentially available in terms of existing data on residential GHP installations. Many more case studies have already been monitored by utilities and other organizations and there are thousands of installations that have not been monitored but for which billing data could be collected from utilities.

- **Perform Monitoring** - It would also be valuable to generate new case studies by performing submetering on some of the thousands of homes that have been built or retrofitted with GHPs in recent years or will be built or retrofit in the near future. Detailed monitoring could remove uncertainty from variables such as occupant behavior and weather and make it possible to get a better picture of how GHPs installed under normal conditions are performing.

- **Focus on Distribution Systems** - Experiments should also be designed to allow a better understanding of the role of distribution system losses, which appears to be the primary reason why GHP systems do not perform as well as expected compared to electric resistance systems.

VII. References

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VIII. APPENDIX 1: List of Contacts

Table 3. Inventory of Data Leads

Inventory of GSHP Data and Leads (partial list)				
Name	**quanitity**	**data we have**	**possible data**	**contact/status**
MT - GSHP	27-40	see detailed analysis section	YR 2 final report; pre and post monitoring of a retrofit house began 10/96	Jim Maunder
Alaska	7	see detailed analysis section	Smoots or ERHA may have rating data	U Alaska-Fairbanks:Mueller; Sterling Larsen of MEA sent me before and after elec bills for Hills, Hammeling houses & photos
Arkansas	1	area, 10/94-1195: total monthly kwh	none?	Mike Housh
Penn - PP&L	??	none	PP&L test 6 "Slinky" designs-collected performance data; 4.	Mike Armstrong referred me to Don Frazier who referred me to Jake Hammond (around 8/5) (610-774-5251) who will check and get back to me.
Penn - PP&L			Bob Boyer says data exists	Penn Power & Light, Kathy Billy 610-774-5704, left msg 7/22, referred me to Jake Hammond (see above)
SMUD-SHRA	21-22 (6 i	child care center (Huang)	starting June for 1 yr;GSHP kwhr; Tsupply, Twater, etc; air fl	Bruce Vincent, SMUD 916-452-3211
Maine--Failure Stori	4	system cost, estimated montly tot kwh, approx actual monthly		Energy Design Update
Wisconsin	7, 2 control		over 1 yr for >=3 homes; interim report due out 6/96; modeling	Wisc Cntr for Demand-Side Rsch=Craig Schepp; CDH Energy Corp=Steve Carlson 315-655-1063
NY State (CDH Ene	?		monitoring beginning 6/69; results in 1yr	CDH= Hugh Henderson 315-655-1063
Georgia ($ fr NREC/	18-30		several yrs ongoing; 15 minute data, 20 channels; Hugh has monthly and annual summaries	Hugh Henderson; Susanne Martin (Jackson EMC Coop); Payton Collie (NRECA="touchy about giving data") - 6/10: Hugh is pursuing permission from Susanne and Payton; left msg 6/24, 7/15
EPRI	10		several people said data exists	Carl Hiller - left msg 6/7,6/10, 7/29, etc
AL - U Alabama ($ N		92 ASHRAE article on '88 retrofit house	other houses?	Steve Kavanagh, U. Alabama 203-348-1649
S. Dakota State U.	2		Raymond's house: 4 yrs; hydronic sys.	Dr. Charles Raymond,Chris Jepson 605-688-6387
Fort Polk-LA	4003	ACEEE Summer Study '96 paper	recent data	Patrick Hughes, ORNL
Ft. Irwin-CA		1 test GSHP using tap water vs control	12 GSHP to be installed 1996	Mark Hinrichs, ASW Engineering, Tustin CA 714-731-8193
Navy-Patuxent	4		4 of 17 GSHP were instrumented for COP and cost effectivness; all 17 monitored for reliability, avail, and maint.	Suresh Garg, Gary Phetteplace
Naval Securities Group NW				
Dyess AFB				ORNL: interim report 12/94?
NRECA/EPRI EUTA	69	"GSHP Study" summary chapter	full CEED/EUTAP report on Buckeye and EKPC/KU GSHP houses	John Farley (401-621-2240), contractor for CEED; Rich Gillman, CEED 800-377-0220; Richard Scheer 410-290-0370
CT				United Illuminating (800-722-5584)
OK			report to be completed 9/96	Brian Henderson, Public Service of OK (918-594-4009)
AR				Douglas Rye 501-455-2305
MO - Sac Osage		12-16 months of bill data for 500 GSHP homes	install dates on retrofits or bill data for ASHP homes	Jim Davis 417-876-2721.
U. Kentucky				Bill Murphy, U. Kentucky 606-257-3000
IGSHPA				Marvin Smith 405-744-5708, Dr. Jim Bose 405-744-6270
GHP Consortium			no data	Harvey Sachs, Mike L'Ecuyer
Plumas Sierras		disk with data from Paul Bony's house	monitoring of retrofit houses	Dave Springer, Dick Borne, Mark Hoeschele 916-753-1100, Davis Energy Group; Paul Bony, Plumas Sierra 916-832-4261
E. Kentucky Power			few studies, extensive database	Con Abnee, E. Kentucky Power 1-800-262-7464
OH - Cinergy		1995 monthly heating/cooling/total kwh for 31 GSHP homes, some new, some with built yr.		Pat Gaston 1-800-428-4337 ext 1020
Penn Elec Co.				Penn Elec Co, Joe Boito, David Fyock
PG&E			DEG report on CA Mkt Potential	PG&E, Brad Wilson, 415-973-4856
OK - CREC		before and after bill data for 3 retrofits, type of previous equip	he might be willing to give us more houses, if we ask	Randy Jarvis, Central OK Rural Elec Coop
Waterfurnace		anecdotal		Dorothea Rynearson, 1-800-231-5667 ext. 225
Sacromento				Pat Bernard, 916-944-6600, is a Sacromento architect who has worked on GSHP homes at River Oaks low income housing
Michigan Electric Coop Assoc				Mike Buda, 517-351-6322
Associated Electric Cooperatives, Springfield MO			ACH&R News article 9/6/93	417-881-1204
NRECA				Dennis Hein, Dr. Vernie Gealing 402-421-7135

IX. APPENDIX 2: Specific Analyses

A. *Missoula, MT*

1. Contact

Jim Maunder, Missoula Electric Cooperative Inc., 1700 W. Broadway, Missoula, MT 59802; phone 800-352-5200.

2. Data

Test Houses

As part of a joint demonstration project between Missoula Electric Cooperative and the Bonneville Power Administration, 40 homes in the Mullan Trail Subdivision in Missoula were constructed in 1993 and 1994 with GHP and desuperheaters. The houses have been monitored for over two years starting shortly after construction. Data was collected on heat pump electrical energy consumption, water heater electrical energy consumption, thermal energy contributed to the water heater from the heat pump, heat pump coefficient of performance, and whole house electricity consumption.

They were constructed according to the BPA Long Term Super Good Cents specifications, including: Ceilings - R-49; Walls - R-26 above grade, R-21 below grade with thermal break; Floor - R-19; Crawl-space perimeter - R-19; Slab - R-10 blueboard; Rigid Ducts - R-11; Flexible Ducts - R-8. Glazing consists of double pane, low E, argon filled windows with U-value less than 0.35.

Little is known about the occupants or the stock of appliances. All of the houses have well pumps and air exchangers providing mechanical ventilation. The air exchangers operate for approximately 8 hours per day.

Our contact has supplied us with all of the monthly submetered data for each house for the first two years of monitoring: '94-'95 and '95-'96. We also have floor area, and Wattsun runs for most of the houses, which includes total UA values. The average floor area is 1880 ft2 and the average total UA is 314 Btu/hr-ft2-F.

Control Houses

The control houses for the Montana GHP houses are taken from the Bonneville Power Administration's Residential Standards Demonstration Project (RSDP). Several hundred homes were built according to this highly efficient standard in the early 1980's in Idaho, Montana, Oregon, and Washington. From this large sample we extracted out the 20 houses that met the following criteria: located in Montana; heated by electric resistance heat; no fireplace or wood stove. These 20 houses constitute the Montana controls.

The houses were submetered for one year from May 1985 to April 1986. Monitoring data was available from Meier (1988) and others at LBNL and includes total energy, space heat energy, hot water energy and indoor and outdoor temperatures.

A significant amount of building data is available on the houses, including floor area, basement type, heating system, UA values, and infiltration rate. The average floor area is 2278 ft2 and the average total UA value is 261 Btu/hr-ft2-F.

The number of occupants and some appliance data such as the presence of a fireplace or well pump is known. None of the houses have fireplaces or wood stoves. About 1/3 of the control houses have well pumps. None of the houses have central air conditioning. Since they are "tightly" insulated all of the control houses have air exchangers but it is not clear how many hours per day they are working, if at all.

3. Analysis

The predicted savings were extrapolated from the Interim Report on the Mullan Trail Project (Koca, 1995). According to this report, the average measured COP was 2.5 in heating mode, and 3.8 in cooling mode, for a yearly average of 2.7. This implies a predicted HVAC savings of approximately 60% compared to a electric resistance system with a COP of 1. The report also reports an average total energy savings of 757 kWh/month based on measured COP. Given that the average measured total energy use is 16700 kWh/yr. for all of the GHP houses, this implies a predicted total energy savings of 35%.

According to the NCDC there were 8159 heating degree days during the control homes' monitoring period (May 85 - April 86) and only 7487 heating degree days during the GHP year 2 monitoring period (March 95 - February 96). Therefore the control houses space heating energy consumption values were weather normalized to account for the colder winter in 85/86 (i.e. multiplied by 7487/8159). The other two components of total energy use (DHW and "other") were not weather normalized. Total energy use, HVAC energy use and HVAC + DHW energy use for both groups were plotted versus both floor area and Total UA (see Figures 8 and 9).

HVAC energy use of the GHP houses was UA-normalized to account for the fact that the control houses had significantly lower total UA values. DHW and "other" energy use were not UA-normalized (see Table 4). Since total UA was only available for 20 of the 38 GHP homes, only those homes were used to calculate the UA adjusted HVAC energy. Furthermore, since DHW and UA was only available for 8 of the 38 GHP houses, only those houses were used to calculate the GHP houses' electric resistance DHW energy use.

In addition to the corrections for weather and differences in insulation, a correction was made to the GHP HVAC energy to account for the fact that some of this energy went into water heating. We assumed that the GHP homes used the same DHW energy as the control homes. The difference between the measured energy use of the electric resistance water heater in the control houses and the GHP houses is assumed to be equal to the amount of energy from the GHP contributed to water heating. Thus, this amount is subtracted from the GHP HVAC energy use.

It is possible to make another correction for the fact that the GHP homes have air conditioning and the control homes do not. According to our contact, approximately 11% of the GHP runtime is in air conditioning mode. Therefore, we reduced the average GHP space heat energy by 11% and carried this correction through to GHP total energy.

4. Results

It is clear from the plots that energy use is essentially the same for the GHP and control homes. The control homes used slightly less space heat and total energy on a floor area basis than the GHP homes. However, on a UA basis the GHP homes used slightly less space heat and total energy.

After correcting for weather and for differences in UA value, the GHP homes were calculated to save 14% of HVAC energy and 0% of total energy (see Table 4). However, after accounting for DHW savings, the GHP homes were calculated to have a savings of 21% of HVAC or space conditioning energy. Total energy savings remained the same at 0%. Finally, after normalizing for the difference in level of service (i.e. air conditioning), the GHP houses were calculated to save 31% of HVAC energy and 3% of total energy. However, correcting for AC differences may be double counting HVAC savings because it is very possible that the time that the GHP unit is in cooling mode is also the time that the unit is in DHW mode and we have already subtracted the DHW mode energy from the GHP HVAC energy. Furthermore, the purpose of this research is to characterize *actual* energy savings, without accounting for differences in level of service. Therefore, we feel that the non-AC-corrected calculations of 21% HVAC savings and 0% total savings are the more appropriate figures to include in the tables and figures in this report.

	Space Heat Savings	Total Energy Savings
Savings	21%	0%

(accounting for weather, UA differences, and GHP contribution to DHW)

Table 4. Montana Data

	Control Avg	GHP Avg.	Savings
total energy (kwh)	16729	17067	
HDD in monitoring period	8159	7487	
total energy-weather adjusted (kwh)	16290	17067	
HVAC equip--weather adjusted (kwh)	4897	5075	
UA value	261	314	
HVAC equip--UA adjusted (kwh)	4897	4218	14%
total energy--UA adjusted (kwh)	16290	16210	0%
DHW from electric resist (kwh)	4967	4607	7%
DHW correction:			
HVAC energy in DHW mode (kwh) = Control DHW - GHP DHW		360	
HVAC--space conditioning energy only	4897	3858	21%
=HVAC(UA adjusted) - DHW mode			
total DHW (by definition = elec resist + HVAC in DHW mode)	4967	4967	
Space conditioning + DHW	9864	8825	11%
AC correction:			
HVAC runtime in cooling mode		11%	
HVAC kwh in cooling mode		464	
HVAC kwh not in DHW or cooling mode	4897	3394	31%
total energy excluding cooling mode	16290	15746	3%

Figure 8. Montana: Floor Area vs Energy Use

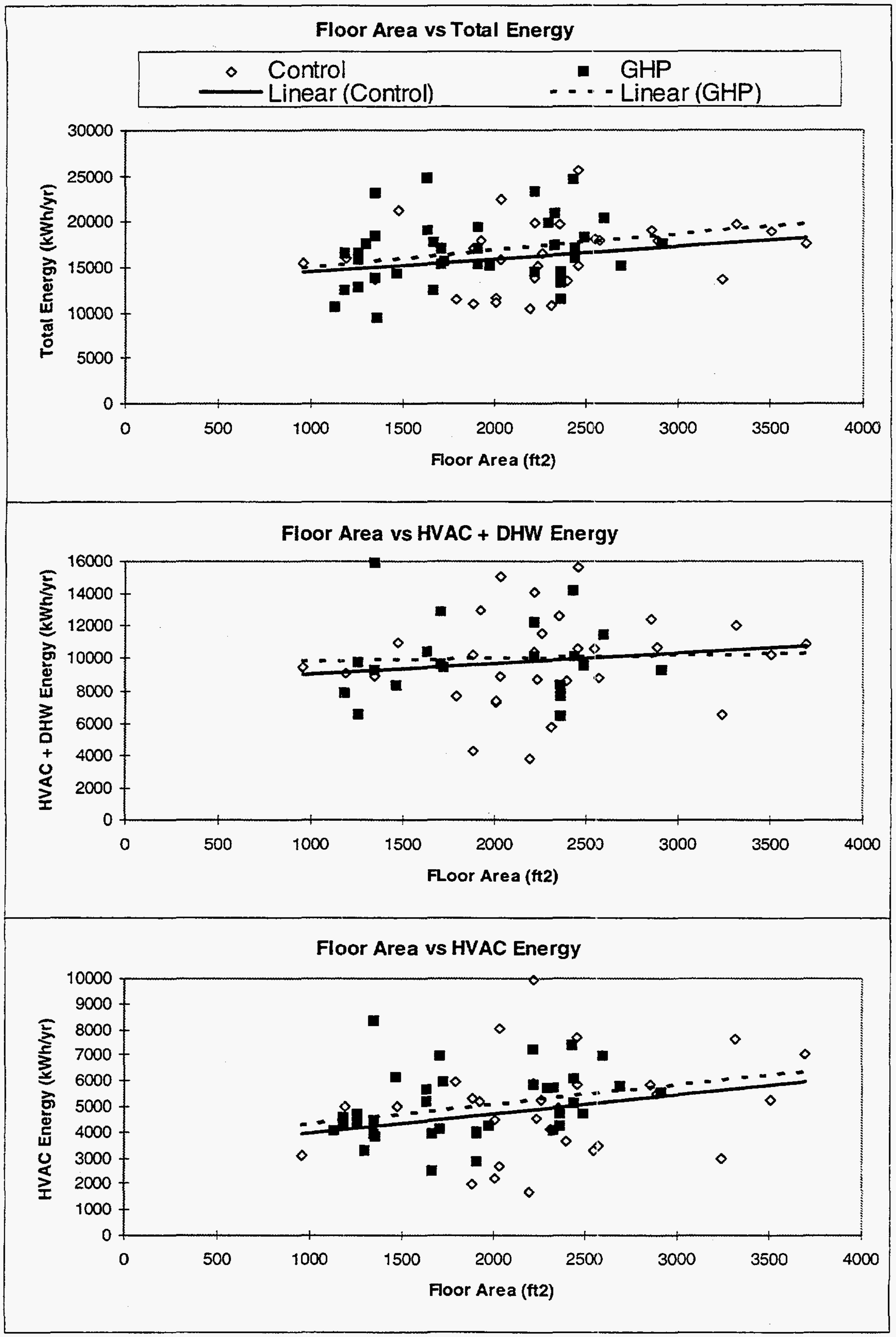
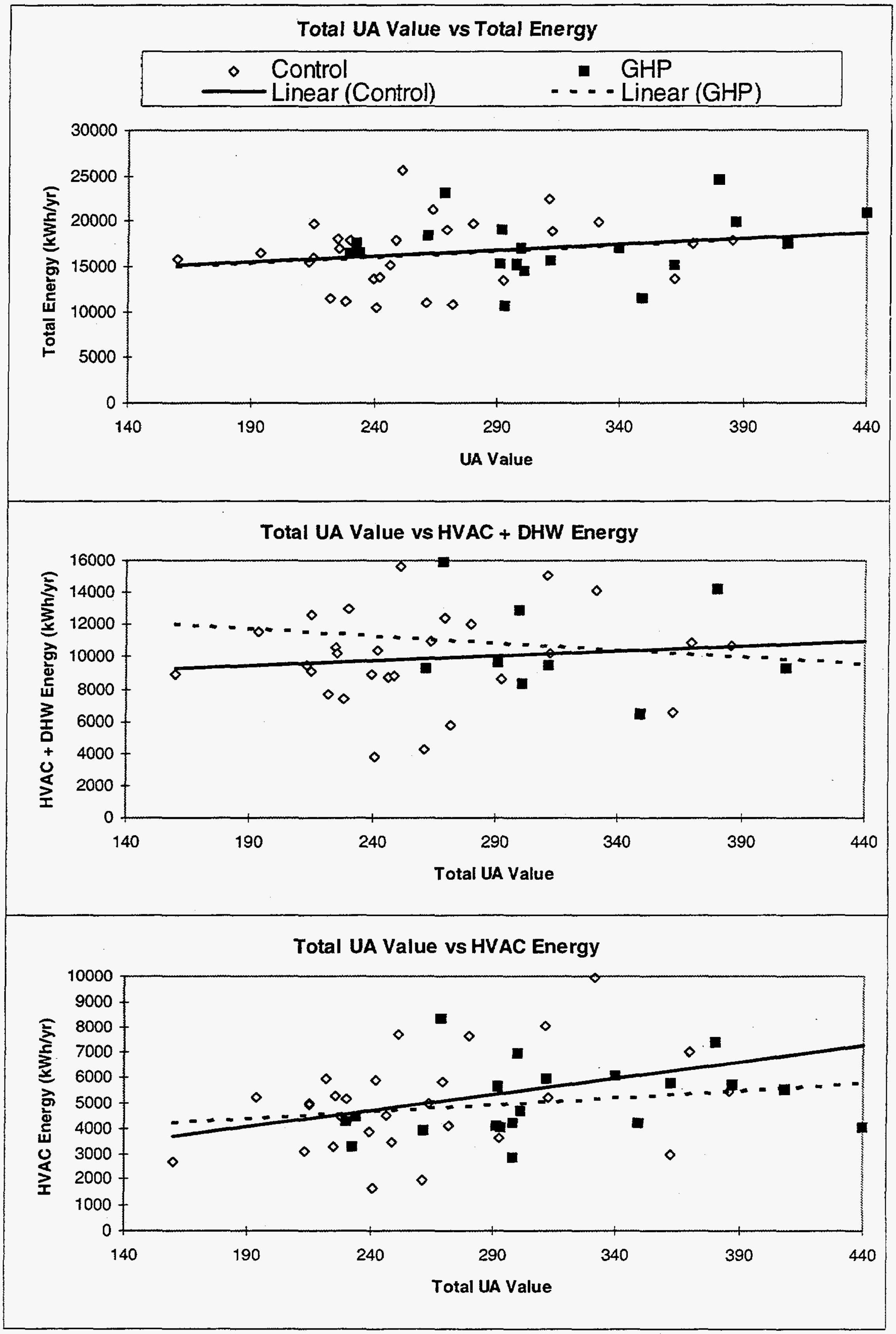


Figure 9. Montana: Total UA vs Energy Use



B. Anchorage, AK

1. Contact

George "Bub" Mueller, University of Alaska, Fairbanks
Sterling Larsen, Matanuska Electric Association, PO Box 2929, Palmer, AK, 99645; phone: 907-745-3231

2. Data

From May 1994 through May 1995, the Institute of Northern Engineering at the University of Alaska Fairbanks performed a detailed monitoring study of 5 residential GHPs in the Anchorage area. No control houses were monitored. Data available from the study includes indoor and outdoor temperatures, HVAC and whole house electricity usage, and COP. Two of the houses were retrofitted electric resistance homes: the Hills residence and the Harmeling residence. We were able to obtain billing data for the Hills house from September '92 through May 1995 (their GHP was installed October 1993) and for the Harmeling house from January '91 through December '95 (their GHP was installed October '92).

The Harmeling residence is a single story, 1700 ft2, with 8 ft ceilings, vented attic, and 7 occupants. It has two GHPs, one for heating and one for hot water. According to Mr. Harmeling, they burned 5 cords of wood per year and rarely used the electric heating before the GHP, but on the request of the utility they did not burn wood after the GHP was installed.

The Hills house is 1600 ft2, two stories, with ceiling heights from 8 to 20 feet, 2x4 walls, and two occupants. According to our contact, the Hills do not use wood backup.

Detailed data is available on the GHPs including installation date, manufacturer, model, size, and equipment type and configuration.

3. Analysis

The monthly billing data for each house was plotted (see Figures 10 and 11). The average of the lowest usage periods is assumed to be entirely non-HVAC energy use i.e., the base energy amount. Therefore, HVAC energy is assumed to be the incremental energy usage in each period above the base amount.

Annual heating degree day data was downloaded from the NCDC web site for the Anchorage weather station. For each mode of operation (GHP and electric resistance) 12 month rolling totals for electricity consumption were plotted against 12 month rolling totals for heating degree days for the same periods (see Figures 12 and 13). The average difference in energy use between each mode represents the average total energy savings. The average difference between each mode minus the base amount represents the HVAC energy savings.

Given that measured COPs for both houses were around 3.5, heating plus hot water consumption would be predicted to decline about 75%. Considering that heat and hot water account for about half of the homes' total electric bills, total electric is predicted to decline about 40%.

4. Results

The Institute of Northern Engineering extrapolated from the measured COP of 3.89 that the Harmelings were saving 17,900 kWh/y in space heating energy and 14,100 kWh/y in water heating energy for a total energy savings of 32,000 kWh ($3,200 at local rates). However, our bill analysis shows that they only consumed 23,500 kWh/y before installing the GHP and 30,000 kWh/y after installing the GHP for a savings of negative 27%. This does not include the wood energy savings of 5 cords/yr. Since word was not accounted for in the savings, this result (-27%) was not included in the calculation of average savings for electric controls or all GHP houses.

Our analysis shows that the Hills home consumed a total of about 34,000 kWh/y before the installation and 24,000 kWh after the installation for a total savings of about 28%.

Figure 10. Alaska-Harmeling House: Electricity Use

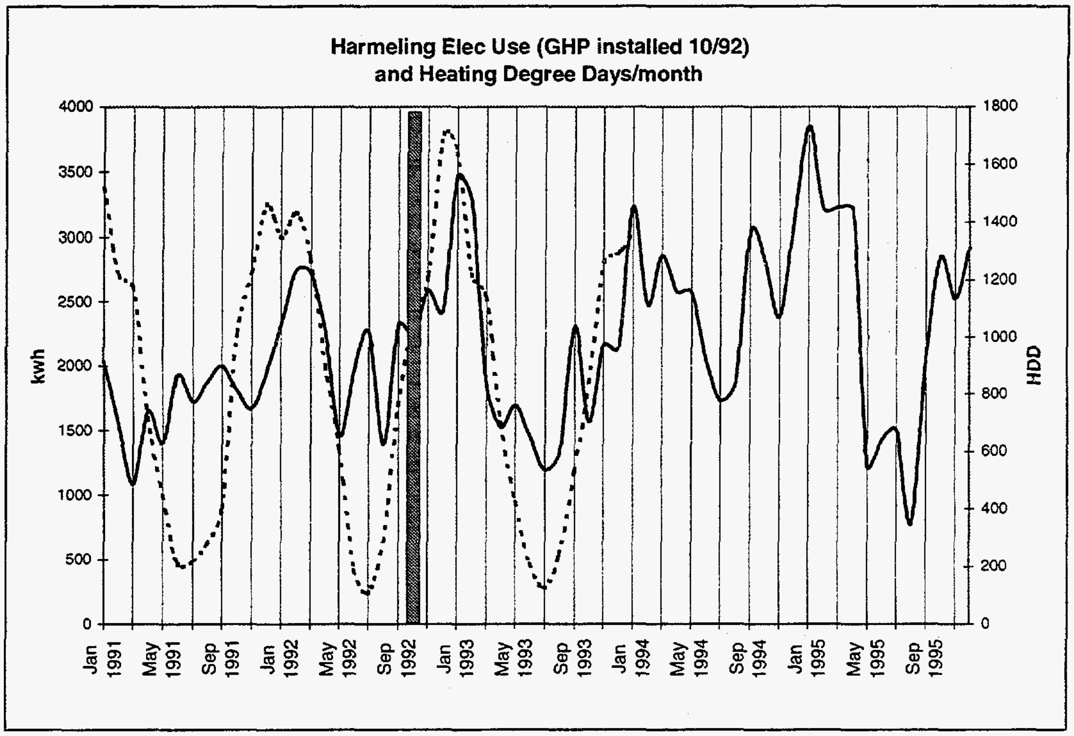


Figure 11. Alaska-Hills House: Electricity Use

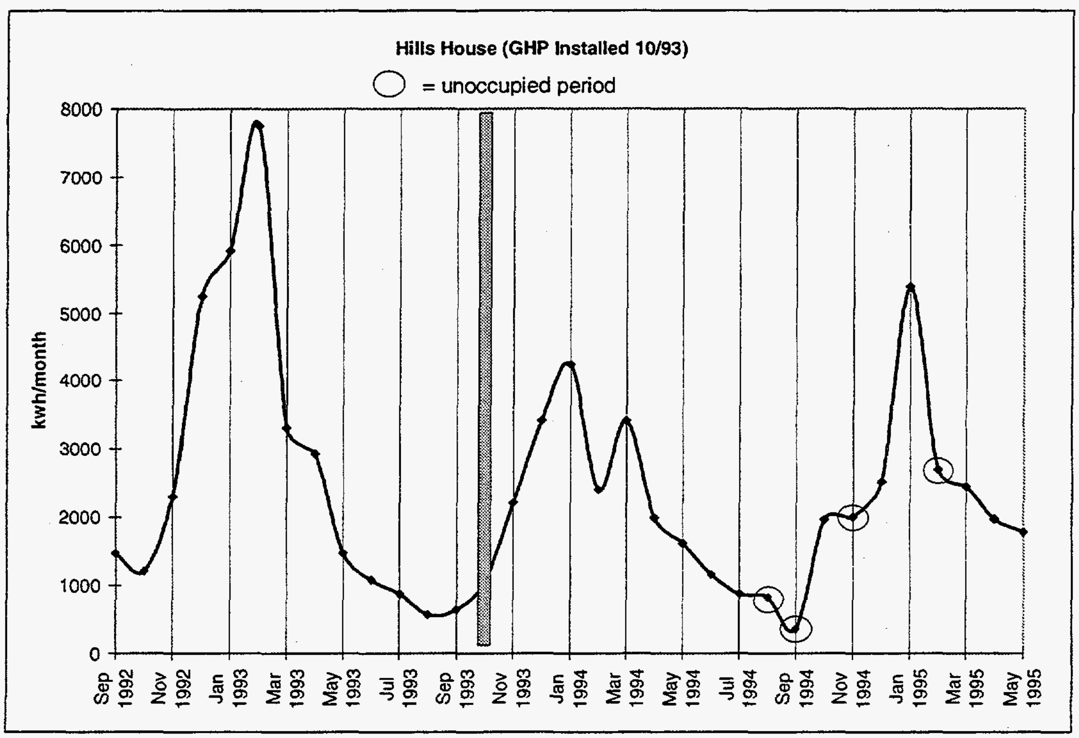


Figure 12. Alaska Harmeling House: Energy vs HDD

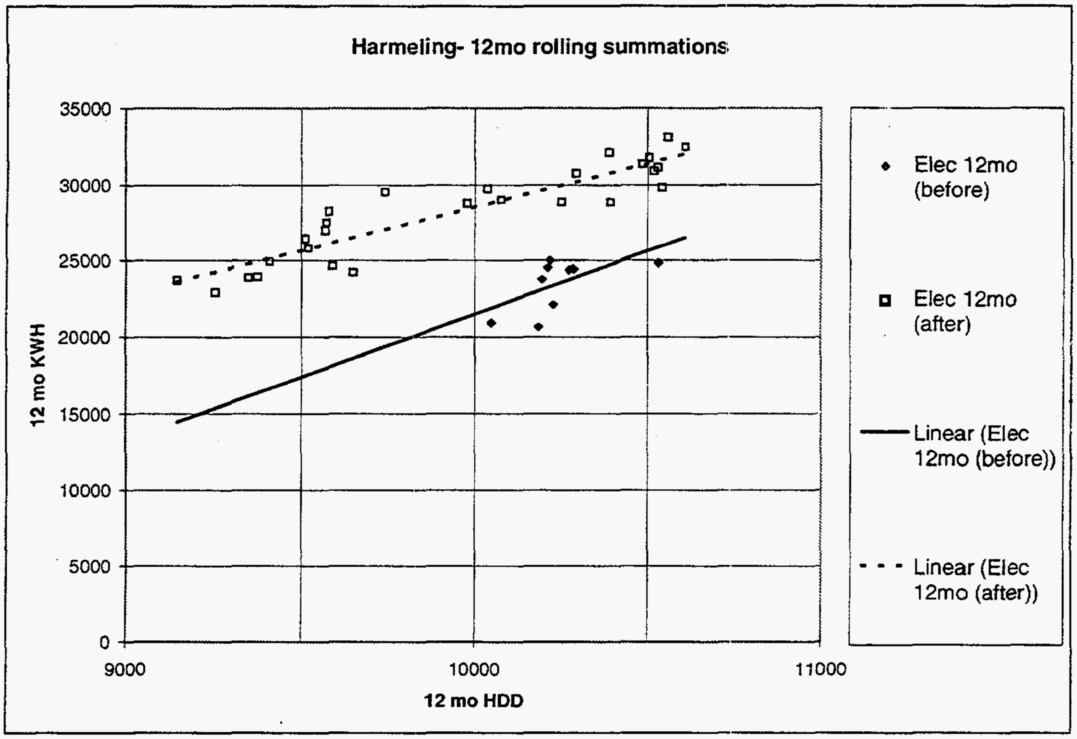
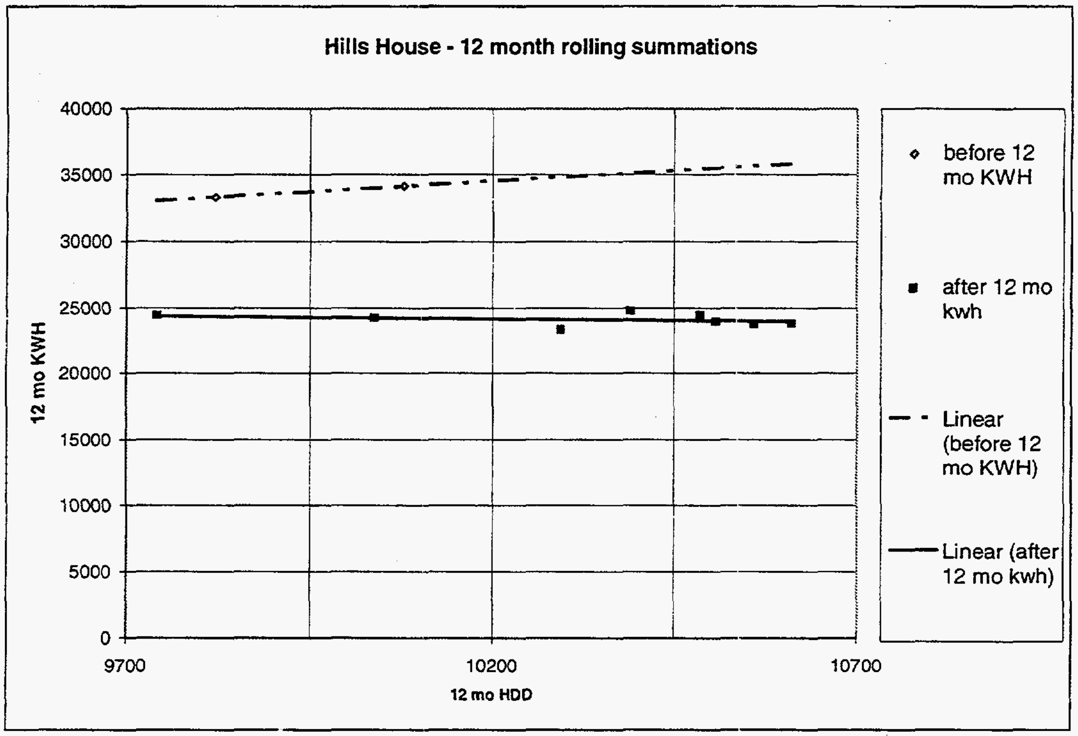


Figure 13. Alaska-Hills House: Energy vs HDD



C. NYSERDA, NY

1. Contact

Robert Carver, Project Manager, Buildings Research, New York State Energy Research and Development Authority, 2 Empire State Plaza, Suite 1901, Albany, NY 12223; phone:518-465-6251; email: rmc@nyserda.org

2. Data

NYSERDA conducted an extensive monitoring study of 4 homes with GHP in '94-'95. Data available include measured COP, indoor temperatures, and HVAC kWh consumption. However, we only included two of these homes in our analysis because only two were retrofits which allow a before-after comparison of utility bills. The two homes are in Ithaca and Hyde Park.

For the Ithaca home, bi-monthly billing data is available from April 1978 through July 1995. From 1978 through 1989 this home had an ASHP. From 1990 through 1993, the compressor on the ASHP failed, effectively rendering it an electric resistance forced air system. In 1993 a GHP was installed. Thus, this house provides two comparisons: GHP versus ASHP and GHP versus electric furnace.

Bi-monthly billing data is available for the Hyde Park home from February 1992 to June 1996. The home converted from ASHP to GHP in December 1993.

Building data available includes floor area, year built, insulation materials or R-values and number of occupants. Both are 2 stories with full basement.

3. Analysis

The bi-monthly billing data for each house was plotted (see Figures 14 and 15). The average of the lowest usage periods is assumed to be entirely non-HVAC energy use i.e., the base energy amount. Therefore, HVAC energy is assumed to be the incremental energy usage in each period above the base amount.

Annual heating degree day data was downloaded from the NCDC web site for the locations and years of interest (Syracuse weather station was used for Ithaca and Albany weather station for Hyde Park). For each mode of operation (GHP, ASHP, and electric resistance) 12 month rolling totals for electricity consumption were plotted against 12 month rolling totals for heating degree days for the same periods (see Figures 16 and 17). The average difference in energy use between each mode represents the average total energy savings. The average difference between each mode minus the base amount represents the HVAC energy savings.

The Predicted HVAC savings is calculated by assuming that ASHP COP equals 1.46 (HSPF = 5) and that electric resistance COP =1 and comparing these values to the measured GHP COPs of 2.61. Predicted total savings are derived by multiplying predicted HVAC savings by the fraction of total energy that HVAC accounts for.

4. Results

The actual HVAC and total energy savings for both the Ithaca and Hyde Park homes were about the same or slightly more than predicted by measured COP. However, the measured COPs (2.61) and SEERs were less than the rated efficiencies. According to Water Furnace International (NYSERDA 1996), heating rating for the GHP is 2.7 COP at ARI 330-hi and 3.2 at ARI 330-lo, while cooling rating is 14.0 EER at ARI 330-lo.

Figure 14. NY-Ithaca House: Electricity Use

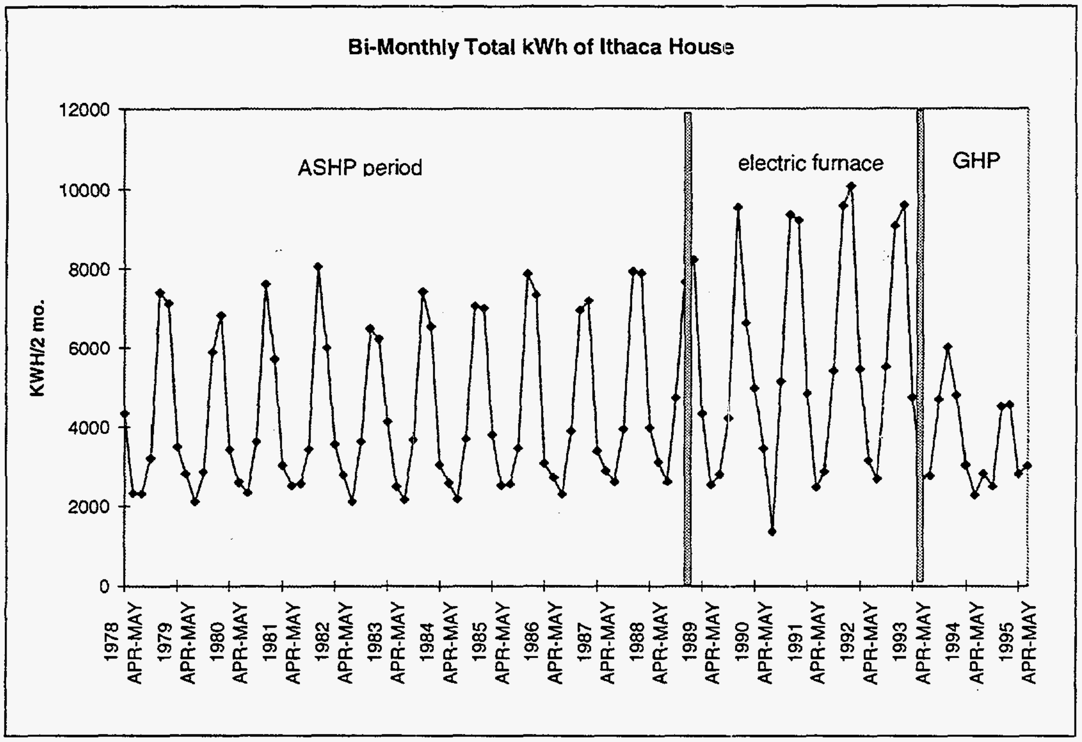


Figure 15. NY-Hyde Park House: Electricity Use

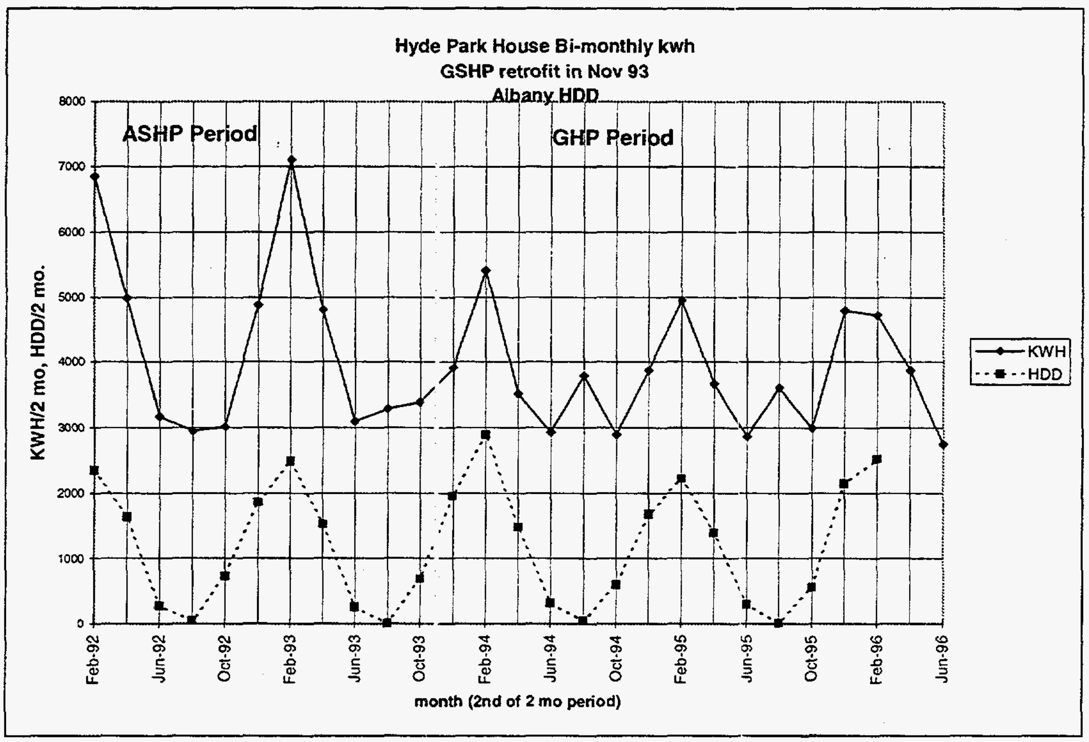


Figure 16. NY-Ithaca House: Energy vs HDD

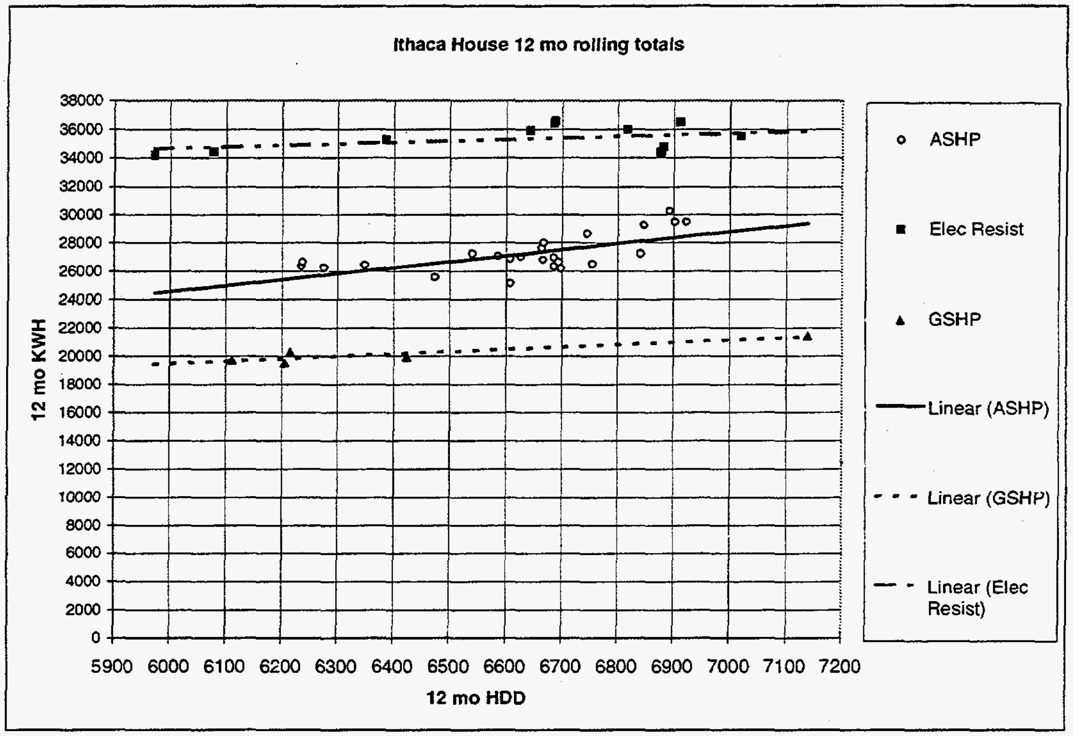
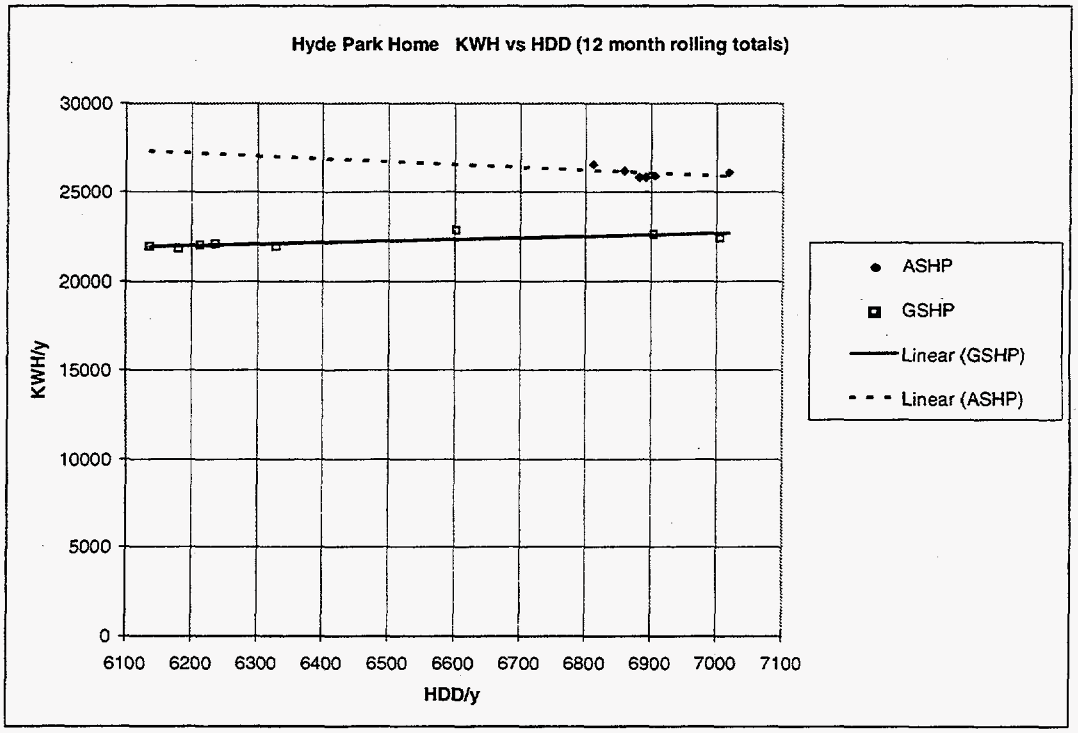


Figure 17. NY-Hyde Park House: Energy vs HDD



D. *Fort Hood, TX*

1. Contact

William Sullivan, Sandia National Labs, Dept 6111/MS1033, Albuquerque NM 87185; phone 505-844-3354; email wnsulli@somnet.sandia.gov

2. Data

Two duplexes (Unit 6 & 7) at Fort Hood in Texas were monitored. Each duplex consists of two identical homes--one has GHP, the other has a gas furnace and electric AC. Both homes have gas hot water. HVAC electricity consumption and monthly HVAC equipment duty cycle was monitored from February '95 to February '96. No whole house data was collected.

We have no information about the occupant behavior (setpoints, number of people, etc.), characteristics of homes (age, floor area, UA values, etc.), or date of GHP installation.

Monitoring may be ongoing and may be available for more units at this site.

3. Results/Analysis

Average summertime (May-Sept.) HVAC electricity consumption for GHP homes was 2634 kWh. Average summertime (May-Sept.) HVAC electricity consumption for electric AC homes was 4604 kWh, for an average summer HVAC energy savings of 43%.

From the plots of monthly duty cycle of the gas furnaces and the fact that the gas furnaces are 75,000 Btu/hr input (Sullivan) we estimated annual gas use for Units 6 and 7 of 35 and 45 million Btu/yr., respectively. Using a conversion of 10,000 Btu = 1 kWh we calculated total HVAC energy for the controls and found that on average the GHP homes used 20% *more* energy than the controls.

Table 5. TX-Ft. Hood Data

Annual HVAC energy savings for Fort Hood TX Units 6 and 7					
	Controls			GSHP	
Monthly Gas Duty Cycle (%)	Unit 6	Unit 7		Unit 6	Unit 7
(estimated from duty cycle plots)					
Feb-95	9	14.5			
Mar-95	8.5	12.5			
Apr-95	4	9.5			
May-Sept	0	0			
Oct-95	1	3.5			
Nov-95	10.3	11			
Dec-95	16	14			
Jan-96	16	20.2			
Feb-96	9.5	9.5			
Annual Duty (%)	5.42	6.89			
(averaging the two Febs)					
Duty Hours/yr	475	604			
Btu/yr	35,614,875	45,278,250			
(furnace=75K Btu/hr input)					
Kwhr/yr for gas*	3,478	4,422			
(source conversion: 10239 Btu=kwh)					
total annual AC or GSHP electricity	5,635	5,846		5,567	3,927
summer electricity (May-Sept)	4,740	4,469		2,839	2,429
(from Annual Performance plots)					
Total HVAC energy (kwh/yr)	3,478	4,422		5,567	3,927
Average	3,950			4,747	
Average Annual HVAC Savings*	-20%				
* does not include furnace fan energy					

E. Selfridge, MI

1. Contact

William Sullivan, Sandia National Labs, Dept 6111/MS1033, Albuquerque NM 87185; phone 505-844-3354; email wnsulli@somnet.sandia.gov

2. Data

HVAC and whole house electricity was monitored in six units in three duplexes from Dec 95 to March 96. Half were converted to GHP, the other half use baseboard resistance heat. All units have electric water heating.

We have no information about the occupant behavior (setpoints, number of people, etc.), characteristics of homes (age, floor area, UA values, etc.), or date of GHP installation.

Monitoring may be ongoing and may be available for more units at this site.

3. Results

Average winter time HVAC energy savings were 34% and average whole house energy savings of 32% were observed. Based on manufacturer information, Sullivan expected HVAC energy savings to be at least 60%. Large duct losses could explain why savings fell short. The fact that the HVAC savings are about the same amount as the whole house savings makes the results a little suspicious, at least for whole house savings. The GHP houses are probably savings energy in other areas besides HVAC so that the true total savings due to the GHP system is probably less than 32%.

Table 6. MI-Selfridge Data

Winter Time HVAC and Whole House Energy Savings for Selfridge							
	GSHP HVAC (kwh)				Conventional HVAC (kwh)		
	Unit 1	Unit 2	Unit 3		Unit 1	Unit 2	Unit 3
Dec-95	1600	1731	1863		2625	3117	2903
Jan-96	1793	1957	2285		2189	3320	2988
Feb-96	1924	1868	2146		2700	3039	2969
Mar-96	1611	1588	1940		2540	2672	2732
Average Winter Time HVAC Energy Savings				**34%**			
	GSHP Whole House (kwh)				Conventional Whole House (kwh)		
	Unit 1	Unit 2	Unit 3		Unit 1	Unit 2	Unit 3
Dec-95	3323	2726	2683		3648	5635	4434
Jan-96	3453	3278	3075		3034	6103	4658
Feb-96	3508	3022	2994		3427	5581	4773
Mar-96	3538	2673	2735		3329	5493	4419
Average Winter Time Whole House Energy Savings				**32%**			

F. Kentucky Utilities

Contact: Jerry Bruce, Kentucky Utilities Company, One Quality Street, Lexington, KY 40507; phone 606-255-2100; fax 606-288-1165.

1. Data

HVAC and whole house electricity use was monitored for 24 homes in the Lexington area from early 1989 to late 1991. 8 homes were GHP, 8 were ASHP, and 8 were gas furnace with AC. Total gas consumption for the Gas/AC homes was also monitored.

Houses were selected for this study because they were similar in terms of size, type of occupants, and age (built in the 1980's). Data was given to us for each house on: floor area, year built, ceiling R-value, wall R-value, floor type and window type.

The GHPs were all installed when the houses were constructed: between 1986 and 1988.

2. Analysis

For each house, we aggregated the monthly total kWh and HVAC kWh for 1990 to get annual total and HVAC kWh. For the gas houses, we aggregated 1990 Gas MCF, converted this using a source conversion (100 kWh/MCF), and added it to total kWh. Since gas could be used for cooking and water heating, we cannot determine total HVAC energy for the Gas/AC houses, only total energy. For a few houses, monthly data was not available for a month or two due to equipment malfunction. In those cases, we extrapolated from results of adjacent months or annual average.

3. Results

The GHP homes saved an average of 49% of HVAC energy compared to the ASHP homes and an average of 36% of whole house energy. The GHP homes also saved an average of 26% of whole house energy compared to Gas/AC homes.

Comparing the three groups on total 1990 whole house energy bills, the GHP homes saved 32% compared to the ASHP homes and 36% compared to the Gas/AC homes. Electricity rates for the GHP and ASHP homes were approximately 4 cents/kWh while the rates for the Gas/AC homes were approximately 5 cents/kWh for electricity and 50 cents/therm for natural gas (communication with J. Bruce).

Table 7. KY-Kentucky Utilities Data

Kentucky Utility GSHP homes vs ASHP and Gas/AC homes (1990 data)							
GSHP #	whole house (kwh/y)	heat pump (kwh/y)		ASHP#	whole house (kwh/y)	heat pump (kwh/y)	
1	18,692	7,476		1	50,004	27,392	
2	13,621	6,422		2	22,319	11,283	
3	18,336	9,954		3	29,509	12,793	
4	14,711	5,257		4	27,339	14,946	
5	19,490	7,058		5	19,343	7,309	
6	11,935	6,069		6	29,492	14,799	
7	29,964	11,184		7	28,401	15,160	
8	25,326	7,002		8	32,195	15,113	
average	19,009	7,553		average	29,825	14,849	
since gas could be for cooking and water heating, we cannot determine HVAC energy, only whole house energy.							
Gas/AC #	whouse kwh	HVAC kwh	Gas MCF	kwh/MCF	Gas kwh	whole house kwh (effective)	
1	13,745	5,238	142	100	14,230	27,975	
2	14,260	6,521	130	100	13,040	27,300	
3	14,655	4,044	89	100	8,900	23,555	
4	6,411	1,759	72	100	7,240	13,651	
5	9,897	2,911	67	100	6,659	16,556	
6	8,781	2,103	97	100	9,727	18,508	
7	15,535	7,822	194	100	19,440	34,975	
8	26,344	8,741	156	100	15,617	41,961	
average						25,560	
		HVAC Energy Savings		Whole House Savings			S Savings
GSHP vs ASHP		49%		36%			32%
GSHP vs Gas/AC				26%			36%

G. Pontotoc, MS

1. Contact

George Stegall, Pontotoc Electric Power Association, PO Box 718, Pontotoc, MS 38863, phone: 601-489-3211.

2. Data

Monthly total electricity data has been continuously collected for 4 GHP homes and 3 ASHP homes since they were retrofitted with the systems in 1992 (mid '92 to mid '96).

The building data available is floor area, number of occupants, the number of stories, and slab versus conventional (?) floor.

Data is available on GHP manufacturer, model #, size, and date of installation.

3. Analysis

Since monitoring periods were slightly different, total kWh during the period (about 4 years) was summed and normalized to a yearly average.

4. Results

The 4 GHP homes saved about 27% of total energy compared to the 3 ASHP homes on a kWh/ft2/occupant basis. However, one of the ASHP homes appears to use about 3 times the energy of any other home. According to our contact, the setpoints for this house are extremely hot in the winter and extremely cold in the summer. If we exclude this house from the analysis then the GHP homes used about the same total energy as the ASHP homes.

Table 8. MS-Pontotoc Data

Pontotoc Electric Power Association											
GSHP vs ASHP homes Total Energy Consumption											
Unit #	Type	installed	floor area ft2	occupants	start date	end date	days	kwh	kwh/yr	kwh/yr-ft2	kwh/y-ft-occupant
1	GSHP	1992	1596	4	9/2/92	7/16/96	1413	21420	5533	3.5	0.87
2	GSHP	1992	1759	3	9/1/92	6/13/96	1381	15626	4130	2.3	0.78
3	ASHP	1992	2044	3	8/19/92	6/19/96	1400	22865	5961	2.9	0.97
4	GSHP	1992	2490	5	10/19/92	6/10/96	1330	30618	8403	3.4	0.67
5	ASHP	1992	2034	6	7/3/92	7/17/96	1475	76064	18823	9.3	1.54
6	GSHP	1992	1876	2	9/4/92	7/1/96	1396	20482	5355	2.9	1.43
7	ASHP	1992	1615	4	6/23/92	6/24/96	1462	20482	5113	3.2	0.79
GSHP average			1930	3.5	9/14/92	6/25/96	1380	22037	5855	3.0	0.86
ASHP average			1898	4.3	7/15/92	6/30/96	1446	39804	9966	5.1	1.18
ASHP #3, 7 only			1830	3.5	7/21/92	6/21/96	1431	21674	5537	3.0	0.87
Average Savings										41%	27%
Average Savings										1%	1%
without unit #5											

H. Virginia Power, VA

1. Contact

Richard Jainchell, Virginia Power; phone: 804-775-5547; fax: 804-771-6300

2. Data

90 GHP were installed in homes as part of VA Power's New Technologies Pilot. The only information we have received is an excerpt from a Final Report. The excerpt contains summary data on 18 GHP homes monitored from June 95 to March 96 and an unspecified number of control homes. According to our contact, the control homes were built in 1991 with ASHPs having SEER of 8.7. The GHP homes were built in 1995. The measured GHP COPs range from 3.2 to 5.0.

According to our contact, a disk with more complete monitoring information on a larger sample of GHP homes was sent to the Geothermal Heat Pump Consortium, but no one that we spoke to at the Consortium was familiar with this data.

3. Results

According to the report, average summer and winter HVAC energy use for the GHP and control homes were normalized according to average floor area and compared. The savings were 7.1% in summer, 34.4% in winter, and 27.4% annually. According to the report, this is within the range of the manufacturer's claim of 25% to 40% reduction in energy costs.

I. CREC, OK

1. Contact

Randy Jarvis, Marketing Department, Central Rural Electric Cooperative, POB 1809, Stillwater, OK 74076, ph: 405-372-2884, fx: 405-372-8559.

2. Data

Dozens of homes in the CREC service territory have been built with or retrofitted with GHPs. Randy Jarvis was kind enough to provide us with monthly billing data for 3 homes built with GHPs and 3 that were retrofitted. These houses were previously selected by CREC for other work and do not necessarily constitute a random or representative sample.

3. Analysis

Pre- and post-retrofit whole house energy use was compared for the 3 retrofit houses. Given the data quality and the fact that monitoring was conducted over a relatively long period of time, the data was not weather normalized.

4. Results

Two of the houses showed significant savings (34% savings over electric, and 22% savings over ASHP, while the 3rd house showed little difference (4% savings over ASHP). Results are summarized in the table below.

Table 9 OK-CREC Data

Oklahoma GHP houses			
	House #1	House #2	House #3
floor area (ft2)	1725	1643	2593
GHP installed	1993	1995	1989
pre-retrofit system	ASHP	ASHP	elec. furnace
pre-retro monitoring period	jan 90 - dec 92	aug 92 - Mar 95	may 87 - may 89
GHP monitor period	jan 93 - july 96	May 96 - july 96	jun 89 - july 96
old total kWh/y	28608	26664	44628
GHP total kWh/y	27516	20832	29280
total savings	4%	22%	34%
conventional kWh/yr.-ft2	17	16	17
GHP kWh/yr.-ft2	16	13	11
House Data		fireplace not used, all electric	built in 70's, same occupants before and after, many occupants in summer, poor attic insul, fireplace not for heating

J. Ft. Polk, LA

1. Contact

Patrick Hughes and John Shonder, Oak Ridge National Laboratory.

2. Data

In 1995 and 1996 the space conditioning systems of 4,003 military family housing units at Ft. Polk, Louisiana were converted to GHPs under an energy savings performance contract. At the same time, other efficiency measures, such as compact fluorescent lights, low-flow shower heads, ant attic insulation, were installed.

Pre- and post-retrofit electricity usage was monitored at the feeder level, with each feeder supply electricity to between 6 and 1220 housing units. Some feeders supplied units that were all electric, with

ASHP systems, while other feeder supplied units that used gas furnaces, gas water heaters and standard air conditioning systems (gas use for other appliances was negligible). All of the units were converted to GHP space conditioning and electric water heating with 75% of the units also receiving desuperheaters. Pre-retrofit natural gas usage was derived from billing data. There was no natural gas usage after retrofitting.

3. Results

As Table 10 shows, the ASHP retrofits saved about 35% of whole house energy and the Gas/AC retrofits saved about 30%. Natural gas consumption was converted to kWh units using a "source energy" conversion of 10,000 Btu per kWh. Since other energy saving measures were installed at the same time as the GHPs, the energy savings between pre- and post-retrofit cannot be attributed to the GHPs alone. On the other hand, there is anecdotal evidence that suggests that some of the true savings due to GHPs may have been "taken back" in higher levels of service through the addition of ceiling fans (personal communication with Lew Pratsch). Overall, we suspect that the true savings due to GHPs alone is less than the amounts indicated by the results presented here.

Table 10. Ft. Polk Data

Feeder Number	Pre-Retrofit	Post Retrofit	% savings		
	kWh/y	kWh/y		no. units	total sq. ft.
ASHP Houses					
1	2,873,818	2,008,532	30%	200	231,248
2	27,722,779	19,047,205	31%	1220	1,741,947
3	1,273,006	971,875	24%	40	74,966
6	1,551,444	999,222	36%	80	108,768
7	13,921,102	6,169,796	56%	571	907,593
15	4,132,427	2,669,872	35%	200	276,794
16	6,111,433	4,755,023	22%	306	387,846
17	4,015,635	3,032,894	24%	275	351,873
18	3,393,136	2,354,659	31%	168	232,519
19	3,693,865	2,570,669	30%	181	252,110
ASHP Total	68,688,645	44,579,747	35.1%	3241	4,565,664
Gas/AC Houses					
4	170,119	176,779	-4%	6	12,004
5	2,134,857	2,125,661	0%	100	149,480
11	2,284,612	1,910,931	16%	152	212,170
12	2,008,792	1,670,374	17%	142	184,992
13	2,214,590	1,848,926	17%	162	202,168
14	2,530,362	2,085,527	18%	200	250,134
Gas/AC Total w/o gas	11,343,332	9,818,198	13.4%	762	1,010,948
Pre-retrofit gas use:					
in therms =	260,000				
in kWh =	2,600,000	(using 10,000 Btu = 1 kWh = 0.1 therm)			
Gas/AC Total w/ gas	13,943,332	9,818,198	29.6%		
ASHP+Gas/AC Total	82,631,977	54,397,945	34.2%	4003	
	Whole House Energy Use				
	per house	per square foot			
ASHP Controls					
pre-retrofit	21,194	15			
post-retrofit	13,755	10			
Gas Controls					
pre-retrofit	18,298	14			
post retrofit	12,885	10			