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THE EFFECT OF LOCATION ON THE PREDICTED PERFORMANCE OF A HEAT-PUMP WATER HEATER

William P. Levins

Energy Division

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

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THE EFFECT OF LOCATION OF THE PREDICTED PERFORMANCE OF A HEAT PUMP WATER HEATER

Laboratory testing and field testing have shown that a heat pump water heater (HPWH) uses about half the electrical energy input that an electric resistance water heater does. However, since the heat pump water heater extracts energy from the air in its environment, the question arises as to how this energy extraction would affect the house HVAC system if the HPWH were located in a conditioned space of a household. A second question concerns the savings obtained by locating the HPWH in an unconditioned space such as a garage or basement.

A computer study of these effects was carried out at the Oak Ridge National Laboratory (ORNL). Since geography, house construction, type and efficiency of HVAC system, and hot water usage will all affect the effective performance, some of these variables were fixed and some were allowed to vary in the study.

Figure 1 shows the 18 cities which are covered in this work.

Table 1 contains the assumptions used in the analysis and Table 2 contains a description of the computer models used for the house and the heat pump.

Figure 2 is a heating-cooling plot of the residence (without a heat pump water heater) to which the high performance heat pump performace data have been added. Bin data[1] for each of the 18 citieswere used as input weather data. Table 3 contains the monthly inlet supply water temperatures to the water heater for each of the 18 cities.

The effect of locating the HPWH in the conditioned spaces of houses with a high performance heat pump as well as resistance, gas, and oil heated houses with a high performace electric air conditioner was studied. All calculations were made on a Hewlett-Packard (H-P) 9830, a desktop computer.

Table 4 is a sample of the output of the program. The weather bin data and inlet water temperatures for each city were used to calculate the energy consumption for the house with a resistance water heater and also with a HPWH. The difference between these

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1. Dept. of the Air Force, *Engineering Weather Data*, AFM 88-29 July 1978.

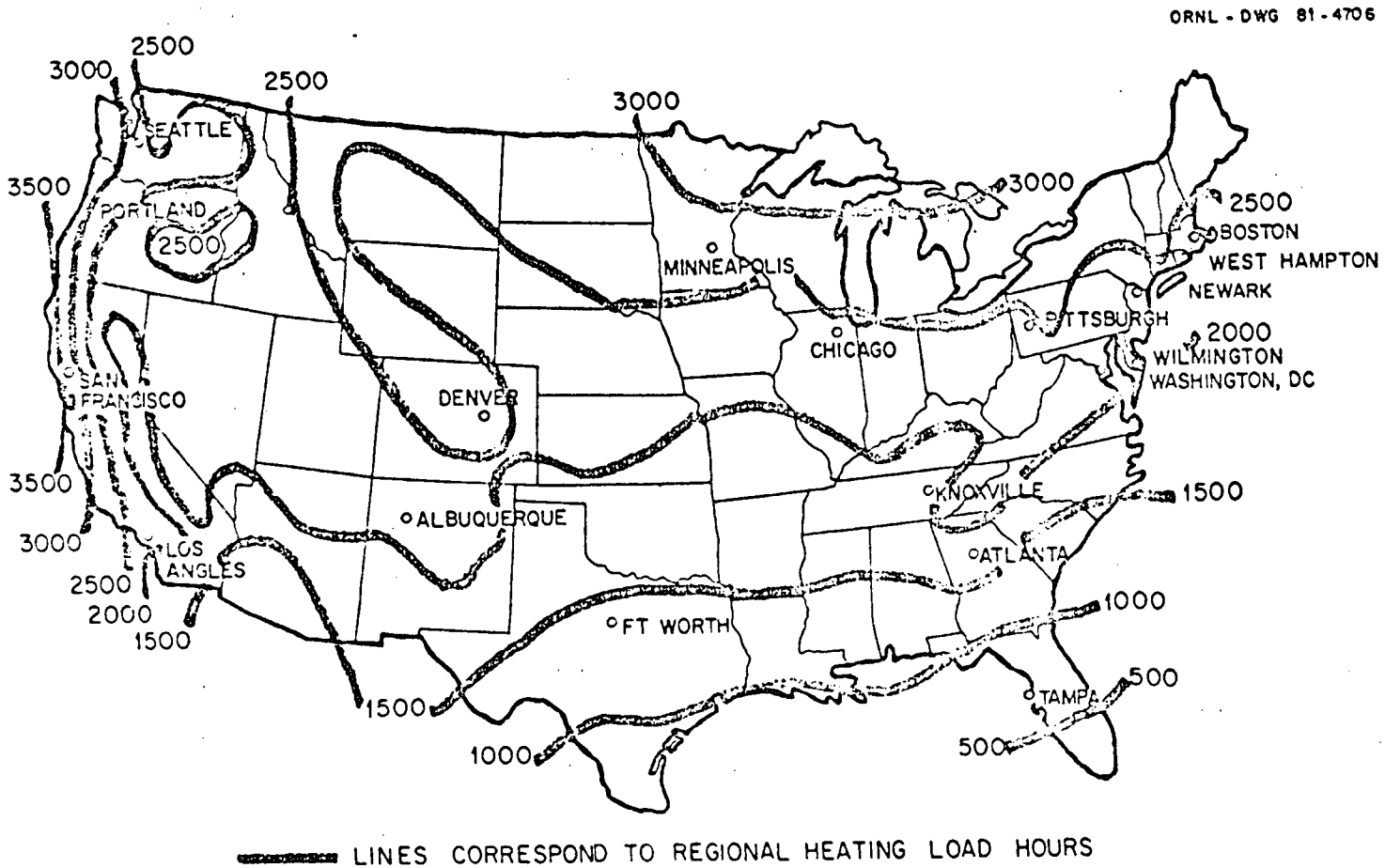

Fig. 1. Map Showing Locations of 18 Cities in Study.

Table 1

Assumptions — House Without Heat Pump Water Heater

1. I^2R water heater located in house
2. Water consumption is 243 l/day (64.3 gal/day) at 60°C (140°F) outlet temperature
3. Water heater losses are 0.146 kW (498 Btu/h)
4. House temperature kept at constant 21.1°C (70°F) — no night setback in heating mode

Additional Assumptions — House with Heat Pump Water Heater

1. HPWH replaces I^2R water heater in same house
2. HPWH Performance Factor = 1.97 - 0.0022W where W = inlet water temperature (°C)
3. HPWH extracts energy uniformly (at a constant rate) from house air 24 h/day
4. House heating and cooling load lines include the hourly enthalpy extraction rate of the HPWH from the house air

Assumptions — Unconditioned Attached Garage

1. HPWH Performance Factor = 1.754 + 0.009C - 0.002(W - 15.5) where C = temperature (°C) in unconditioned space and W = inlet water temperature (°C)
2. When T is between -1.1°C and 18.3°C, C = T + 5.5 where T = outside air temperature (°C)
3. When T is less than -1.1°C, C = 4.4°C
4. When C = 4.4°C, HPWH operates in resistance mode
5. When T is greater than or equal to 18.3°C, C = T

Assumptions — Unconditioned Basement

1. HPWH Performance Factor = 1.754 + 0.009C - 0.002(W - 15.5)
2. When T is greater than 21.1°C, C = 21.1°C
3. When T is less than 12.8°C, C = 12.8°C
4. When T is between 21.1°C and 12.8°C, C = T

Table 2. Computer models of house and heat pump

House Model

Ranch house with finished basement and integral garage:
148.6m^2 (1600ft^2) on main level
74.3m^2 (800ft^2) in basement
Heating load line: kW = 5.43 - 0.362T (° C) (Btu/h = 40412 - 685T (° F))
Cooling load line: kW = 0.828T (° C) - 19.79 (Btu/h = 1571.4T - 117857)

Heat Pump Model

High performance: Carrier Weathermaster III (38HQ 134/940 + 40AQ036)

Data per Carrier catalog # 522-848

Cycling losses applied to capacity and COP listings of Carrier data: A linear decay of 25% at the temperature where heating begins to 0 at the balance point

Defrost losses: Heat pump defrosts for 5 minutes out of each 95 minutes of compressor operation when the outdoor temperature is below 40°F. The heat pump effective heat output is reduced by a factor of 5/95 or 5.3%. Five kilowatts of resistance heat (0.417 kWh) is added to the heat pump electrical input during each 5 minute defrost period to nullify the heat removed from the house by the heat pump.

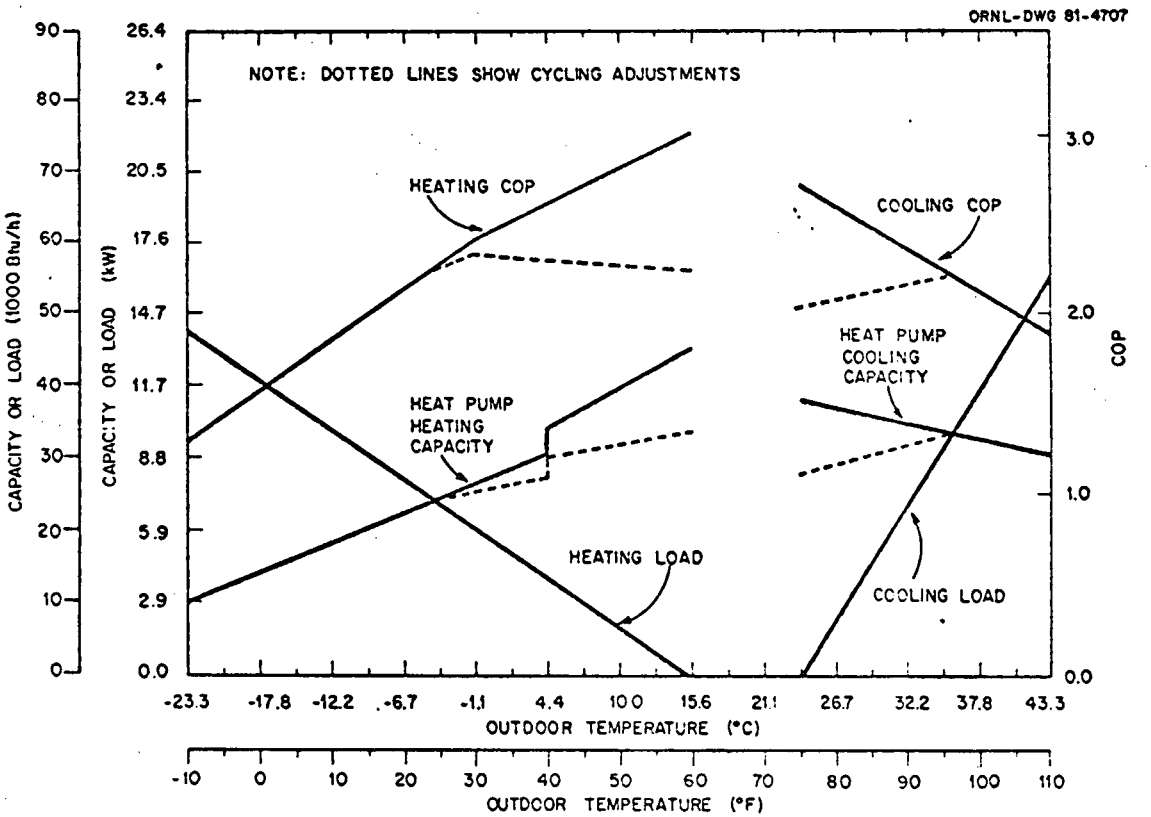

Fig. 2. Heating-Cooling Diagram of Model Residence and Heat Pump.

TABLE 3

MONTHLY INLET WATER TEMPERATURES (C)

CITY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
ALBUQUERQUE	21.1	23.9	23.3	20.6	16.1	10.6	6.1	3.9	4.4	7.2	11.7	16.7
ATLANTA	21.7	23.9	23.9	21.7	17.2	12.8	8.9	6.7	7.2	9.4	13.3	17.8
BOSTON	12.2	15.6	17.2	16.7	14.4	10.6	6.7	3.9	2.2	2.8	5.0	8.9
CHICAGO	11.1	14.4	16.1	16.1	14.4	11.1	7.2	4.4	2.8	2.8	4.4	7.8
DENVER	13.3	16.1	17.8	16.7	14.4	10.6	6.7	3.3	2.2	2.8	5.6	9.4
FT WORTH	25.6	28.3	28.3	25.6	21.1	16.1	11.7	9.4	9.4	11.7	16.1	21.1
KNOXVILLE	21.7	23.9	23.9	21.1	16.7	11.7	7.8	5.6	5.6	8.3	12.8	17.8
LOS ANGELES	17.8	19.4	20.0	19.4	18.3	16.7	15.0	13.9	13.3	13.9	15.0	16.1
MINNEAPOLIS	6.1	8.9	11.1	12.8	12.2	10.6	8.3	5.6	3.3	2.2	2.2	3.9
NEWARK	16.7	19.4	20.6	18.9	15.6	10.6	6.1	3.3	2.2	3.9	7.8	12.2
PITTSBURGH	13.3	16.7	17.8	17.2	14.4	10.6	6.7	3.3	2.2	3.3	5.6	9.4
PORTLAND	15.6	17.2	17.2	16.1	13.3	10.0	7.2	5.6	5.6	6.7	9.4	12.8
SAN FRANCISCO	15.6	16.7	16.7	16.7	15.6	13.9	12.8	11.7	11.1	11.7	12.8	13.9
SEATTLE	13.9	15.6	15.6	14.4	12.2	8.9	6.7	5.0	5.0	6.1	8.9	11.7
TAMPA	26.1	27.8	27.8	26.1	23.3	19.4	16.7	14.4	14.4	16.1	19.4	22.8
WASHINGTON DC	20.0	22.8	22.8	20.0	15.6	10.6	6.1	3.3	3.3	5.6	10.0	15.0
WESTHAMPTON,NY	16.7	19.4	20.6	18.9	15.6	10.6	6.1	3.3	2.2	3.9	7.8	12.2
WILMINGTON,DEL	18.3	21.1	21.7	19.4	15.0	10.0	5.6	2.8	2.2	4.4	8.9	13.9

Source:

E. A. Nephew, et al., *Performance and Economics of the ACES and Alternative Residential Heating and Air Conditioning Systems in 115 U.S. Cities*, ORNL/CON-52, March 1981.

TABLE 4 SAMPLE COMPUTER PROGRAM OUTPUT

HOUSE WITH HIGH PERFORMANCE HEAT PUMP LOCATED IN KNOXVILLE
HOUSE CONTAINS A HEAT PUMP WATER HEATER IN LIVING AREA

HOUSE HEATING LOAD = 40412 - 685*T BTU/HR
HOUSE COOLING LOAD = 1571.4*T - 117857 BTU/HR

HEAT PUMP CAPACITY AT 47F = 37500 BTU/HR
A/C CAPACITY AT 95F = 33500 BTU/HR

	SUMMARY		HEATING			COOLING		
DN	TOTAL BTU	TOTAL KWH	BTU DLVRD	HTG KWH	COP	BTU REMVD	CLG KWH	COP
--	---	---	---	---	---	---	---	---
JN	3.829E+06	523.5	5.175E+04	6.7	2.28	3.777E+06	516.9	2.14
JL	5.271E+06	719.1	3.379E+03	0.4	2.27	5.268E+06	718.6	2.15
JG	4.695E+06	641.3	5.068E+03	0.7	2.27	4.690E+06	640.6	2.14
EP	2.792E+06	380.5	2.680E+05	34.3	2.29	2.524E+06	346.2	2.14
CT	2.756E+06	362.5	2.294E+06	298.0	2.26	4.626E+05	64.5	2.10
OV	6.803E+06	931.8	6.781E+06	928.7	2.14	2.240E+04	3.2	2.08
EC	1.024E+07	1482.9	1.024E+07	1482.9	2.02	0.000E+00	0.0	0.00
AN	1.045E+07	1550.6	1.045E+07	1550.6	1.98	0.000E+00	0.0	0.00
EB	7.587E+06	1094.6	7.587E+06	1094.6	2.03	0.000E+00	0.0	0.00
AR	6.683E+06	915.3	6.649E+06	910.4	2.14	3.415E+04	4.8	2.07
PR	3.137E+06	412.9	2.680E+06	349.2	2.25	4.571E+05	63.7	2.10
AY	2.401E+06	324.9	6.146E+05	78.2	2.30	1.787E+06	246.7	2.12
OT	6.665E+07	9340.0	4.763E+07	6734.8	2.07	1.902E+07	2605.2	2.14

HOUSE WITH HIGH PERFORMANCE HEAT PUMP LOCATED IN KNOXVILLE
NO HEAT PUMP WATER HEATER IN HOUSE

HOUSE HEATING LOAD = 40412 - 685*T BTU/HR
HOUSE COOLING LOAD = 1571.4*T - 117857 BTU/HR

HEAT PUMP CAPACITY AT 47F = 37500 BTU/HR
A/C CAPACITY AT 95F = 33500 BTU/HR

	SUMMARY		HEATING			COOLING		
DN	TOTAL BTU	TOTAL KWH	BTU DLVRD	HTG KWH	COP	BTU REMVD	CLG KWH	COP
--	---	---	---	---	---	---	---	---
JN	4.054E+06	552.1	3.297E+04	4.3	2.26	4.021E+06	547.8	2.15
JL	5.564E+06	755.8	2.187E+03	0.3	2.25	5.562E+06	755.5	2.16
JG	4.967E+06	675.6	3.281E+03	0.4	2.25	4.964E+06	675.2	2.15
EP	2.897E+06	394.0	2.001E+05	25.8	2.27	2.697E+06	368.2	2.15
CT	2.509E+06	333.1	1.988E+06	260.8	2.23	5.216E+05	72.3	2.11
OV	6.246E+06	863.9	6.219E+06	860.2	2.12	2.670E+04	3.7	2.09
EC	9.545E+06	1391.8	9.545E+06	1391.8	2.01	0.000E+00	0.0	0.00
AN	9.738E+06	1453.2	9.738E+06	1453.2	1.96	0.000E+00	0.0	0.00
EB	6.953E+06	1012.5	6.953E+06	1012.5	2.01	0.000E+00	0.0	0.00
AR	6.079E+06	841.5	6.037E+06	835.5	2.12	4.241E+04	6.0	2.09
PR	2.853E+06	379.4	2.333E+06	307.3	2.22	5.200E+05	72.1	2.11
AY	2.442E+06	330.9	4.915E+05	63.0	2.28	1.950E+06	267.9	2.13
OT	6.305E+07	8983.8	4.354E+07	6215.2	2.05	2.030E+07	2768.6	2.15

values was used to calculate the performance factor (PF) of the HPWH. The HPWH will add to the house heating load in winter and lessen the house cooling load in summer. Table 5 contains an explanation of the column headings used in Tables 6 through 8, which contain the results of the calculations for the various combination of HVAC systems.

Table 5. Explanation of column headings used in Table 6 through 9

City	The city names are: Albuquerque, New Mexico Atlanta, Georgia Boston, Massachusetts Chicago, Illinois Denver, Colorado Fort Worth, Texas Knoxville, Tennessee Los Angeles, California Minneapolis, Minnesota Newark, New Jersey Pittsburgh, Pennsylvania Portland, Oregon San Francisco, California Seattle, Washington Tampa, Florida Washington, D.C. Westhampton, New York (Long Island) Wilmington, Delaware
HPWH kWh in	The annual electrical kWh input to the HPWH as measured on a kWh meter
Htg sys add kWh	The additional kWh (or equivalent kWh) input to the house heating system for a house with a HPWH in the conditioned space compared to the same house without a HPWH
Clg sys kWh svd	The kWh saved by the house cooling system because of the cooling supplied by the HPWH
HPWH eq kWh in	The equivalent HPWH kWh input taking into account the added kWh to the heating system and the reduced kWh to the cooling system
Res WH kWh in	The annual electrical input into a resistance water heater
Annual kWh svd	The equivalent kWh savings obtained by using a HPW instead of a resistance water heater taking into account the added kWh to the heating system and the reduced kWh to the cooling system
HPWH ann PF	The predicted HPWH annual performance factor obtained by dividing the HPWH equivalent kWh input (HPW eq kWh in) by the resistance water heater kWh input (Res Wh kWh in)

TABLE 6
HOUSE WITH HIGH PERFORMANCE HEAT PUMP

C I T Y	H P W H KWH IN	HTG SYS ADD KWH	CLG SYS KWH SVD	HPWH EQ KWH IN	RES WH KWH IN	ANNUAL KWH SVD	HPWH ANN PF
ALBUR NM	3076.8	613.5	149.4	3540.9	6009.6	2468.7	1.70
ATLANTA	3008.1	463.3	173.1	3298.3	5839.2	2541.0	1.77
BOSTON	3240.7	911.0	96.7	4055.0	6424.3	2369.3	1.58
CHICAGO	3251.7	883.9	111.8	4023.7	6452.7	2428.9	1.60
DENVER	3231.8	906.4	94.6	4043.6	6401.5	2357.9	1.58
FT WORTH	2867.9	375.8	221.2	3022.5	5498.4	2475.9	1.82
KNOX TN	3035.7	523.0	163.4	3395.2	5907.4	2512.2	1.74
LA CAL	2959.4	438.2	44.4	3353.2	5719.9	2366.8	1.71
MINN MN	3334.9	1066.5	109.7	4291.7	6668.5	2376.8	1.55
NEWARK	3169.4	709.9	121.6	3757.8	6242.5	2484.7	1.66
PITTS PA	3225.1	829.2	99.8	3954.6	6384.5	2429.9	1.61
PTLND OR	3171.7	783.2	42.6	3912.3	6248.2	2335.9	1.60
SF CAL	3063.1	702.7	23.3	3742.5	5975.5	2233.0	1.60
SEATTLE	3214.1	808.0	30.0	3992.0	6356.1	2364.1	1.59
TAMPA	2760.5	152.1	331.3	2581.4	5242.8	2661.5	2.03
WASH DC	3108.6	662.7	125.5	3645.8	6089.1	2443.4	1.67
WHMTN NY	3169.4	810.1	56.2	3923.4	6242.5	2319.1	1.59
WILM DEL	3149.2	709.0	117.8	3740.4	6191.4	2451.0	1.66

TABLE 7

HOUSE WITH RESISTANCE HEAT & HIGH PERFORMANCE A/C

C I T Y	H P W H KWH IN	HTG SYS ADD KWH	CLG SYS KWH SVD	HPWH EQ KWH IN	RES WH KWH IN	ANNUAL KWH SVD	HPWH ANN PF
ALBUR NM	3076.8	1367.1	149.4	4294.6	6009.6	1715.1	1.40
ATLANTA	3008.1	1088.1	173.1	3923.0	5839.2	1916.2	1.49
BOSTON	3240.7	1759.3	96.7	4903.3	6424.3	1520.9	1.31
CHICAGO	3251.7	1673.2	111.8	4813.1	6452.7	1639.6	1.34
DENVER	3231.8	1774.4	94.6	4911.6	6401.5	1489.9	1.30
FT WORTH	2867.9	881.1	221.2	3527.8	5498.4	1970.6	1.56
KNOX TN	3035.7	1198.1	163.4	4070.4	5907.4	1837.0	1.45
LA CAL	2959.4	1034.6	44.4	3949.6	5719.9	1770.3	1.45
MINN MN	3334.9	1769.3	109.7	4994.5	6668.5	1674.0	1.34
NEWARK	3169.4	1537.7	121.6	4585.6	6242.5	1656.9	1.36
PITTS PA	3225.1	1637.4	99.8	4762.7	6384.5	1621.8	1.34
PTLND OR	3171.7	1876.9	42.6	5006.0	6248.2	1242.2	1.25
SF CAL	3063.1	1674.4	23.3	4714.2	5975.5	1261.4	1.27
SEATTLE	3214.1	1954.4	30.0	5138.4	6356.1	1217.7	1.24
TAMPA	2760.5	362.7	331.3	2791.9	5242.8	2450.9	1.88
WASH DC	3108.6	1438.1	125.5	4421.2	6089.1	1667.9	1.38
WHMTN NY	3169.4	1699.7	56.2	4813.0	6242.5	1429.6	1.30
WILM DEL	3149.2	1537.0	117.8	4568.4	6191.4	1623.0	1.36

TABLE 8

HOUSE WITH 60% EFF GAS/OIL HEAT & HIGH PERFORMANCE A/C

C I T Y	H P W H KWH IN	HTG SYS ADD KWH	CLG SYS KWH SVD	HPWH EQ KWH IN	RES WH KWH IN	ANNUAL KWH SVD	HPWH ANN PF
ALBUR NM	3076.8	2278.5	149.4	5206.0	6009.6	803.7	1.15
ATLANTA	3008.1	1813.5	173.1	4648.5	5839.2	1190.8	1.26
BOSTON	3240.7	2932.2	96.7	6076.2	6424.3	348.0	1.06
CHICAGO	3251.7	2788.7	111.8	5928.5	6452.7	524.1	1.09
DENVER	3231.8	2957.3	94.6	6094.5	6401.5	307.0	1.05
FT WORTH	2867.9	1468.5	221.2	4115.2	5498.4	1383.2	1.34
KNOX TN	3035.7	1996.9	163.4	4869.2	5907.4	1038.2	1.21
LA CAL	2959.4	1724.4	44.4	4639.4	5719.9	1080.6	1.23
MINN MN	3334.9	2948.8	109.7	6174.0	6668.5	494.5	1.08
NEWARK	3169.4	2562.9	121.6	5610.7	6242.5	631.8	1.11
PITTS PA	3225.1	2729.0	99.8	5854.3	6384.5	530.2	1.09
PTLND OR	3171.7	3128.2	42.6	6257.3	6248.2	-9.1	1.00
SF CAL	3063.1	2790.6	23.3	5830.4	5975.5	145.1	1.02
SEATTLE	3214.1	3257.4	30.0	6441.4	6356.1	-85.3	0.99
TAMPA	2760.5	604.5	331.3	3033.7	5242.8	2209.1	1.73
WASH DC	3108.6	2396.9	125.5	5380.0	6089.1	709.2	1.13
WHMTN NY	3169.4	2832.9	56.2	5946.1	6242.5	296.4	1.05
WILM DEL	3149.2	2561.6	117.8	5593.0	6191.4	598.4	1.11

All of the energy usages in Tables 6 through 11 are expressed in equivalent kWh at the point of use (primary energy source is not considered). Also oil-fired water heating systems are not considered.

It is interesting to note from Table 6 that houses heated and cooled by heat pumps appear to save about 2400 kWh per year in water heating energy regardless of geographical location. However, Table 7 shows that houses with resistance heat are much more sensitive to geography. Energy savings in resistance heated houses vary from 1217 kWh per year in Seattle to 2450 kWh per year in Tampa. The length of the heating season rather than the severity of the weather appears to be the controlling factor.

Table 8 describes the performance in houses heated by oil and gas central systems. HPWH performance factors and annual energy savings are lower than for electrically heated houses (Tables 6 and 7).

Table 9 shows the performance of the HPWH relative to a resistance water heater in an unconditioned space simulating an attached garage. The savings obtainable by substituting a HPWH for a resistance water heater in this situation averages to about 2500 kWh per year.

Table 10 shows the performance of the HPWH relative to a resistance water heater in an unconditioned space simulating a basement. The HPWH savings here average about 2800 kWh per year over the resistance water heater.

Table 11 summarizes the results of Tables 6 through 10 and shows the equivalent annual energy usage of a HPWH with regard to its placement in a residence. The preferred location in 11 cities is an unconditioned basement; 6 cities favor the unconditioned, attached garage; and only Tampa favors placement inside the residence, provided the residence has a heat pump.

If the residence should not happen to have a basement, then 11 cities show minimum energy consumption by placing the HPW inside a residence with a heat pump, while 7 favor the unconditioned attached garage.

Since energy costs vary from location to location and depend upon the energy source,

TABLE 9

HEAT PUMP WATER HEATER PERFORMANCE IN UNCONDITIONED SPACE
SIMULATING A GARAGE

CITY NAME	AVE IN WATER TEMP(C)	RESIST WTR HTR KWH	HEAT PUMP WTR HTR KWH	HPWH KWH SAVED	HPWH PF
ALBUQUERQUE	13.8	6083.5	3555.7	2527.9	1.71
ATLANTA	15.4	5871.7	3222.8	2648.8	1.82
BOSTON	9.7	6607.3	4235.1	2372.2	1.56
CHICAGO	9.4	6628.7	4260.2	2368.5	1.56
DENVER	9.9	6587.4	4194.9	2392.5	1.57
FORT WORTH	18.7	5469.7	2967.8	2501.9	1.84
KNOXVILLE	14.7	5963.1	3363.9	2599.2	1.77
LOS ANGELES	16.6	5725.9	3018.1	2707.8	1.90
MINNEAPOLIS	7.3	6872.6	4649.7	2222.9	1.48
NEWARK	11.4	6361.4	3779.5	2581.9	1.68
PITTSBURGH	10.0	6558.5	4115.6	2442.9	1.59
PORTLAND,OREGON	11.4	6386.8	3596.2	2790.7	1.78
SAN FRANCISCO	14.1	6020.0	3210.6	2809.4	1.88
SEATTLE	10.3	6492.2	3603.5	2888.8	1.80
TAMPA	21.2	5139.0	2626.5	2512.5	1.96
WASHINGTON DC	12.9	6197.0	3675.3	2521.7	1.69
WESTHAMPTON NY	11.4	6416.4	3956.4	2460.0	1.62
WILMINGTON DEL	11.9	6317.0	3767.4	2549.6	1.68

NOTES: HPWH PF=0.009*C+1.754-0.002*(W-15.5)
C=TEMPERATURE (C) IN UNCONDITIONED SPACE
W=INLET WATER TEMPERATURE (C)
T=OUTSIDE AIR TEMPERATURE (C)
WHEN C=4.4 WATER HEATER OPERATES IN RES MODE
WHEN T IS LESS THAN 18.3, C=T+5.5
C NEVER GETS BELOW 4.4

TABLE 10

HEAT PUMP WATER HEATER PERFORMANCE IN UNCONDITIONED SPACE
SIMULATING A BASEMENT

CITY NAME	AVE IN WATER TEMP(C)	RESIST WTR HTR KWH	HEAT PUMP WTR HTR KWH	HPWH KWH SAVED	HPWH PF
ALBUQUERQUE	13.8	6124.7	3393.7	2731.0	1.80
ATLANTA	15.4	5943.6	3274.0	2669.6	1.82
BOSTON	9.7	6585.4	3648.0	2937.4	1.81
CHICAGO	9.4	6603.1	3641.3	2961.8	1.81
DENVER	9.9	6575.8	3650.8	2925.0	1.80
FORT WORTH	18.7	5580.3	3085.3	2495.0	1.81
KNOXVILLE	14.7	6018.0	3322.8	2695.2	1.81
LOS ANGELES	16.6	5840.2	3254.1	2586.1	1.79
MINNEAPOLIS	7.3	6827.4	3744.4	3083.0	1.82
NEWARK	11.4	6377.8	3523.2	2854.6	1.81
PITTSBURGH	10.0	6547.4	3615.2	2932.2	1.81
PORTLAND,OREGON	11.4	6433.8	3619.2	2814.7	1.78
SAN FRANCISCO	14.1	6138.7	3465.7	2673.1	1.77
SEATTLE	10.3	6546.0	3674.7	2871.3	1.78
TAMPA	21.2	5280.9	2867.0	2413.9	1.84
WASHINGTON DC	12.9	6219.0	3442.9	2776.0	1.81
WESTHAMPTON NY	11.4	6408.1	3571.3	2836.8	1.79
WILMINGTON DEL	11.9	6331.6	3503.9	2827.7	1.81

NOTES: HPWH PF=0.009*C+1.754-0.002*(W-15.5)
C=TEMPERATURE (C) IN UNCONDITIONED SPACE
W=INLET WATER TEMPERATURE (C)
T=OUTSIDE AIR TEMPERATURE (C)
WHEN T IS GREATER THAN 21.1, C=21.1
WHEN T IS LESS THAN 12.8, C=12.8
WHEN T IS BETWEEN 21.1 AND 12.8, C=T

TABLE 11

EFFECT OF LOCATION ON EQUIVALENT ANNUAL KWH ENERGY USAGE OF HPWH

CITY	HPWH LOC INSIDE HOUSE WITH HVAC TYPE HI EFF HP	RES+A/C	60%G/O+A/C	HPWH LOC IN UNCOND GARAGE	BASEMENT
ALBUQUERQUE	3540.9	4294.5	5205.9	3555.7	3393.7
ATLANTA	3298.3	3923.1	4648.5	3222.8	3274.0
BOSTON	4055.0	4903.3	6076.2	4235.1	3648.0
CHICAGO	4023.8	4813.1	5928.6	4260.2	3641.3
DENVER	4043.6	4911.6	6094.5	4194.9	3650.8
FT WORTH	3022.5	3527.8	4115.2	2967.8	3085.3
KNOXVILLE	3395.3	4070.4	4869.1	3363.9	3322.8
LOS ANGELES	3353.2	3949.6	4639.3	3018.1	3254.1
MINNEAPOLIS	4291.7	4994.5	6174.0	4649.7	3744.4
NEWARK	3757.7	4585.5	5610.6	3779.5	3523.2
PITTSBURGH	3954.5	4762.7	5854.3	4115.6	3615.2
PORTLAND, OR	3912.3	5006.0	6257.3	3596.2	3619.2
SAN FRANCISCO	3742.5	4714.2	5830.5	3210.6	3465.7
SEATTLE	3992.1	5138.5	6441.4	3603.5	3674.7
TAMPA	2581.3	2791.9	3033.7	2626.5	2867.0
WASHINGTON DC	3645.8	4421.2	5379.9	3675.3	3442.9
WESTHAMPTON,NY	3923.3	4812.9	5946.0	3956.4	3571.3
WILMINGTON DEL	3740.4	4568.4	5593.1	3767.4	3503.9

NOTE: ALL FIGURES BASED ON DAILY USAGE OF 243 LITERS AT 60C

minimizing energy consumption will not necessarily result in minimizing costs. Table 12 uses the energy cost figures from Table 14 and applies them to the data generated in Tables 6 through 10. The unconditioned basement is the most economical location in 10 cities; the unconditioned attached garage is most economical in 5 cities; and inside a house with a central gas system is most economical in 3 cities.

Table 13 adds yet another variable into the picture. This table includes estimated operating costs of resistance water heaters and gas-fired water heaters. When the operating costs of Tables 12 and 13 are compared it is no surprise that gas-fired water heaters are the most economical water heating system in 17 of the 18 cities studied. Seattle has inexpensive electricity and hence favors a HPWH over a gas-fired system.

Many homes however, do not have access to natural gas, and must heat their water electrically. For this case Tables 12 and 13 show the operating cost advantage of a HPWH over a resistance water heater.

In many of the cities studied, especially those in the south, differences in operating costs between HPWH's in both heat pump conditioned spaces and uncondtioned spaces are small. Also, in Atlanta and Knoxville, HPWH's compare favorably with gas-fired water heating systems. The cost figures in Tables 12 and 13 will change as gas, oil, and electricity prices change. This being the case, that system with the lowest operating cost in many cities may vary as prices change.

TABLE 12

EFFECT OF LOCATION ON ANNUAL OPERATING COST ($) OF HPWH

CITY	HPWH LOCATED INSIDE HOUSE WITH HVAC TYPE HI EFF HP	RES+A/C	60%GAS+A/C	60%OIL+A/C	HPWH LOC IN UNCOND GARAGE	BASEMENT
ALBUQUERQUE	249.60	302.72	229.85	268.56	250.64	239.22
ATLANTA	140.18	166.73	146.45	172.21	136.97	139.15
BOSTON	318.76	385.45	303.19	331.50	332.92	286.77
CHICAGO	224.21	268.19	212.58	251.78	237.38	202.89
DENVER	215.12	261.30	210.11	244.04	223.17	194.22
FT WORTH	171.04	199.64	167.36	191.66	167.95	174.60
KNOXVILLE	128.48	154.02	133.68	165.64	127.29	125.73
LOS ANGELES	235.33	277.18	222.28	252.08	211.81	228.37
MINNEAPOLIS	213.04	247.93	197.31	239.89	230.81	185.87
NEWARK	260.37	317.73	264.61	285.53	261.88	244.12
PITTSBURGH	232.60	280.14	217.29	260.34	242.08	212.65
PORTLAND, OR	157.31	201.29	158.09	211.23	144.60	145.53
SAN FRANCISCO	200.49	252.54	192.35	239.04	171.99	185.66
SEATTLE	64.23	82.68	111.29	140.96	57.98	59.13
TAMPA	136.83	148.00	136.33	146.01	139.23	151.98
WASHINGTON DC	179.88	218.14	183.65	215.55	181.34	169.87
WESTHAMPTON,NY	264.94	325.02	271.33	291.73	267.18	241.17
WILMINGTON DEL	190.01	232.07	201.27	225.81	191.38	178.00

NOTE: ALL FIGURES BASED ON DAILY USAGE OF 243 LITERS AT 60C

TABLE 13

ESTIMATED ANNUAL COST TO OPERATE ELEC RES AND GAS-FIRED WATER HTRS

CITY	ELEC RES COND SP	WATER HEATER IN GARAGE	WATER HEATER IN BASEMENT	GAS-FIRED COND SP	GAS-FIRED WATER HEATER IN GARAGE	GAS-FIRED WATER HEATER IN BASEMENT
ALBUQUERQUE	423.62	428.83	431.73	99.17	100.39	101.07
ATLANTA	248.17	249.55	252.60	133.76	134.51	136.16
BOSTON	505.01	519.40	517.68	196.46	202.05	201.38
CHICAGO	359.54	369.35	367.92	139.29	143.09	142.54
DENVER	340.56	350.45	349.83	149.65	154.00	153.73
FT WORTH	311.15	309.53	315.79	105.33	104.78	106.90
KNOXVILLE	223.54	225.64	227.72	118.29	119.41	120.51
LOS ANGELES	401.42	401.84	409.87	93.96	94.05	95.93
MINNEAPOLIS	331.02	341.16	338.91	134.63	138.75	137.84
NEWARK	432.54	440.78	441.92	208.22	212.18	212.73
PITTSBURGH	375.54	385.77	385.12	125.23	128.65	128.43
PORTLAND, OR	251.24	256.81	258.70	103.11	105.40	106.17
SAN FRANCISCO	320.11	322.49	328.85	101.09	101.84	103.85
SEATTLE	102.27	104.46	105.33	187.50	191.51	193.10
TAMPA	277.92	272.42	279.94	104.81	102.74	105.58
WASHINGTON DC	300.44	305.76	306.85	148.20	150.83	151.36
WESTHAMPTON,NY	421.56	433.30	432.74	215.41	221.41	221.12
WILMINGTON DEL	314.52	320.90	321.65	182.81	186.52	186.95

NOTE: ALL FIGURES BASED ON DAILY USAGE OF 243 LITERS AT 60C
GAS WATER HEATERS WERE ASSUMED TO BE 50% EFFICIENT

TABLE 14

ENERGY COSTS (JAN,1981) USED IN PREPARATION OF TABLES 12 AND 13

CITY	FUEL OIL $/GAL	NATURAL GAS $/100 THERMS	ELECTRICITY $/1000 KWH
ALBUQUERQUE	1.12	30.22	70.49
ATLANTA	1.17	41.95	42.50
BOSTON	1.18	56.00	78.61
CHICAGO	1.13	39.53	55.72
DENVER	1.07	42.81	53.20
FT WORTH	1.17	35.08	56.59
KNOXVILLE	1.17	36.67	37.84
LOS ANGELES	1.13	30.08	70.18
MINNEAPOLIS	1.11	36.97	49.64
NEWARK	1.19	61.08	69.29
PITTSBURGH	1.15	35.92	58.82
PORTLAND, OR	1.12	30.22	40.21
SAN FRANCISCO	1.12	30.98	53.57
SEATTLE	1.13	54.02	16.09
TAMPA	1.17	36.61	53.01
WASHINGTON DC	1.17	44.57	49.34
WESTHAMPTON,NY	1.18	63.19	67.53
WILMINGTON DEL	1.15	54.07	50.80

NOTES: SOURCES OF DATA INCLUDE

E. A. Nephew, et al., *Performance and Economics of the ACES and Alternative Residential Heating and Air Conditioning Systems in 115 U.S. Cities*, ORNL/CON-52, March 1981.

U. S. News and World Report, p. 57 (February 9, 1981).

U. S. Department of Energy, "Typical Electric Bills - January 1, 1979," DOE EIA-0040(79), October 1979.