ENERGY AND DEMAND STUDY OF HEATING AND COOLING EQUIPMENT

Air-Conditioners, Furnaces, Air Heat Pumps, and Ground Source Heat Pumps

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An attractive alternative to conventional heating, cooling, and water heating equipment is the ground-source heat pump. The higher initial cost of this equipment must be justified by operating cost savings. Therefore, it is necessary to predict energy use and demand. However, there are no seasonal ratings for this type of equipment. The ratings for ground-source heat pumps calculate performance at a single fluid temperature (32°F) for heating COP and a second for cooling EER (77°F). These ratings reflect temperatures for an assumed location and ground heat exchanger type, and are not ideal indicators of energy use.

This problem is compounded by the nature of ratings for conventional equipment. The complexity and many assumptions used in the procedures to calculate the seasonal efficiency for air-conditioners, furnaces, and heat pumps (SEER, AFUE, HSPF) make it difficult to compare energy use with equipment rated under different standards. The accuracy of the results are highly uncertain, even when corrected for regional weather patterns. These values are not indicators for demand since they are seasonal averages and performance at severe conditions is not heavily weighted.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends a weather driven energy calculation, like the bin method, in preference to single measure methods like SEER, HSPF, EER, COP, and AFUE. The bin method permits the energy use to be calculated based on local weather data and equipment performance over a wide range of temperatures. The bin method also calculates demand at the most severe conditions.

This method was used to compare the energy use and demand of high efficiency equipment in Sacramento, California and Salt Lake City, Utah. The equipment considered were a high efficiency single speed air source, a variable speed air source heat pump and electric air-conditioner with a natural gas furnace, and a ground-source heat pump.

EQUIPMENT SPECIFICATIONS

Table 1 lists the rated capacities and efficiencies of the equipment used in this study. The single speed unit is a split system with a piston compressor. The variable speed unit uses a piston compressor and brushless DC motors to drive the compressor and fans. Both units are rated according to ARI Standard 210/240-89. Equations for heat pump capacity and power as a function of outdoor air temperature were developed for manufacturer’s data. The units were also corrected for indoor air temperature, defrost, and auxiliary heat. This method was applied to the air source cooling unit with the furnace. However, the furnace performance is not strongly influenced by outdoor temperature and was only corrected for cycling losses.

The ground-source heat pump is rated according to ARI Standard 330-90. The unit has a scroll compressor and a brushless DC indoor fan motor. Equations for capacity and power as a function of water temperature were developed. These equations were used in a computer code that also incorporated an iterative calculation for the performance of the ground heat exchanger. These heat pumps were also corrected for indoor air temperature, pump energy, and auxiliary heat. The calculations were conducted for vertical ground-couplings buried in a saturated soil. The length of the couplings are 600 ft. of bore in Sacramento and 700 ft. in Salt Lake.

TABLE 1. RATINGS OF EQUIPMENT USED IN SACRAMENTO

	COOLING		**HEATING**	
EQUIPMENT TYPE	Capacity Btu/h	SEER-air EER-wtr.	Capacity MBtu/h	EFF.
AIR HEAT PUMP	34,600	10.3	35,400	7.3 HSPF
VS AIR HEAT PUMP	37,500	15.2	34,600	8.8 HSPF
AC W GAS FURN.	34,600	10.3	48,000	80% AFUE
GS HEAT PUMP	41,000	15.2	29,400	3.4 COP

GROUND HEAT PUMPS ARE COUPLED TO VERTICAL 1" U-BENDS 600FT. OF BORE IN TOTAL LENGTH

The calculations for the natural gas furnace are based on a heat content of 106,000 Btu per 100 cubic feet (ccf) which is typical of natural gas in the Western States.

TABLE 1A. RATINGS OF EQUIPMENT USED IN SALT LAKE

	COOLING		**HEATING**	
EQUIPMENT TYPE	Capacity Btu/h	SEER-air EER-wtr.	Capacity MBtu/h	EFF.
AIR HEAT PUMP	45,500	10.5	45,500	7.8 HSPF
VS AIR HEAT PUMP	48,500	15.1	43,500	9.4 HSPF
AC W GAS FURN.	34,600	10.3	48,000	80% AFUE
GS HEAT PUMP	48,000	14.9	35,400	3.4 COP

GROUND HEAT PUMPS ARE COUPLED TO VERTICAL 1" U-BENDS 700 FT. OF BORE IN TOTAL LENGTH

Table 2 lists the conditions of the local climate and building descritption for which the study was performed.

TABLE 2. DESIGN TEMPERATURES AND LOADS

	COOLING		HEATING		
SITE	Load MBtu/h	Design Temp	Ground Temp	Load MBtu/h	Design Temp
Sacramento	36	98	66	30	30
Salt Lake City	36	95	55	48	3

INDOOR TEMPERATURE:	75°F (Clg.) , 70°F (Htg.)
OCCUPANTS:	4
LIGHTS:	400 Watts (Average)
APPLIANCES:	1200 Watts (Average)

WATER HEATING AND COMFORT

The ground-source machines are equipped to heat water. Since the heat recovery unit is located indoors and only a few inches away from the compressor, losses can be minimized. Winter heat recovery is also effective because ground-source heat pumps have excess heating capacity in all but a few hours. A typical hot water energy use (60 gallons/day with 70°F rise) requires 4120 kWh of electrical energy without heat recovery. The HRUs reduced electrical energy requirement for hot water by 30 to 40% in the study. Water heating with high efficiency air equipment is not recommended by the manufacturers because of the low operating temperatures and heat losses that occur with the split systems. Water heating with the furnace system is accomplished with a 78% AFUE gas water heater.

The variable speed air unit and the ground-source heat pump are well suited to meet the dehumidification need of Sacramento. The constant speed unit has poor latent cooling capacity and discomfort is a possibility during mild cooling days. Winter air delivery temperatures with the ground machines will be 98 to 102°F with the heat recovery unit operational and 100 to 106°F if it is off. The air machines will deliver air at a lower temperature.

RESULTS

Table 3 summarizes the results of the study. The single speed air unit used the most energy in heating and cooling and had the highest demand in heating. The demand includes auxiliary electric resistance requirements. The variable speed unit used much less cooling energy but had the highest demand. Heating energy requirement was lower than the constant speed air unit but demand is about the same. Total energy was greater than with the ground-source unit. The ground-source machine had lower demand (summer and winter) and lower heating energy use than either of the air heat pumps. Comparisons with natural gas must be based on cost since the units for natural gas (therm=100,000 Btu) are different than electrical energy units(kWh).

TABLE 3. ENERGY AND DEMAND FOR EQUIPMENT

	COOLING		HEATING				WATER	
SACRAMENTO	**KWH**	**KW**	**TOTAL KWH**	**KWH (thm)**	**AUX KWH**	**KW**	**KWH (thm)**	**TOTAL KWH (thm)**
SAHP	3488	3.8	7024	6783	241	8.3	4120	14633
VSHP	2861	4.2	4897	4776	121	7.4	4120	11878
AC/FUR	3488	3.8	527			.5		4015
				(633)			(163)	(796)
GSHP	2237	2.7	3477	3476	1	2.8	2404	8118
SALT LAKE	**KWH**	**KW**	**TOTAL KWH**	**KWH (thm)**	**AUX KWH**	**KW**	**KWH (thm)**	**KWH (thm)**
SAHP	2398	3.9	17232	13035	4198	18.8	4120	23751
VSHP	1409	4.4	11816	9639	2176	18.7	4120	17345
SC/FUR	2290	3.6	862			.6		3152
				(914)			(163)	(1077)
GSHP	1288	2.9	7584	7407	176	9.5	2484	11356

NOTE: Energy units for natural gas are therms (thm) or 100,000 Btus.

TABLE 4. COST OF OPERATING HEATING, COOLING, AND WATER HEATING EQUIPMENT

UNIT	COOLING	HEATING	WATER HT.	TOTAL
SACRAMENTO				
SAHP	$443	$604	$441	$1488
VSHP	363	421	441	1225
AC/GAS HEAT	443	536*	86**	1065
GSHP	284	299	257	840
SALT LAKE				
SAHP	$167	$1211	$290	$1668
VSHP	99	831	290	1220
AC/GAS HEAT	167	497	136**	800
GSHP	91	533	175	799

* Includes electric fan energy ($62 in Sac., $37 in SLC).
** Includes gas base charges ($0 in Sac., $62 in SLC).

The cost of operating the four different systems are shown in Table 4. Results are based on rates of 7¢/kWh and 50¢ /therm (40¢/therm in summer) in Salt Lake City. Gas rates in Sacramento are 53¢ below the baseline and 85¢/therm above. The calculations assume water heating and the first 200 therms/year of heating are baseline. Baseline electric rates are 8¢/kWh (summer) and 5.4¢/kWh (winter). Above baseline costs are 12.7¢ and 8.6¢/kWh. All electric heating, cooling, and water heating is above the baseline, since appliance and lighting use normally would consume all baseline energy.

CONCLUSIONS

1. The air heat pumps can not match the lower cost of operating typical electric/gas equipment.

2. The ground-source equipment can operate with lower cost that the electric/gas equipment in Sacramento and about the same in Salt Lake City.

3. The variable-speed heat pump would seem to be the least desirable unit for a utility to advocate since it reduces energy but increases summer demand and has little impact on reducing winter demand.

4. The ground-source heat pump reduces demand and energy. It would appear to be a logical unit to rebate for a winter or summer peaking utility.

5. Energy savings are sufficient enough to warrant added investments in the $600 to $900/ton range, especially if costs can be assumed in a 15 or 30 year mortgage.