RESIDENTIAL GAS HEAT PUMP ASSESSMENT: A MARKET-BASED APPROACH

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ABSTRACT

There has been considerable activity in recent years to develop technologies that could reduce or levelize residential and light-commercial building space cooling electrical use and heating/cooling energy use. For example, variable- or multispeed electric heat pumps, electric ground-source heat pumps, dual-fuel heat pumps, multifunction heat pumps, and electric cool storage concepts have been developed; and several types of gas heat pumps are emerging. A residential gas heat pump (GHP) benefits assessment is performed to assist gas utility and equipment manufacturer decision making on the level of commitment they should make to this technology. The methodology and generic types of results that can be generated are described. National market share is estimated using a market segmentation approach. The assessment design requires dividing the 334 Metropolitan Statistical Areas (MSAs) of the United States into 42 market segments of relatively homogeneous weather and gas/electric rates (14 climate groupings by 3 rate groupings). Gas and electric rates for each MSA are evaluated to arrive at population-weighted rates for the market segments. GHPs are competed against 14 conventional equipment options in each homogeneous segment.

INTRODUCTION

As part of its ongoing R&D planning activity, the U.S. Department of Energy (DOE) performs market assessments of advanced heating/cooling equipment technologies. Since residential heating/cooling technology assessments are a recurring need, a research investigation was undertaken to develop an improved methodology for estimating the benefits of advanced heating/cooling technologies. The objective of the market assessment methodology is to determine realistic relationships between price point and U.S. domestic shipments, as well as project shipments and energy, environmental, and economic impacts for the period 1996 to 2010. The methodology builds on previous work (Hughes et al. 1979) and is applied to the case of GHPs in residential applications.

METHODOLOGY

The objective of this assessment is to estimate the potential benefits of GHPs expected to be commercially available by 1996. The cumulative potential benefits from 1996 to a horizon year of 2010 are estimated. The base technologies for the analysis are conventional classes of equipment already in the market and expected to be competing in the same market segments as the emerging GHPs in the 1996-2010 time frame. Benefits of GHPs occur in proportion to the cumulative 1996-2010 market share they can be expected to obtain when competing against the base technologies. The total available market equals the projected shipments of base technologies from 1996-2010.

GHP national market share is estimated using a market segmentation approach. For each market segment, simple payback is used as a pass/fail indicator. "Pass" means GHPs captured the entire segment, while "fail" means GHPs captured none of it.

Market segments are defined so that customers in a segment experience similar simple paybacks and therefore can be treated as a group. The most important segmentation parameters are those having the greatest impact on simple payback. Then realistic variation within these parameters is considered without dividing the available market into an unmanageable number of segments.

This analysis found that the most important segmentation parameters for residential heating/cooling equipment market analyses are as follows:

1. **Rates.** Relative gas/electric rates are most important because of the variability of rates among utilities, the prevalence of special electric rates for all-electric or electric space heating customers, and the strong influence that special rates have on end user cost and payback when comparing heating/cooling systems that primarily use gas to those that primarily use electricity.
2. **Heating/cooling equipment characteristics.** The types and efficiency levels of the base heating/cooling technologies have a very strong influence on end user cost and payback

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3. **Location.** The heating/cooling loads of residences tend to be heavily weather-influenced, and as a result, location also has a strong influence on end user cost and payback.
4. **Building characteristics**. Appropriate regional selection of insulation levels, glazing, infiltration mitigation features, and basement/crawlspace/slab options to the basic wood frame design adequately captures the important housing characteristics that influence representative heating/cooling requirements.
5. **Building type**. Residences can be single-family, mobile homes, or multi-family, but the mid- and premium ends of the residential market where GHPs will be introduced are primarily single-family, which is assumed in this study.

Based on this ranking, the market segments are developed while treating candidate segmentation parameters in order of importance. The selected assessment design is based on a previous 14-climate agglomeration of the largest population centers of the United States (Andersson 1985). The 14 regions and the base cities for each region identified as having the most representative weather (compared to the population-weighted average) are used directly from this previous study. The large number of climates results from the high ranking of this segmentation parameter.

Population centers in each climate are further divided into three groups based on favorable to gas (G), neutral (N), or favorable to electricity (E) relative pricing of gas versus electricity for residential heating/cooling. The very high number of gas/electric rate cells ($3 \times 14 = 42$) stems from the primary importance of this segmentation parameter.

The base systems used in this study are defined below:

new	=	new construction
rep	=	heating/cooling equipment replacements
EHP	=	electric air-source heat pump with electric resistance backup
GF	=	gas warm-air furnace
AC	=	central air conditioner
GSHP	=	electric ground-source heat pump with electric resistance backup
OF	=	oil warm-air furnace
SEER	=	seasonal energy efficiency ratio (the standard cooling performance factor for electric vapor compression cooling equipment)
AFUE	=	annual fuel utilization efficiency (the standard heating performance factor for gas or oil furnaces)

Then, the 14 base cases are

new:	EHP2 — SEER = 12
new:	EHP3 — SEER = 15
new:	GF2/AC2 — AFUE = 80%, SEER = 12
new:	GF2/EHP1 — AFUE = 80%, SEER = 10
new:	GF3/AC2 — AFUE = 90%, SEER = 12
new:	GF3/AC3 — AFUE = 90%, SEER = 15
new:	GSHP — SEER = 15
rep:	EHP>>EHP2 — SEER = 12
rep:	EHP>>EHP3 — SEER = 15
rep:	GF or GFAC>>GF2/AC2 — AFUE = 80%, SEER = 12
rep:	GF or GFAC>>GF2/EHP1 — AFUE = 80%, SEER = 10
rep:	GF or GFAC>>GF3/AC2 — AFUE = 90%, SEER = 12
rep:	GF or GFAC>>GF3/AC3 — AFUE = 90%, SEER = 15
rep:	OF or OFAC>>OF2/AC2 — AFUE = 80%, SEER = 12

Oil furnaces, ground-source heat pumps, and dual-fuel (or add-on) heat pumps (GF2/EHP1) are only considered in some regions. Other base systems are considered in all regions. The good/better/best cooling efficiency levels for electric vapor compression devices are assumed to be SEERs of 10, 12, and 15. The better/best efficiency levels for gas warm air furnaces are assumed to be AFUEs of 80% and 90%. In general, the 10 SEER equipment is not included in the analysis, because GHPs are not expected to be competitive in the low efficiency, low price end of the market within the study horizon. The 10 SEER efficiency level is selected for the dual-fuel heat pump because with this system, it is common practice to select a low-efficiency heat pump to maintain price competitiveness of the overall system. The very detailed base system segmentation is a reflection of the relative importance of this segmentation parameter.

Wood frame construction is assumed because it is the dominant construction type in the target mid-to-premium single family market throughout the United States (American Housing Survey 1987, NAHB 1981). Appropriate regional selection of insulation levels, glazing, infiltration mitigation features, and basement/crawlspace/slab options to the basic wood frame design adequately capture the important housing characteristics that influence representative heating/cooling requirements. The low number of housing characteristic segments reflects the relatively low importance of this segmentation parameter. No special segmentation is performed for building type.

REGIONS AND REFERENCE CITIES

Previous work agglomerated the 125 largest Metropolitan Statistical Areas (MSAs) into 14 climates and identified representative base cities for each (Andersson 1985). For this study, the remaining MSAs (any urban area of 50,000 people or more) are also assigned to the regions. Each MSA is assigned to the region where bin analysis (ARI Standard 210/240-89), using base city and MSA bin temperature data, resulted in the closest agreement between base city and MSA estimates of annual kWh consumption of a nominal SEER 12 air-source electric heat pump (EHP). The 334 MSAs considered represent about 80% of the U.S. population (Department of Commerce 1990) and represent even a larger percentage of the population having both natural gas and electricity available for residential heating/cooling. The regions and the representative cities are shown in Table 1 and Figure 1.

The region numbers, names, and representative cities established in the previous work are adopted here (Andersson 1985). Originally, the regions were numbered in order of population, but due to the assignment of the remaining MSAs, this is no longer the case. For the equipment analysis, WYEC bin temperature data are used where available (ASHRAE 1990), and data from nearby military air bases are used in the remaining locations (AFM88-29).

REFERENCE BUILDINGS AND LOADS

Four generic housing designs (one-story ranch, two-story, split-level, two-story townhouse) have been found to represent over 90% of all new single-family construction in the United States (NAHB 1981), and these designs are described in detail elsewhere (Huang 1987). The two-story design was selected for this study because, for a given floor space, there is less envelope area and lower heating/cooling energy requirements than with the other detached configurations making the assessment of GHPs conservative. This configuration is also believed to be the most common in the mid-to-premium end of the market where floor space is greater. The building characteristics assumed for the 2240 ft^2 two-story in the 14 regions are summarized in Table 2.

The glazing levels are selected to meet the requirements of the second public review draft of a proposed residential new construction standard (BSR/ASHRAE Standard 90.2P). A computer program (ZIP v2.0) developed by the National Institute of Standards and Technology (NIST 1991) is used to estimate the economic insulation levels for the roof, walls, and floor. These insulation levels are influenced by the cost of energy, the existing insulation levels (if weatherization of an existing home is being considered), and the type and efficiency level of the heating/cooling equipment. ZIP runs are made for a variety of assumptions (new vs. existing homes, GFAC vs. EHP equipment) and intermediate insulation levels are selected.

Hourly simulations of the buildings in each representative city using DOE-2 (LBL 1984) are not necessary for this study because the required simulations were previously completed at Lawrence Berkeley Laboratory and simplified via regression analysis into algebraic representations contained in a computer program, PEAR v2.1 (LBL 1987). PEAR is based on thousands of DOE-2 runs and is accurate within 1% of DOE-2 for annual heating load and within 10% for annual cooling load (cooling magnitudes are smaller, and absolute errors are similar to those for heating). PEAR is used to estimate annual heating and cooling loads that need to be met by heating/cooling equipment after internal gains, solar gains, and thermal mass and ground contact effects are taken into consideration (see Table 3). The assumptions built into PEAR are explained in detail in Huang et al. (1987).

Standard methods are used to estimate the design heating and cooling loads at 97.5% and 2.5% outdoor design conditions, respectively (Manual J, 7th ed.). These results are also summarized in Table 3.

EQUIPMENT MODELS

Standard methods (Manual S) are used to size equipment to the design loads, and the sizing results for equipment

TABLE 1
Regions and Representative Cities

Region	City	Population of MSAs	Weather Data
1. Great Lakes	Detroit	39,326,900	ASHRAE WYEC
2. Northeast	New York	41,991,400	ASHRAE WYEC
3. S. California	Los Angeles	16,483,200	ASHRAE WYEC
4. Upper South	Atlanta	18,727,600	ASHRAE WYEC
5. Gulf Coast	Houston	12,841,700	AFM88-29(Ellington)
6. Lower South	Dallas	12,367,800	ASHRAE WYEC
7. N. California	San Francisco	6,390,600	AFM88-29(Moffett)
8. Kansas-Kentucky	St. Louis	6,917,200	ASHRAE WYEC
9. Northern Tier	Minneapolis	8,260,100	ASHRAE WYEC
10. Tropics	Miami	6,318,200	ASHRAE WYEC
11. Pacific Northwest	Seattle	4,977,000	ASHRAE WYEC
12. Fresno-El Paso	Fresno	6,203,500	AFM88-29(Merced)
13. Mountains	Denver	5,310,800	ASHRAE WYEC
14. Desert Southwest	Phoenix	3,296,800	ASHRAE WYEC
Total MSA population 1988 estimate		189,412,300	(79% of total population)
Total population 1988 estimate		240,000,000	

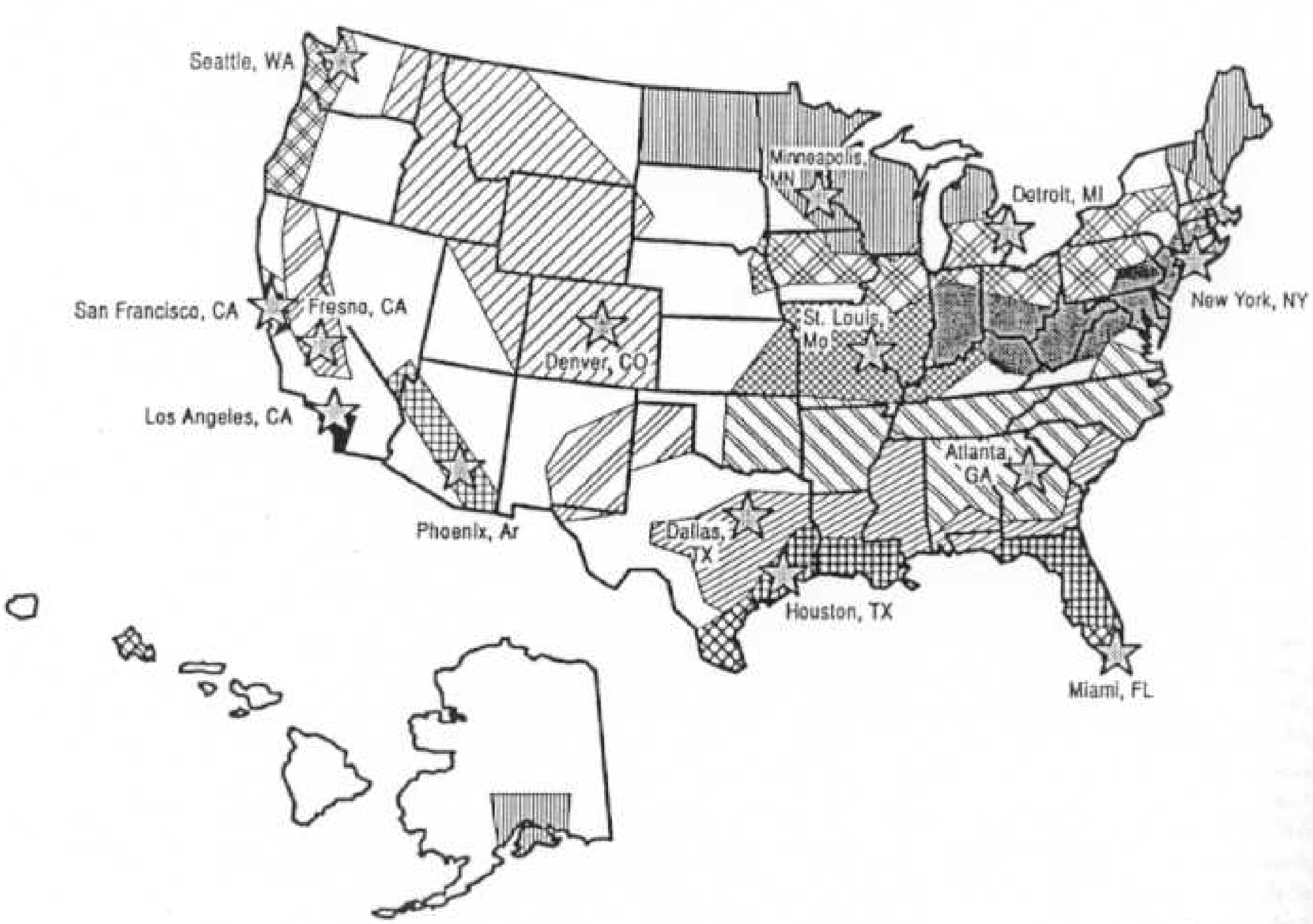

Figure 1 Climate regions and representative cities.

used in each region are summarized in Table 4. Annual bin analysis is used to estimate the quantities of gas and electricity required by the GHP system and the various base systems to meet the loads of Table 3.

The annual bin analysis follows the standard methodology of the Department of Energy seasonal performance rating procedures (e.g., ARI Standard 210/240-89) for systems covered by such standards in all but one important respect. The DOE rating procedure assumes that the house balance point (average heating load above this temperature equals zero) is 65°F, the average heating load at the design condition is 0.77 times the design heating load, and average loads for temperature bins between these extremes follow a straight line. The assumption in this study is that average loads fall on a line parallel to the line defined by the following two points: (1) outdoor temperature = indoor heating set point = 70°F, load = 0 Btu/hr, and (2) outdoor temperature = 97.5% heating design condition, load = Manual J heating design load.

The heating load line assumption used in this study results in different allocations of the heating load between temperature bins than the DOE rating procedure, as illustrated in Figure 2. The assumption used here is consistent with field test data indicating that internal gains, solar gains, windspeed, and other variables that impact the average heating load are essentially independent of outdoor dry-bulb temperature (Hughes et al. 1985, 1988). The DOE rating procedure assumes that offsetting loads resulting from these other effects are greater at the colder temperatures. In some locations, the rating procedure assumption allocates more of the annual heating load to moderate temperature bins and less to the cold temperature bins. This type of allocation can have the effect of favoring technologies, such as EHPs that have better performance at moderate conditions. To clarify the average heating load line assumptions of this study, Table 4 indicates the house balance points which resulted in bin analysis annual heating loads that closely matched the PEAR results of Table 3.

Except for the furnaces, the sizes listed in Table 4 are for cooling. It should be understood that EHPs require supplemental backup electric resistance heat in most locations (all but S. California, Tropics, and Desert Southwest), and even here, systems are typically installed with electric resistance heat for emergency use (e.g., compressor failure). GSHP

TABLE 2
Reference Building Characteristics

Region	Glazing	Roof	Walls	Floor
1. Great Lakes	wood, 2p argon	R-30	R-16	bsmnt, R-5, 8 ft
2. Northeast	alum TB, 2p	R-30	R-16	bsmnt, R-5, 8 ft
3. S. California	alum TB, 2p	R-19	R-11	crawl, R-0
4. Upper South	alum TB, 2p	R-22	R-16	crawl, R-11
5. Gulf Coast	alum TB, 2p	R-19	R-11	crawl, R-11
6. Lower South	alum TB, 2p	R-19	R-11	crawl, R-11
7. N. California	alum TB, 2p	R-19	R-11	crawl, R-5
8. Kansas-Kentucky	wood, 2p argon	R-30	R-16	bsmnt, R-5, 8 ft
9. Northern Tier	wood, 2p argon	R-30	R-23	bsmnt, R-10, 8 ft
10. Tropics	alum TB, 1p	R-19	R-11	slab, R-0
11. Pac. Northwest	alum TB, 2p	R-19	R-16	bsmnt, R-5, 8 ft
12. Fresno-El Paso	alum TB, 2p	R-22	R-16	crawl, R-5
13. Mountains	wood, 2p argon	R-30	R-16	bsmnt, R-5, 8 ft
14. Desert S'thwest	alum TB, 2p	R-30	R-16	slab, perim R-5, 4 ft

Key:
wood or alum = window framing material,
1p or 2p = number of panes,
TB = thermal break,
argon = argon gas between the panes,
R = thermal resistance value of the insulation,
basement, crawlspace or slab = type of ground contact,
basement insulation is on the outside wall surface to the depth indicated,
crawlspace insulation is between the floor joist, and
slab insulation is around the perimeter to the width indicated.

TABLE 3
Annual Heating/Cooling Loads

Region	Annual Heating Load (mill Btu)	Annual Cooling Load (mill Btu)	Design Heating Load (kBtuh)	Design Cooling Load (kBtuh)
1. Great Lakes	66.0	8.5	45	23
2. Northeast	53.3	14.6	42	23
3. S. California	14.8	4.4	28	25
4. Upper South	33.6	23.5	35	26
5. Gulf Coast	21.0	55.2	31	30
6. Lower South	28.5	50.5	38	30
7. N. California	33.3	3.8	29	25
8. Kansas-Kentucky	56.9	25.0	45	27
9. Northern Tier	84.6	14.6	51	22
10. Tropics	1.5	101.1	24	29
11. Pac. Northwest	68.5	4.9	34	23
12. Fresno-El Paso	30.7	25.9	32	28
13. Mountains	55.9	8.3	48	26
14. Desert S'thwest	14.1	64.5	26	39

TABLE 4
Equipment Sizing Results

Region	GF/OF Size (kBtuh)	AC Size (RT)*	EHP Size (RT)*	Dual Fuel EHP Size (RT)*	GSHP Size (RT)*	GHP Size (RT)*	Bal Temp (F°)
1. Great Lakes	75	2	2.5	2	2.5	2	55
2. Northeast	75	2	2	2	2	2	55
3. S. California	50	2	2	—	—	2	58
4. Upper South	50	2.5	2.5	2.5	2.5	2.5	58
5. Gulf Coast	50	2.5	2.5	—	2.5	2.5	60
6. Lower South	50	2.5	2.5	2.5	2.5	2.5	58
7. N. California	50	2	2	—	—	2	59
8. Kansas-Kentucky	75	2.5	2.5	2.5	2.5	2.5	57
9. Northern Tier	100	2.5	3	2.5	3	2.5	56
10. Tropics	50	2.5	2.5	—	—	2.5	60
11. Pac. Northwest	75	2	2	—	2	2	55
12. Fresno-El Paso	50	2.5	2.5	—	—	2.5	58
13. Mountains	75	2	2	—	—	2	55
14. Desert S'thwest	50	3	3	—	—	3	58

*RT - nominal cooling capacity in refrigeration tons (1 ton = 12000 Btuh)

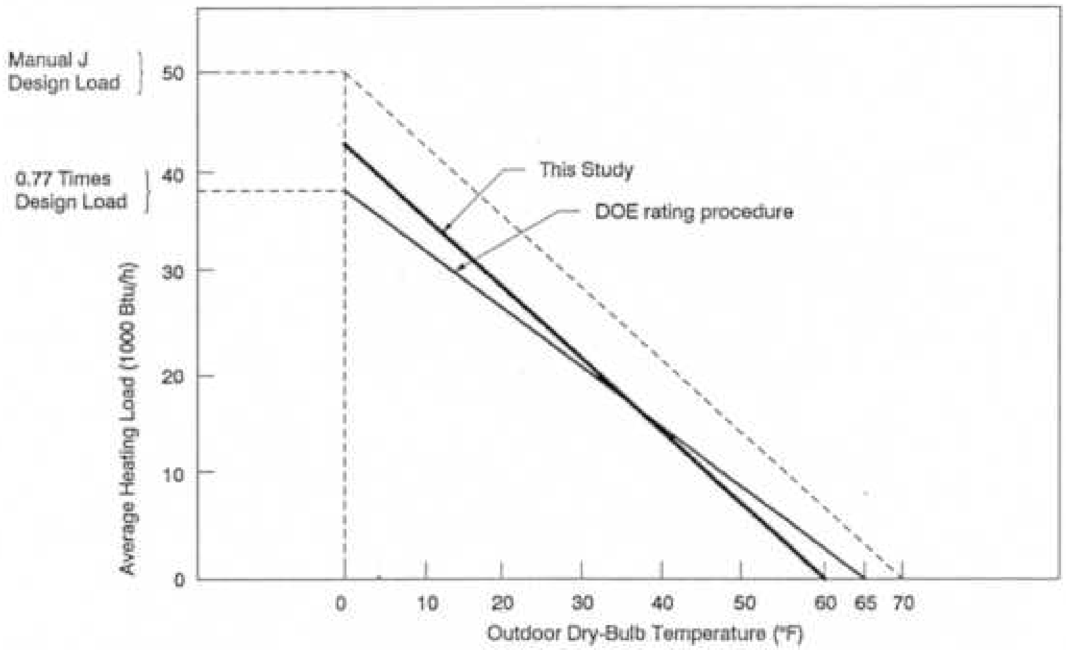

Figure 2 *Average heating load lines for annual bin analysis: This study vs. DOE rating procedure.*

systems eliminate the need for supplemental electric resistance backup heat in more parts of the country, but full emergency backup is still normally installed. It is anticipated that GHPs will require supplemental heat (this time in the form of gas) in only a few of the northern-most regions (Northern Tier, Great Lakes, and Mountains), because heating capacities relative to cooling capacities are greater than with EHPs. In the ground-source configuration (not considered here), GHPs could go without supplemental backup throughout the country. Whether supplemental backup is required or not, early GHP systems may be installed with emergency backup due to the newness of the technology.

Table 5 summarizes the results of the equipment analysis. For the sake of brevity, results are only presented for the four regions with the greatest GHP market potential (based on the assumptions used here). Shown are the estimated winter and summer gas and electric consumptions for heating/cooling. Winter consumption is defined as heating mode consumption as estimated by annual bin analysis. Summer consumption is defined as cooling mode consumption. The fact that some cooling mode energy gets billed under winter rates, and vice versa, was considered and found to be of no consequence to the results.

The equipment analysis included all uses of energy. For example, non-scroll compressor EHP systems in cold climates have crankcase heaters, and GSHP systems have recirculator pumps. Also, GF requires indoor air movement and power-assisted combustion. Several types of GHPs are expected to be commercially available in the 1996 time frame (e.g., engine-driven and absorption). The performance analysis presented is for GHPs as a generic equipment category approximately representative of all varieties. In general, GHPs consume electricity for air movement, power-assisted combustion, and recirculator pumps.

The results of the equipment peak demand analysis are also summarized in Table 5. Electric demand is defined as cooling mode application level peak hour demand per RT (refrigeration ton = 12000 Btu/hr) of installed cooling capac-

TABLE 5
Energy Consumption and Peak Demand Results in the Four Best Regions

	CONSUMPTION					PEAK	
period	season	season	season	season		hour	day
electricity (elec), gas, or oil	elec	elec	gas	gas	oil	elec	gas
winter (W) or summer (S)	W	S	W	S	W	S	W
	(kWh)	(kWh)	(10^6 Btu)	(10^6 Btu)	(10^6 Btu)	(kW per RT)	(10^6 Btu per day)
(a) Great Lakes--Detroit							
new or rep:GHP	1219	258	46.8	10	0	0.4	1.22
new:EHP2	10178	708	0	0	0	1.15	0
new:EHP3	9669	567	0	0	0	1.3	0
new:GF2/AC2	612	708	82.5	0	0	1.15	1.37
new:GF2/EHP1	5140	850	41.3	0	0	1.3	1.37
new:GF3/AC2	795	708	73.3	0	0	1.15	1.22
new:GF3/AC3	795	567	73.3	0	0	1.3	1.22
new:GSHP	6906	567	0	0	0	1	0
rep:EHP•EHP2	10178	708	0	0	0	1.15	0
rep:EHP•EHP3	9669	567	0	0	0	1.3	0
rep:GForGF/AC•GF2/AC2	612	708	82.5	0	0	1.15	1.37
rep:GForGF/AC•GF2/EHP1	5140	850	41.3	0	0	1.3	1.37
rep:GForGF/AC•GF3/AC2	795	708	73.3	0	0	1.15	1.22
rep:GForGF/AC•GF3/AC3	795	567	73.3	0	0	1.3	1.22
rep:OForOF/AC•OF2/AC2	612	708	0	0	82.5	1.15	0
(b) Northeast--New York							
new or rep:GHP	939	442	36	17	0	0.4	0.675
new:EHP2	7437	1217	0	0	0	1.15	0
new:EHP3	6247	973	0	0	0	1.3	0
new:GF2/AC2	494	1217	66.6	0	0	1.15	1.1
new:GF2/EHP1	5117	1460	20	0	0	1.3	1.1
new:GF3/AC2	642	1217	59.2	0	0	1.15	0.975
new:GF3/AC3	642	973	59.2	0	0	1.3	0.975
new:GSHP	5577	973	0	0	0	1	0
rep:EHP•EHP2	7437	1217	0	0	0	1.15	0
rep:EHP•EHP3	6247	973	0	0	0	1.3	0
rep:GForGF/AC•GF2/AC2	494	1217	66.6	0	0	1.15	1.1
rep:GForGF/AC•GF2/EHP1	5117	1460	20	0	0	1.3	1.1
rep:GForGF/AC•GF3/AC2	642	1217	59.2	0	0	1.15	0.975
rep:GForGF/AC•GF3/AC3	642	973	59.2	0	0	1.3	0.975
rep:OForOF/AC•OF2/AC2	494	1217	0	0	66.6	1.15	0

TABLE 5 (Cont'd)
Energy Consumption and Peak Demand Results in the Four Best Regions

(c) Kansas/Kentucky--St. Louis							
new or rep:GHP	1042	802	40	29	0	0.4	0.84
new:EHP2	7939	2083	0	0	0	1.15	0
new:EHP3	7248	1667	0	0	0	1.3	0
new:GF2/AC2	528	2083	71.1	0	0	1.15	1.26
new:GF2/EHP1	5110	2500	24.9	0	0	1.3	1.26
new:GF3/AC2	686	2083	63.2	0	0	1.15	1.12
new:GF3/AC3	686	1667	63.2	0	0	1.3	1.12
new:GSHP	5749	1667	0	0	0	1	0
rep:EHP»EHP2	7939	2083	0	0	0	1.15	0
rep:EHP»EHP3	7248	1667	0	0	0	1.3	0
rep:GForGF/AC»GF2/AC2	528	2083	71.1	0	0	1.15	1.26
rep:GForGF/AC»GF2/EHP1	5110	2500	24.9	0	0	1.3	1.26
rep:GForGF/AC»GF3/AC2	686	2083	63.2	0	0	1.15	1.12
rep:GForGF/AC»GF3/AC3	686	1667	63.2	0	0	1.3	1.12
rep:OForOF/AC»OF2/AC2	528	2083	0	0	71.1	1.15	0
(d) Northern Tier--Minneapolis							
new or rep:GHP	1604	456	63	17	0	0.4	1.3
new:EHP2	14581	1217	0	0	0	1.15	0
new:EHP3	13771	973	0	0	0	1.3	0
new:GF2/AC2	588	1217	105.8	0	0	1.15	1.46
new:GF2/EHP1	6491	1460	52.9	0	0	1.3	1.46
new:GF3/AC2	764	1217	94	0	0	1.15	1.3
new:GF3/AC3	764	973	94	0	0	1.3	1.3
new:GSHP	8853	973	0	0	0	1	0
rep:EHP»EHP2	14581	1217	0	0	0	1.15	0
rep:EHP»EHP3	13771	973	0	0	0	1.3	0
rep:GForGF/AC»GF2/AC2	588	1217	105.8	0	0	1.15	1.46
rep:GForGF/AC»GF2/EHP1	6491	1460	52.9	0	0	1.3	1.46
rep:GForGF/AC»GF3/AC2	764	1217	94	0	0	1.15	1.3
rep:GForGF/AC»GF3/AC3	764	973	94	0	0	1.3	1.3
rep:OForOF/AC»OF2/AC2	588	1217	0	0	105.8	1.15	0

ity. Cooling application level peaks are often nearly coincident with summer electric utility system peaks. Gas demand is defined as 10^6 Btu per winter peak day at the application level. Summer electric peaks and winter gas peaks are of greatest concern to the majority of electric and gas utilities in the four best regions.

GAS/ELECTRIC RATE CELL ANALYSIS

Actual gas (AGA 1991) and electric (CSA 1991; direct utility contact) utility general service rate schedules are used to derive incremental rates for heating/cooling energy by season (winter, summer). The incremental rates are determined by taking the difference between operating costs (i.e.,utility bills) with and without the HVAC system, and dividing the cost difference by the HVAC system energy use. The resulting incremental rate was the effective cost of energy ($/kWh or $/$10^6$ Btu) to heat and cool the building, inclusive of all rate schedule cost components (energy, block sizes, surcharges).

The incremental rates are derived for gas and electricity in each MSA. The rates are used to determine the difference in annual operating costs between the most common conventional gas/electric and all-electric HVAC systems. All the MSAs in a region are ranked by this operating cost difference. The MSAs are then divided into three groups: favorable to gas (G), favorable to electric (E), and neutral (N). The groups are selected using a population guideline, i.e., 25% of the MSA population in a region in (G), 25% in (E), and 50% in (N). Significant deviations from the guideline can occur for practical reasons (e.g., Northern California had only one utility, so all MSAs are in N).

Finally, the regional average incremental rates are determined by calculating the population-weighted average across MSAs in each group (G, N, E) in each region. The weighted-average incremental rates are determined by group (G, N, E), fuel type (gas, electric), and season (winter, summer). This process is repeated for each heating/cooling system type using the same MSA groups (G, N, E). For this residential analysis, GHP has the same incremental electric and gas rates as furnace/air conditioners, and the all-electric options all have the same rates. The results of the gas/electric rates analysis are summarized in Table 6. For this study, GHP summer gas rates are assumed to equal winter gas rates. Several gas utilities offer discounted summer gas rates (AGA 1991), but these are not considered so that conservative GHP technology impacts could be estimated.

COST AND SIMPLE PAYBACK ANALYSIS

Annual operating cost is estimated from the seasonal energy consumption values of Table 5 and the marginal seasonal gas/electric rates of Table 6. Winter operating cost is estimated as the product of heating mode consumption times the winter marginal rate. Summer operating cost is estimated

TABLE 6
Marginal Seasonal Heating/Cooling Rates by System, Fuel, and Rate Cell in 1991

Systems key:
EHP = electric air-source heat pump
GF/AC = gas furnace and central air-conditioner
OF/AC = oil furnace and central air-conditioner
GSHP = electric ground-source heat pump
GF/EHP = dual-fuel heat pump (gas furnace and electric air-source heat pump)
GHP = gas air-source heat pump

Rate cell key:
G = favorable to gas
N = neutral
E = favorable to electric

Systems:	EHP -- -- GSHP GF/EHP --	EHP -- -- GSHP GF/EHP --	-- GF/AC OF/AC -- -- GHP	-- GF/AC OF/AC -- -- GHP	-- GF/AC -- -- GF/EHP GHP	-- -- -- -- -- GHP
Fuel:	elec	elec	elec	elec	gas	gas
Season:	W	S	W	S	W	S
Rate Cell	($/kWh)	($/kWh)	($/kWh)	($/kWh)	($/10⁶ Btu)	($/10⁶ Btu)
Gr. Lakes-G	.096	.112	.104	.106	4.88	4.88
Gr. Lakes-N	.067	.099	.068	.100	5.27	5.27
Gr. Lakes-E	.060	.091	.070	.082	5.42	5.42
Northeast-G	.134	.190	.178	.192	6.43	6.43
Northeast-N	.065	.101	.093	.100	6.33	6.33
Northeast-E	.032	.047	.066	.059	4.98	4.98
S. Cal-G	.129	.129	.129	.129	4.55	4.55
S. Cal-N	.104	.107	.107	.107	4.54	4.54
S. Cal-E	.128	.128	.128	.128	6.64	6.64
U. South-G	.078	.083	.077	.083	5.07	5.07
U. South-N	.056	.078	.071	.075	5.03	5.03
U. South-E	.051	.072	.075	.072	5.64	5.64
G. Coast-G	.138	.137	.135	.136	5.15	5.15
G. Coast-N	.063	.078	.079	.078	5.09	5.09
G. Coast-E	.053	.070	.089	.084	4.61	4.61
L. South-G	.060	.073	.057	.071	4.72	4.72
L. South-N	.046	.066	.072	.066	5.22	5.22
L. South-E	.031	.052	.054	.051	5.45	5.45
N. Cal-G	--	--	--	--	--	--
N. Cal-N	.142	.142	.142	.142	7.11	7.11
N. Cal-E	--	--	--	--	--	--

TABLE 6 (Cont'd)
Marginal Seasonal Heating/Cooling Rates by System, Fuel, and Rate Cell in 1991

Systems:	EHP -- -- GSHP GF/EHP --	EHP -- -- GSHP GF/EHP --	-- GF/AC OF/AC -- -- GHP	-- GF/AC OF/AC -- -- GHP	-- GF/AC -- -- GF/EHP GHP	-- -- -- -- -- GHP
Fuel:	elec	elec	elec	elec	gas	gas
Season:	W	S	W	S	W	S
	($/kWh)	($/kWh)	($/kWh)	($/kWh)	($/10⁶ Btu)	($/10⁶ Btu)
Rate Cell						
KS-KY-G	.077	.094	.077	.095	4.02	4.02
KS-KY-N	.047	.079	.074	.081	4.36	4.36
KS-KY-E	.037	.046	.057	.057	4.68	4.68
N. Tier-G	.089	.086	.092	.090	5.09	5.09
N. Tier-N	.063	.075	.067	.075	5.42	5.42
N. Tier-E	.056	.066	.074	.070	5.03	5.03
Tropics-G	.089	.088	.087	.088	5.76	5.76
Tropics-N	.089	.089	.089	.089	12.41	12.41
Tropics-E	.023	.046	.039	.046	4.95	4.95
Pac. NW-G	.051	.046	.049	.047	5.01	5.01
Pac. NW-N	.051	.042	.048	.042	5.08	5.08
Pac. NW-E	.034	.034	.034	.034	4.85	4.85
Fres-E.P.-G	.142	.142	.142	.142	7.97	7.97
Fres-E.P.-N	.079	.104	.077	.092	6.32	6.32
Fres-E.P.-E	.041	.063	.056	.063	6.49	6.49
Rockies-G	.068	.068	.068	.068	3.41	3.41
Rockies-N	.070	.068	.071	.070	4.52	4.52
Rockies-E	.051	.048	.045	.046	3.82	3.82
Desert SW-G	.089	.139	.089	.131	6.26	6.26
Desert SW-N	.073	.084	.073	.084	6.26	6.26
Desert SW-E	.048	.048	.048	.048	6.26	6.26

as the product of cooling mode consumption times the summer marginal rate. If systems use both gas and electricity, the calculations are repeated for both fuel types. Annual operating cost is estimated as the sum of seasonal values (and sum of fuel values for mixed fuel systems). Heating oil is assumed to cost $1.25 per gallon. Some types of GHPs are expected to have no additional maintenance requirements beyond what is typical for conventional systems. In this generic GHP analysis, no annual maintenance cost adder was considered.

Considerable effort was expended to estimate typical installed costs for GHP and base systems. This task was difficult because actual prices for installed residential heating/cooling systems are negotiated and can vary widely depending on market conditions. The typical manufacturer to distributor to dealer path to market is assumed for all systems. Typical gross margins at each level of the path to market are assumed. Product categories are assumed to have three efficiency tiers (good, better, best) and the higher efficiencies are assumed to command higher gross margins. Regional labor rates and costs for site-applied materials are considered. Standard labor hours for the various installation functions are assumed.

GHP equipment costs are derived from the most recent manufacturing cost estimates by applying gross margins typical for "best" efficiency levels. The manufacturing cost estimates are only available for the 3 RT size, whereas the typical sizes required for most regions in the analysis are 2 or 2.5 RT (see Table 4). Adjustments for size are estimated from experience with conventional equipment.

Job costs to end user (mechanical, electrical, and forced air system) are derived for the GHP system and for each base system in the various new construction and replacement applications. Annual operating costs are estimated for the same cases. Simple payback is estimated as the incremental installed cost of GHP over the alternative divided by the annual operating cost savings of GHP over the alternative. All costs (electricity, gas, equipment, installation) are in 1991 dollars. The analysis assumes these costs remain the same or all escalate at the same rates over the 1996 to 2010 period.

BASELINE MARKET PROJECTIONS

The 1996-2000 market projections for conventional equipment are summarized in Table 7. Projected shipments of conventional equipment represent the available market for GHPs. Actual 1986-1990 unit shipments are provided in the first column of (a) for reference (ARI 1991, Pietsch 1989, The NEWS 1991). Several previous projections are reviewed to establish the 1996-2000 unit shipment projections (Easton 1990, Appliance Magazine 1989, Hiller 1990). Projected unit shipments are converted to projected capacity shipments using a projected regional shipment breakout (Market Tracks, Ltd. 1991) and the typical sizes of Table 4. It was conservatively assumed that the 2001-2005 and 2006-2010 shipments equal the 1996-2000 shipments.

The projected capacity shipments are disaggregated by base system and rate cell within each region using a detailed data base that identifies the location and makeup of the existing stock of residential heating/cooling equipment and that provides the basis for making disaggregated projections (Market Tracks, Ltd. 1991). National totals and totals over the four best regions for the various base systems are provided in Table 7(b).

BENEFITS ASSESSMENT DESIGN

The major products of the benefits assessment are the market potential for GHPs (Figure 3), the potential primary energy savings (Figure 4), and the potential deferred electric generation capacity additions (Figure 5), resulting from GHP deployment. All of these analysis outputs are for the period 1996-2010 and are expressed as a function of simple payback hurdle. These outputs are also expressed as potentials, meaning that segments meeting the payback hurdle are counted in their entirety, and segments not meeting the payback hurdle are not counted at all.

The available market for GHPs equals the projected shipments of base systems. It is assumed here that the available national market at competitive efficiency levels and where gas is available, equals 22.2 million RT over each of three 5-year periods from 1996-2010. For each 5-year period, the available market is disaggregated by region, rate cell, and base system resulting in 588 (14 x 3 x 14) market segments where simple payback calculations are performed.

The energy consumptions of Table 5, the gas/electric rates of Table 6, and the same base system installed costs are used for all three 5-year periods. These assumptions are equivalent to assuming that either all energy and installed costs stay the same, or they inflate at the same rate during the 15-year interval. The only parameter that varies from one 5-year interval to the next is the installed cost of the GHP. At the 3 RT size, it is assumed that the cost to end user for an installed GHP (minus forced air system) is \$6800, \$5000, and \$4000 for the three five-year periods.

Based on recent new technology roll-outs (ground-source heat pumps, variable speed EHPs), \$6800 is a typical price for entry into the premium end of the residential market. It is conservatively assumed here that this GHP pricing will last for 5 years. The next two price points reflect prices that the manufacturing cost studies of the various GHPs predict at higher volumes.

Using these assumptions, four cases are investigated relating to the level of subsidy of the base technologies. The prevalence of discounted winter electric rates for residential electric space heating or all-electric end users is apparent in Table 6. It is also known that many electric utilities have initiated demand-side management (DSM) programs that provide rebates for high-efficiency residential electric heating/cooling systems. Since the magnitude and extent of rebates is unknown, it was treated parametrically. The four cases investigated are (1) \$200 per RT rebate and discounted winter electricity, (2) \$100 per RT rebate and discounted winter electricity, (3) zero rebate and discounted winter electricity, and (4) zero rebate and zero winter electric rate discount.

RESULTS

Market Potential

GHP market potential fraction versus simple payback hurdle is presented in Figure 3. For the assumptions used in this study, nearly 90% of the market potential existed in 4 of the 14 regions (Northeast, Great Lakes, Northern Tier, and Kansas/Kentucky). Consequently study results are expressed only for the four best regions so that the benefits analysis could be more specific. In Figure 3, market potential fraction is defined as the fraction of the four-region market (Table 7—8.4 $\times$ three five-year periods = $25.2(10)^6$ RT from 1996-2010), where GHP meets the payback hurdle relative to the various base technologies.

Note from Figure 3 that the level of base technology subsidy has a large impact on the market potential of GHPs. At a three-year payback, the GHP market potential in the zero subsidy case is approximately double that in the case where base technologies receive \$200 per RT rebates and discounted winter electricity.

TABLE 7
1996-2000 Available Market for GHPs

Systems key:
EHP = electric air-source heat pump
GF/AC = gas furnace and central air-conditioner
OF/AC = oil furnace and central air-conditioner
GSHP = electric ground-source heat pump
GF/EHP = dual-fuel heat pump (gas furnace and electric air-source heat pump)
GHP = gas air-source heat pump

(a) Projected National Unit and Capacity Shipments

	Actual 1986-1990 Shipments (10^3 units/yr)	Projected 1996-2000 Shipments (10^3 units/yr)	Projected 1996-2000 Capacity Shipments: All Capacity Shipped (10^6 RT/5 yr)	Gas Available, Better/Best Efficiency (10^6 RT/5 yr)	By System Type (10^6 RT/5 yr)
AC: all	3066a				
AC: residential	2400b	2600	28.3	14.9	
GF/AC					14.4
OF/AC					0.5
EHP: all	856a				
EHP: residential	790b	1025	11.6	6.7	
EHP					5.3
GF/EHP					1.4
GSHP: all	21c				
GSHP: residential	20c	50	0.7	0.6	0.6
Capacity totals			40.6	22.2	22.2

Notes:
a -- ARI, 1991.
b -- Pietsch, 1989.
c -- The NEWS, 1991.

(b) Projected Capacity Shipments By Base System

	Nation (10^6 RT/5 yr)	4 Best Regions (10^6 RT/5 yr)
new:EHP2	1.24	0.38
new:EHP3	0.21	0.06
new:GF2/AC2	2.68	1.33
new:GF2/EHP1	0.29	0.25
new:GF3/AC2	0.08	0.04
new:GF3/AC3	0.46	0.23
new:GSHP	0.58	0.46
rep:EHP•EHP2	3.27	0.75
rep:EHP•EHP3	0.55	0.13
rep:GForGF/AC•GF2/AC2	9.48	2.83
rep:GForGF/AC•GF2/EHP1	1.16	1.00
rep:GForGF/AC•GF3/AC2	0.90	0.36
rep:GForGF/AC•GF3/AC3	0.81	0.19
rep:OForOF/AC•OF2/AC2	0.53	0.43
total all systems	22.2	8.4

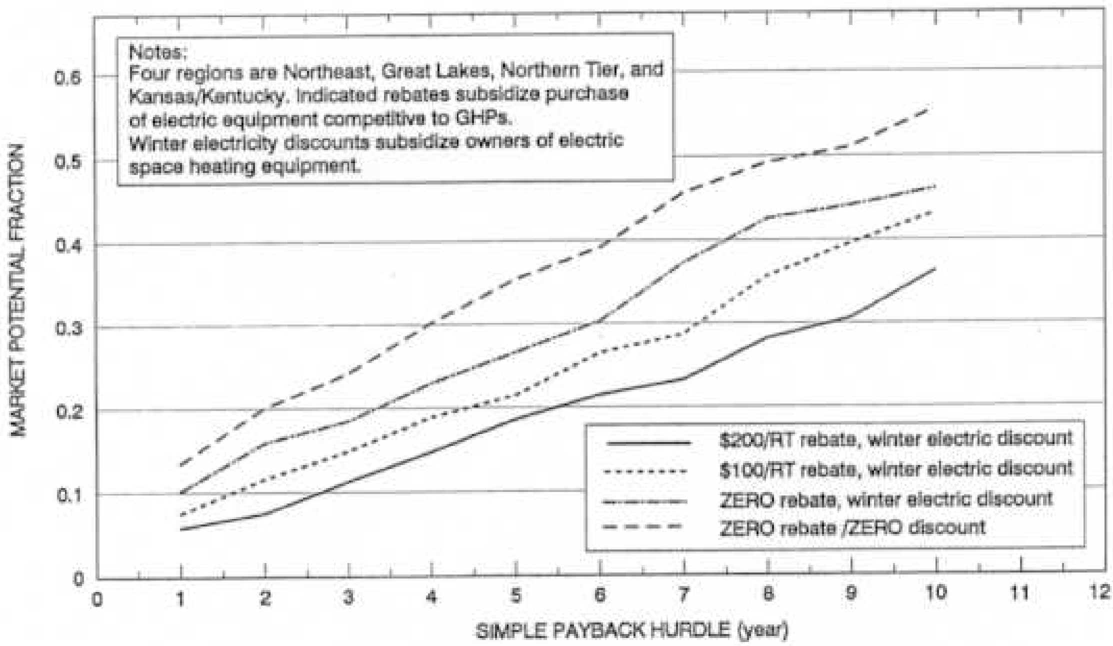

Figure 3 *GHP market potential as a fraction of projected 1996-2010 base technology capacity shipments in the four best regions.*

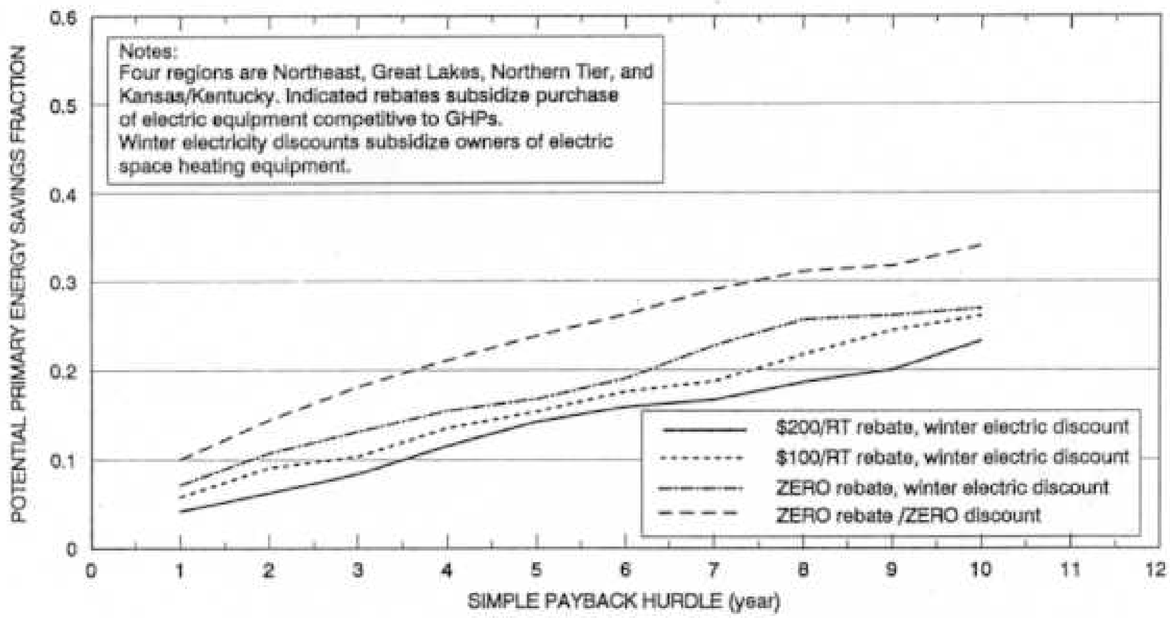

Figure 4 *GHP primary energy savings potential in the four best regions as a fraction of energy use in 2010 to operate base technologies added from 1996-2010 if GHPs are not available.*

End User Benefits

GHPs provide another option for end users to meet heating/cooling needs at lower cost. If all end users with 3-year paybacks selected GHPs, about 1.4 to 2.9 million GHPs (depending on the level of base technology subsidies) would be in operation in the 4 regions by 2010. [Note: unit shipments are estimated as the available market (Table 7—8.4 10^6 RT/5 yr × 3 5-year periods), multiplied by market potential fraction (Figure 3—0.12 to 0.25 range at a 3-year payback), and divided by the average sized GHP placed (2.2 RT average over the four regions)]. The availability of GHPs provides a new end user technology option that can help defer facility investments by utilities. Electric utilities in the four regions are typically summer-peaking, and gas utilities are typically winter-peaking. GHPs have the effect of

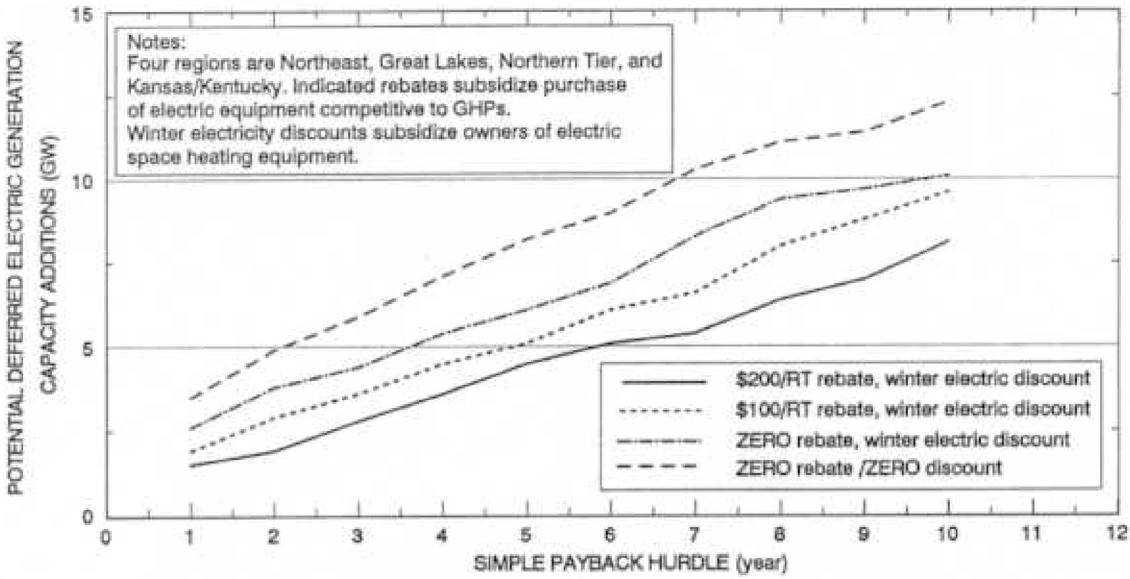

Figure 4 *Potential electric generation capacity addition deferrals by 2010 as a result of GHP adoption in the four best regions.*

increasing load factors of both electric and gas utilities. By so doing, GHPs should provide downward pressure on both electric and gas rates compared to the case where GHPs are not available.

Environmental Benefits

GHP potential primary energy savings fraction versus simple payback hurdle is presented in Figure 4. The analysis indicated that if all end users with 3-year paybacks selected GHPs, about 8 to 18% (depending on the level of base technology subsidies) of primary energy use in 2010 needed to operate base technologies added from 1996-2010 (if GHPs are not available) could be saved. The denominator of the primary energy fraction is defined as the energy used to generate electricity to operate the 1996-2010 base technology additions plus the oil used to operate equipment at end user sites. The numerator is defined as the denominator minus electric generation and site oil decreases due to GHP plus site gas increases due to GHP.

Lower primary energy use means less fossil fuel combustion and lower atmospheric emissions of acid rain precursors and global warming gases. Also, some types of GHPs use refrigerants with zero stratospheric ozone depletion potential.

Gas Utility Benefits

In residential applications in the four best regions, GHPs use less gas on an annual basis than a condensing furnace and electric air conditioner, except in Kansas/Kentucky. However, GHPs serve to defend the space heating market from electric air-source and ground-source heat pumps that use no gas, and from dual-fuel heat pumps that use less gas. When new construction markets are defended from these technologies, the gas company also typically benefits from additional base loads, such as water heating, cooking, and clothes drying. Lastly, since summer spot market prices for gas are generally lower, the additional summer loads can be served with less expensive gas. When all of these factors are considered, most local distribution companies (LDCs) in the four regions would benefit from GHPs.

GHPs in the Northeast and Kansas/Kentucky should have significant winter peak day benefits, but GHPs in the Great Lakes and Northern Tier may be no better than (or slightly worse than) condensing furnaces. The difficulty in the far north stems from trying to pump heat out of subzero outdoor air. The availability of GHPs in a ground-source configuration would enable significant winter peak day benefits everywhere. The combination of lower winter peak day requirements and new summer loads will raise LDC load factors and increase revenues relative to facility investment.

Electric Utility Benefits

Potential electric generation capacity addition deferrals by 2010, as a result of GHP deployment, are presented in Figure 5. The analysis indicated that if all end users with 3-year paybacks selected GHPs, about 3 to 6 GW (depending on the level of base technology subsidies) of electric generation capacity could be deferred. Combination utilities that distribute both electricity and gas may recognize deferral of new electric generation investments as a benefit of GHPs.

CONCLUSIONS

An analysis of residential GHP benefits is presented. Simple payback comparisons with base heating/cooling equipment are used to estimate GHP market potential and benefits. It is found that nearly 90% of the market potential occurred in 4 of the 14 regions; therefore, market potential and benefits are presented for the four best regions. Four cases related to the level of subsidy of base technologies that GHPs must compete against are considered.

It is found that GHPs are potentially beneficial to end users, society, gas utilities, and electric utilities. It is also found that the level of benefits to be realized in each category are strongly related to competing technology subsidy levels. Subsidies to existing technologies limit GHP market penetration and benefits.

As an example, GHPs competing against base technologies with $200 per RT rebates and rates that discount winter electricity to all-electric or electric space heating customers generate the following benefits at a 3-year payback: (1) capture about 12% of the 1996-2010 high efficiency market, (2) serve about 1.4 million end users by 2010, (3) defer about 3 GW of electric generation capacity additions by 2010, and (4) save about 8% of the primary energy that would otherwise be needed to operate base technologies placed between 1996-2010. If the rebates and winter discounts are removed, the GHP impacts and benefits approximately double. If GHPs are subsidized (a case not examined here), the impacts and benefits would be even larger.

ACKNOWLEDGMENTS

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DISCUSSION

Sam Shelton, Professor, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta: What was the HVAC system technology that was assumed to be replaced by the gas heat pump?

Patrick J. Hughes: As described in the Methodology section of the paper, 14 base cases were considered—7 each for new construction and replacements. The seven technologies included electric air-source heat pumps at two efficiency levels, an electric air-source heat pump add-on to a gas furnace, gas furnace/electric air conditioner combinations at three efficiency levels, and the electric ground-source heat pump.