ornl

OAK
RIDGE
NATIONAL
LABORATORY

UNION
CARBIDE

ORNL/CON-81

Estimated Seasonal Performance of a Heat Pump Water Heater Including Effects of Climate and In-House Location

W. P. Levins

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A03 Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/CON-81

Contract No. W-7405-eng-26

ENERGY DIVISION

ESTIMATED SEASONAL PERFORMANCE OF A HEAT PUMP WATER HEATER INCLUDING EFFECTS OF CLIMATE AND IN-HOUSE LOCATION

W. P. Levins

Date Published: January 1982

Department of Energy
Office of Buildings Energy Research and Development

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

CONTENTS

ABSTRACT v
SUMMARY 1
INTRODUCTION 1
MODELS, ASSUMPTIONS, AND METHODOLOGY 7
RESULTS AND DISCUSSION 8
REFERENCES 12
Appendix A. DATA, ASSUMPTIONS, AND SAMPLE COMPUTER OUTPUT 13
Appendix B. TABLES OF RESULTS 21

ABSTRACT

Both field and laboratory testing have shown that a heat pump water heater (HPWH) uses about half the energy for supplying domestic hot water as does an electric resistance water heater. The HPWH accomplishes this savings by extracting energy from its surroundings, boosting it with some electromechanical energy, and depositing the total energy in the water being heated. If the HPWH is located in the conditioned space of a residence, the energy extracted from the conditioned space must be replaced by the house heating system in the winter. During the cooling season, however, the HPWH will reduce the load on the house air conditioning system.

This report presents the results of a computer study of the effect on the house heating and cooling system brought about by locating a HPWH in either the conditioned space of a house or in unconditioned spaces simulating garages and basements. The effect of climate on HPWH performance and an operating cost comparison of oil, gas, electric resistance, and electric heat pump water heaters are also presented.

SUMMARY

A computer study of the estimated performance of a heat pump water heater (HPWH) under various in-house and geographical locations was carried out at the Oak Ridge National Laboratory (ORNL). An estimated operating cost comparison was also made of gas-fired, oil-fired, electric resistance, and heat pump water heaters for the same in-house and geographical locations. Field test data, laboratory data, and manufacturers' literature were used to model the various types of water heaters and heating, ventilating and air conditioning (HVAC) systems for the study. A ranch-style house was used as the model residence. Monthly groundwater temperature and bin weather data for 18 different U.S. cities were used to model climactic effects. Daily domestic hot water usage was fixed at 243 L (64.3 gal) at a delivery temperature of 60°C (140°F).

The results of the study show that a HPWH in a heat pump– conditioned space of a house can save an average of 2400 kWh/year over an electric resistance water heater. The savings vary from 1200 to 2500 kWh/year in a resistance-heated (HVAC) house, with longer heating seasons corresponding to reduced savings. Locating the HPWH in an unconditioned attached garage saves about 2500 kWh/year compared to a similarly located resistance water heater, while an unconditioned basement location for the HPWH will save about 2800 kWh/year.

Although the operating costs for the HPWH are lower than those for oil-fired water heaters, gas-fired water heaters are the most economical of the modeled water heating systems to operate in 17 of the 18 cities studied, with Seattle being the exception. HPWH operating costs were only slightly higher than gas in both Atlanta and Knoxville. If natural gas is not available, a HPWH is a very attractive choice for a domestic water heating system.

INTRODUCTION

The HPWH is currently making its appearance in the market place. The concept of a heat pump dedicated to heating water for residential use is not new, as two firms manufactured and field tested prototype units in the 1950s.[1] These units proved to be ahead of their time as energy prices were low and the then exisiting heat pump technology did not match the potential of the concept. However, present-day rising energy costs and a more mature heat pump technology and hardware industry have brought about the reemergence of the HPWH.

Figure 1 depicts the national residential primary energy consumption for 1978. This figure shows that domestic water heating accounted for 2.5 EJ (2.4×10^{15} Btu), or 14.4% of the total primary energy consumed to supply residential service.

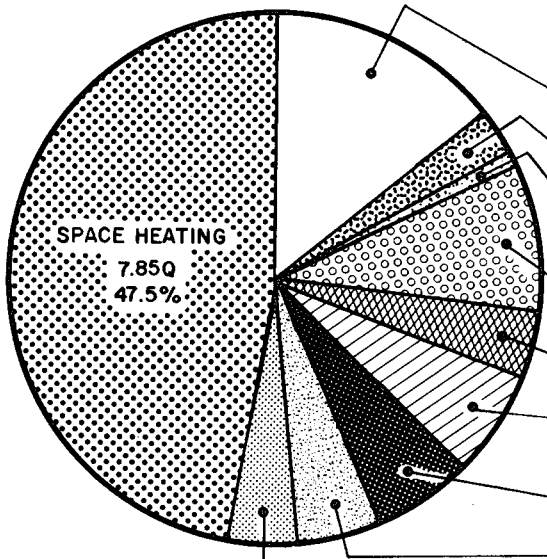
The National Bureau of Standards has stated that an average family of four heats 64.3 gal of water per day 90 F° (from 55°F to 145°F) for their hot water use.[2] This usage corresponds to about 17.5 kWh/d (including tank losses) if an electric resistance water heater is used or 100 MJ/d (0.95 therms/d) if a gas-fired water heater is used.

Of the 76 million households in the United States in 1978, about 31 million contained an electric resistance water heater[3–5] and 43 million had a gas-fired water heater. The potential replacement market of HPWHs for electric resistance water heaters may be estimated at somewhere around 33 million units based on 1981 figures.

There are two types of HPWHs available in today's marketplace, the integral type and the separated or retrofit type. Figure 2 is a photograph of a display model of the integral type HPWH.

ORNL-DWG 81-4793

RESIDENTIAL PRIMARY ENERGY CONSUMPTION
(ESTIMATED AS 16.5 QUADS IN 1978)



APPLIANCE	ANNUAL ENERGY USE (QUADS)	% OF SECTOR
WATER HEATERS	2.37	14.4
GAS	0.88	
ELECTRIC	1.27	
DRYERS	0.46	2.8
GAS	0.07	
ELECTRIC	0.39	
WASHERS	0.06	0.4
REFRIGERATORS	1.49	9.0
FREEZERS	0.65	3.9
AIR CONDITIONERS	1.12	6.8
ROOM	0.37	
CENTRAL	0.75	
LIGHTING	0.96	5.8
RANGES	0.89	5.4
OTHER	0.67	4.0
TOTAL	8.67Q	52.5 %

Fig. 1. National primary residential energy consumption for 1978.

The upper section of the unit contains the compressor, evaporator, expansion valve, etc. Figure 3 is a photograph showing the location of these components. The lower section of the unit contains the water storage tank, in which the condenser is located. The condenser may be seen through the window of the display model in Fig. 2. As the word integral implies, the heat pump and water storage tank of this type HPWH form a single unit. The water storage tank may be replaced, however, should it prove necessary during the life of the system. This operation could be difficult and costly.

Figure 4 is a photograph showing three different models of separated HPWHs. All the heat pump parts are located within these units. This type of HPWH may either be connected to a standard water heater using "washing machine" hoses, or be hard-plumbed to the tank. The separated-type HPWH has components similar to the integral HPWH but also contains a small water pump housed in the unit to circulate water from the storage tank through the condenser and back to the storage tank.

Figure 5 shows an experimental setup in the laboratory in which several HPWHs are undergoing simulated draw schedule tests.

Figure 6 shows a schematic diagram of a HPWH. The four main parts of a HPWH are a compressor, a condenser, an evaporator, and an expansion (flow control) device. In operation a relatively low-pressure, low-temperature refrigerant vapor is compressed to a higher pressure and temperature. The superheated vapor enters the condenser where it condenses to a high-pressure liquid, giving up both sensible and latent heat to the cooler water surrounding the condenser. The high-pressure refrigerant liquid passes through the expansion device and enters the evaporator, a region of low pressure. Because the liquid refrigerant is above its boiling point in the evaporator, it

ORNL–PHOTO 7496–81A

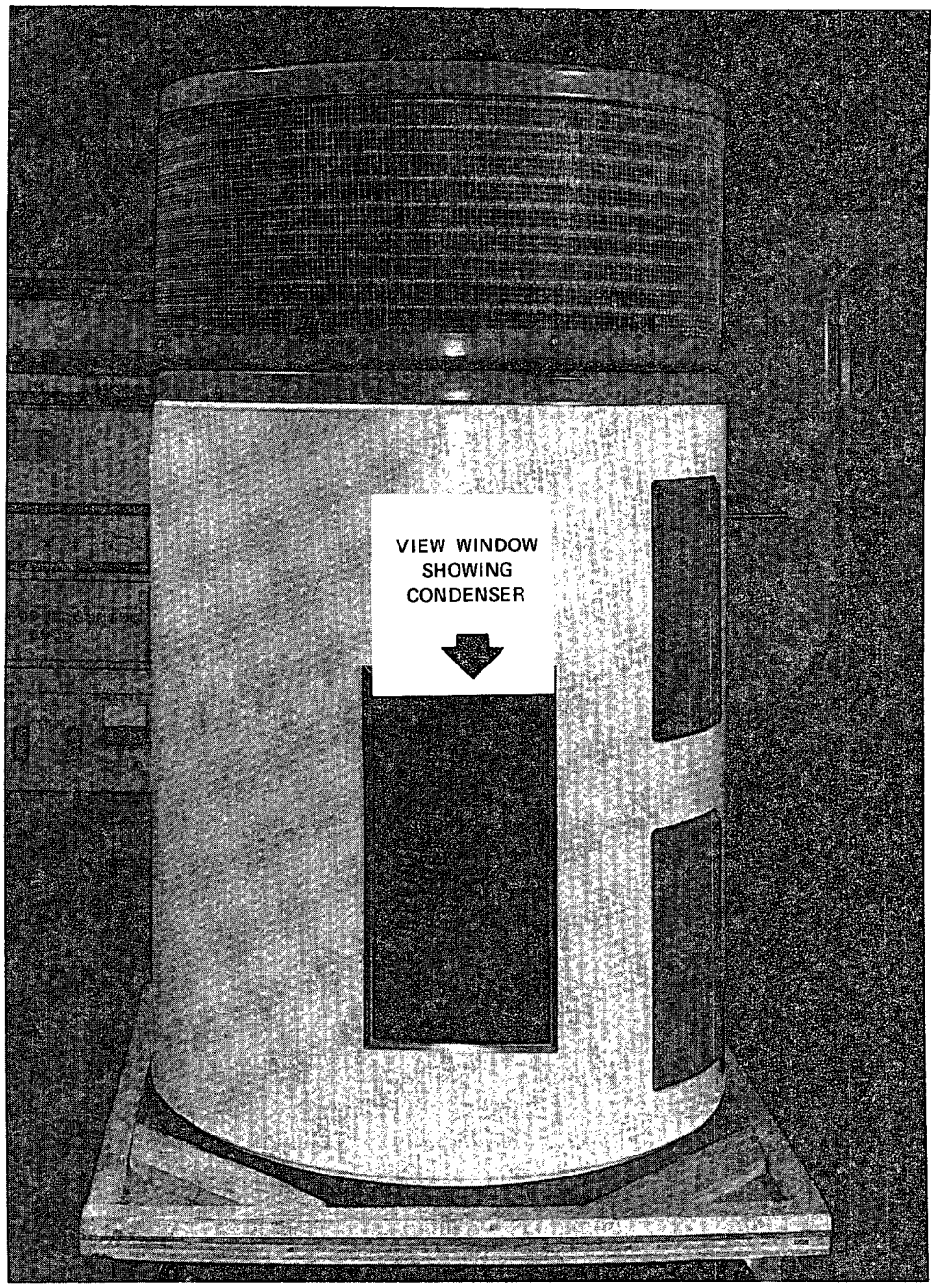


Fig. 2. Display model of integral-type HPWH.

ORNL–PHOTO 7493–81A

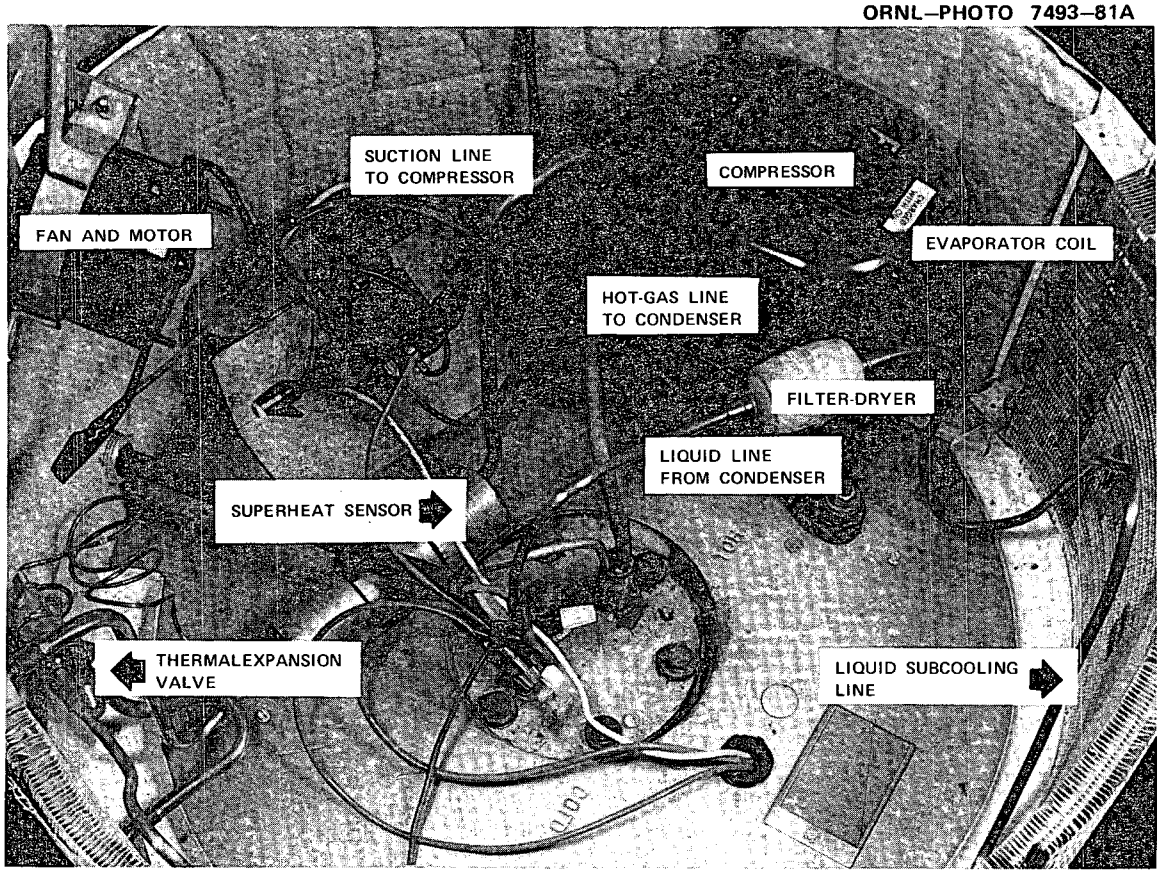


Fig. 3. Location of components of an integral-type HPWH.

ORNL–PHOTO 7497–81A

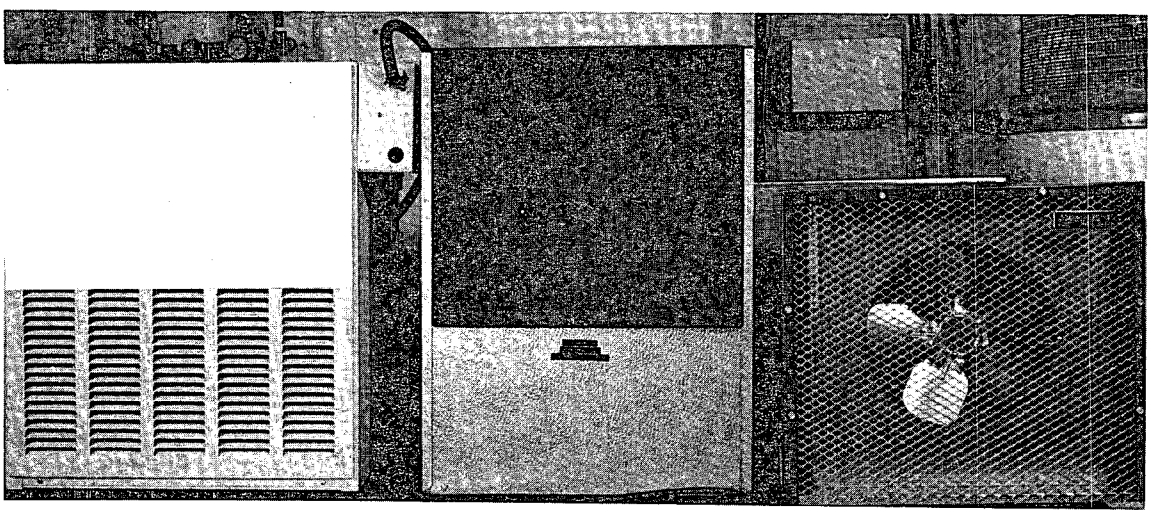


Fig. 4. Three different separated-type HPWHs.

ORNL–PHOTO 7495–81

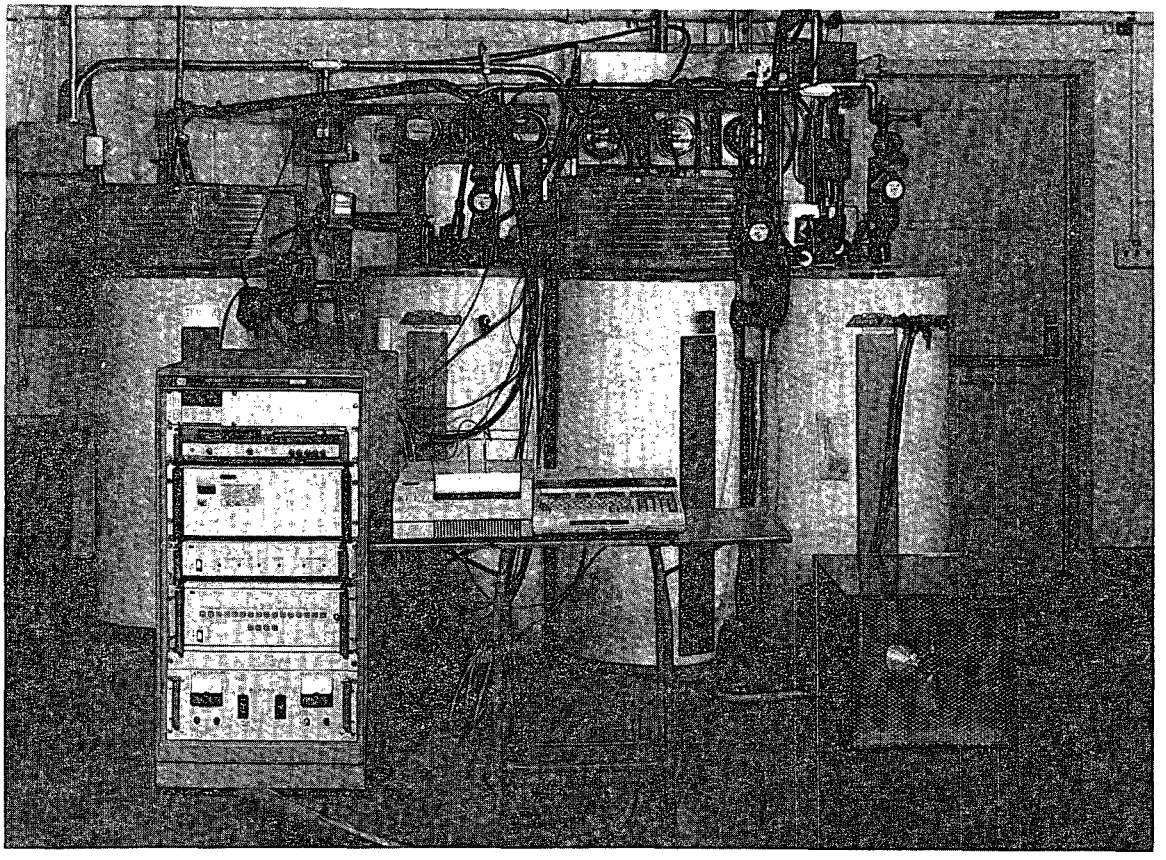


Fig. 5. Laboratory setup used for testing HPWHs.

ORNL-DWG 81-4728R

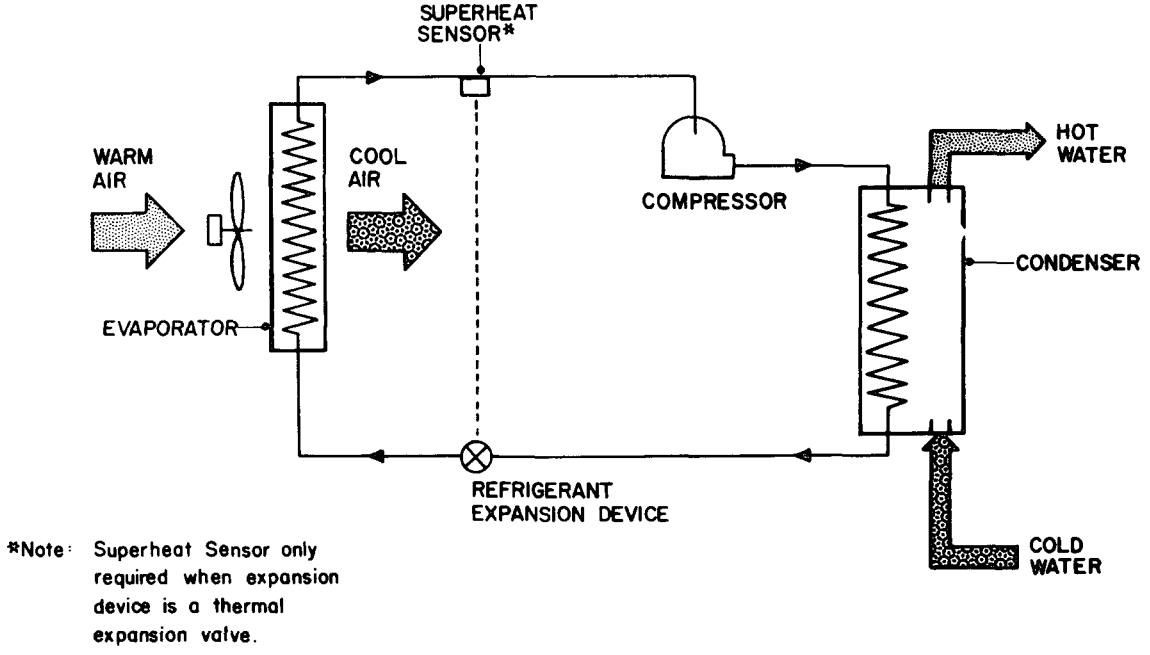


Fig. 6. Schematic of HPWH.

starts to boil, becoming a relatively low-pressure, low-temperature vapor. The latent heat for boiling the refrigerant is supplied by ambient air blown over the evaporaor coil by a small fan. The temperature of the air decreases as it passes over the evaporator. The refrigerant completes its cycle by returning to the compressor.

Figure 7 schematically shows the concept for the HPWH, where the energy comes from, and where it goes.

Given the performance information for a HPWH, one could estimate the potential savings obtained by a given market penetration of the HPWH. The performance of the HPWH, however, is a rather nebulous parameter to quantify. Because the HPWH contains a refrigeration system, its performance is a function of both the source (evaporator side) temperature and the sink (condenser side) temperature. Also, if the HPWH is located in a conditioned (heated and cooled) space in a residence the HPWH will increase the heating load of the HVAC system during the heating season and decrease the cooling load of the HVAC during the cooling season.

This report addresses the problem of the effect of geographic and in-house location on the performance of the HPWH and uses the information to make an annual operating cost comparison of HPWH and electric resistance, gas-fired, and oil-fired water heaters.

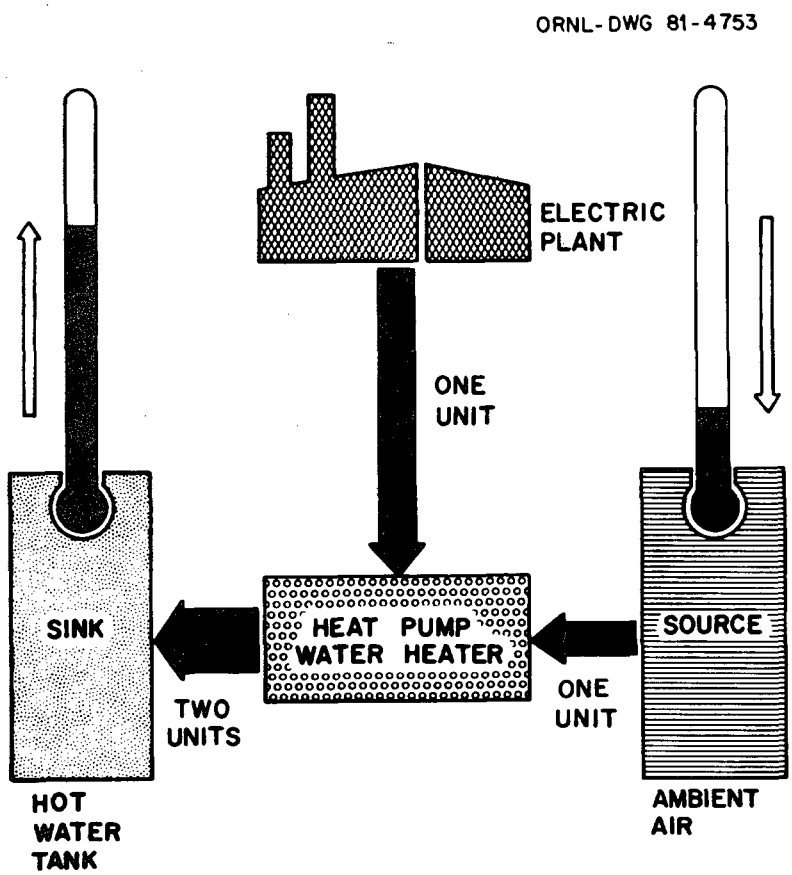


Fig. 7. Concept for HPWH showing approximate energy transfers.

MODELS, ASSUMPTIONS, AND METHODOLOGY

Laboratory and field tests[6] have shown that a HPWH uses about half the electrical energy input when compared to an electric resistance water heater. However, since the HPWH 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 ORNL. Since geography, house construction, type and efficiency of HVAC system, and hot water usage will all affect the effective HPWH performance, some of these parameters were fixed, and some were allowed to vary in the study.

The effect of geographical location was determined by using weather and water temperature data for 18 different cities in the United States and applying them to the same model residence. Figure A.1 in Appendix A shows the locations of these 18 cities.

The house construction was fixed — the author's house was used as the model residence. It is a single-story, well-insulated, ranch-style house, built in 1978, with a partly finished basement and an integral garage. The house heating load line was estimated from data obtained during a 2.5-month winter heating period with central resistance heating, and the house cooling load line was estimated from observed data of air conditioner operating hours.

The HVAC systems covered in this work include heat pumps, resistance heating with electric air conditioning, and 60% efficient gas or oil furnaces with electric air conditioning. Table A.1 contains a description of the computer models used for the house and the HVAC systems.

Figure A.2 is a heating-cooling plot for the residence (without a HPWH) to which the high-performance heat pump performance data have been added. Monthly bin data for each of the 18 cities[7] were used as input weather data so that monthly HVAC loads could be calculated.

The hot water usage of the house was fixed at 243 L/d (64.3 gal/d) at a delivery temperature of 60°C (140°F). Inlet temperatures to the hot water tank varied monthly for each location, and the appropriate value of this parameter[8] was used in the calculations. Table A.2 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 heat pumps as well as resistance-, gas-, and oil-heated houses with electric air conditioners was studied. All calculations were made on a Hewlett-Packard (H-P) 9830A, a desktop computer. Table A.3 contains the assumptions used in the analyses of both conditioned- and unconditioned-space HPWH locations.

Table A.4 is a sample of the output of the program showing monthly HVAC heating and cooling loads for houses with and without a HPWH in a conditioned space. The weather bin data and inlet water temperatures for each city were used to calculate the HVAC energy consumption for the house first with a resistance water heater and then with a HPWH. The difference between these values is the additional HVAC energy used in the house because of the presence of the HPWH. This additional HVAC energy was added to the electrical input of the HPWH to give the equivalent HPWH energy input. The HPWH annual performance factor was calculated by dividing the annual electrical input to a resistance water heater by the annual equivalent HPWH energy input.

Laboratory and field test data[5] were used to model the performance of an integral-type HPWH as a function of ambient temperature, inlet water temperature, and delivery water temperature.

Unconditioned spaces simulating an attached garage and a basement were modeled as described in Table A.3. These models were also used with monthly bin and inlet water temperatures to compute the performance of both resistance water heaters and HPWHs in unconditioned spaces.

RESULTS AND DISCUSSION

Tables B.2 through B.10 in Appendix B contain the results of calculations for each of the 18 cities studied for a HPWH located in the conditioned space of a house with various HVAC systems. Table B.1 contains an explanation of the several column headings used in these tables. All of the energy usages in this report, except in Fig. 1, are expressed in equivalent kWh at the point of use (primary energy source is not considered).

Tables B.2 through B.4 show that locating a HPWH in a conditioned space of a house with a heat pump HVAC saves about 2400 kWh per year in effective water heating energy compared to the same house with a resistance water heater. Both geography (climate) and heat pump HVAC efficiency show minor effects on the results.

Tables B.3 through B.7 show that locating a HPWH in a conditioned space of a house with a resistance heat-electric air conditioner HVAC reduces the effective water heating energy (relative to a resistance water heater) substantially in most cases, with climate having a major effect on the results. A longer heating season will reduce savings, while a longer cooling season will increase savings. The annual savings ranged from 1200 to 2500 kWh for a resistance-heated house.

Tables B.8 through B.10 show that locating a HPWH in a conditioned space of a house with a 60% efficient gas or oil-electric air conditioner HVAC causes the results to be extremely climate sensitive. Seattle and Portland have long heating seasons and short cooling seasons and show a slight negative energy savings when a HPWH is used in place of a resistance water heater.

Tables B.11 and B.12 show the energy savings for a HPWH over a resistance water heater when the comparison is made for locating each in unconditioned areas such as attached garages and basements. The HPWH energy savings for these cases do not appear to be overly climate sensitive. Savings obtained from locating the HPWH in an attached garage average about 2500 kWh per year, and a basement location saves about 2800 kWh per year.

Table 1 summarizes Tables B.2 through B.12 and shows the effective annual kWh energy usage of a HPWH (including any HVAC effects) as a function of both in-house and geographical location. The energy usages of both electric resistance and 50%-efficient gas-fired water heaters are also included in Table 1. This table shows that the preferred location for minimizing energy input to a HPWH in 11 of the cities is an unconditioned basement; six cities favor the unconditioned, attached garage; and of the cities studied, only Tampa favors HPWH placement inside the residence, provided the residence has a heat pump HVAC.

If a residence does not have a basement, then 11 cities show minimum energy consumption by locating the HPWH inside a residence with a heat pump HVAC, while seven cities favor the unconditioned attached garage.

Because energy costs vary from location to location and also depend upon the energy source, mimimizing energy consumption will not necessarily result in minimized energy costs. Table 2 uses the energy cost figures presented in Table B.13 and applies them to the data of Table 1. Data on 50% efficient oil-fired water heaters are also included in Table 2.

TABLE 1

EFFECT OF LOCATION ON EQUIVALENT ANNUAL KWH ENERGY USAGE OF HPWH, ELECTRIC RESISTANCE, AND GAS-FIRED WATER HEATERS

CITY	HPWH LOC INSIDE HOUSE WITH HVAC TYPE			HPWH LOC IN UNCOND		ELEC RES WATER HEATER IN			GAS-FIRED WATER HEATER IN		
	HI EFF HP	RES+A/C	60%G/O+A/C	GARAGE	BASEMENT	COND SP	GARAGE	BASEMENT	COND SP	GARAGE	BASEMENT
ALBUQUERQUE	3540.9	4294.5	5205.9	3555.7	3393.7	6009.6	6083.5	6124.7	9615.4	9733.6	9799.5
ATLANTA	3298.3	3923.1	4648.5	3222.8	3274.0	5839.2	5871.7	5943.6	9342.7	9394.7	9509.8
BOSTON	4055.0	4903.3	6076.2	4235.1	3648.0	6424.3	6607.3	6585.4	10278.9	10571.7	10536.6
CHICAGO	4023.8	4813.1	5928.6	4260.2	3641.3	6452.7	6628.7	6603.1	10324.3	10605.9	10565.0
DENVER	4043.6	4911.6	6094.5	4194.9	3650.8	6401.5	6587.4	6575.8	10242.4	10539.8	10521.3
FT WORTH	3022.5	3527.8	4115.2	2967.8	3085.3	5498.4	5469.7	5580.3	8797.4	8751.5	8928.5
KNOXVILLE	3395.3	4070.4	4869.1	3363.9	3322.8	5907.4	5963.1	6018.0	9451.8	9541.0	9628.8
LOS ANGELES	3353.2	3949.6	4639.3	3018.1	3254.1	5719.9	5725.9	5840.2	9151.8	9161.4	9344.3
MINNEAPOLIS	4291.7	4994.5	6174.0	4649.7	3744.4	6668.5	6872.6	6827.4	10669.6	10996.2	10923.8
NEWARK	3757.7	4585.5	5610.6	3779.5	3523.2	6242.5	6361.4	6377.8	9988.0	10178.2	10204.5
PITTSBURGH	3954.5	4762.7	5854.3	4115.6	3615.2	6384.5	6558.5	6547.4	10215.2	10493.6	10475.8
PORTLAND,OR	3912.3	5006.0	6257.3	3596.2	3619.2	6248.2	6386.8	6433.8	9997.1	10218.9	10294.1
SAN FRANCISCO	3742.5	4714.2	5830.5	3210.6	3465.7	5975.5	6020.0	6138.7	9560.8	9632.0	9821.9
SEATTLE	3992.1	5138.5	6441.4	3603.5	3674.7	6356.1	6492.2	6546.0	10169.8	10387.5	10473.6
TAMPA	2581.3	2791.9	3033.7	2626.5	2867.0	5242.8	5139.0	5280.9	8388.5	8222.4	8449.4
WASHINGTON DC	3645.8	4421.2	5379.9	3675.3	3442.9	6089.1	6197.0	6219.0	9742.6	9915.2	9950.4
WESTHAMPTON,NY	3923.3	4812.9	5946.0	3956.4	3571.3	6242.5	6416.4	6408.1	9988.0	10266.2	10253.0
WILMINGTON,DEL	3740.4	4568.4	5593.1	3767.4	3503.9	6191.4	6317.0	6331.6	9906.2	10107.2	10130.6

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

TABLE 2

EFFECT OF LOCATION ON ESTIMATED ANNUAL OPERATION COST ($) OF HPWH, ELECTRIC RESISTANCE, GAS-FIRED, AND OIL-FIRED WATER HEATERS

CITY	HPWH LOCATED INSIDE HOUSE WITH HVAC TYPE				HPWH LOC IN UNCOND		ELEC RES WATER HEATER IN			GAS-FIRED WATER HEATER IN			OIL-FIRED WATER HEATER IN		
	HI EFF HP	RES+A/C	60%GAS+A/C	60%OIL+A/C	GARAGE	BASEMENT	COND SP	GARAGE	BASEMENT	COND SP	GARAGE	BASEMENT	COND SP	GARAGE	BASEMENT
ALBUQUERQUE	249.60	302.72	229.85	268.56	250.64	239.22	423.62	428.83	431.73	99.17	100.39	101.07	262.54	265.77	267.57
ATLANTA	140.18	166.73	146.45	172.21	136.97	139.15	248.17	249.55	252.60	133.76	134.51	136.16	266.48	267.96	271.25
BOSTON	318.76	385.45	303.19	331.50	332.92	286.77	505.01	519.40	517.68	196.46	202.05	201.38	295.69	304.11	303.10
CHICAGO	224.21	268.19	212.58	251.78	237.38	202.89	359.54	369.35	367.92	139.29	143.09	142.54	284.41	292.17	291.04
DENVER	215.12	261.30	210.11	244.04	223.17	194.22	340.56	350.45	349.83	149.65	154.00	153.73	267.17	274.93	274.45
FT WORTH	171.04	199.64	167.36	191.66	167.95	174.60	311.15	309.53	315.79	105.33	104.78	106.90	250.93	249.62	254.67
KNOXVILLE	128.48	154.02	133.68	165.64	127.29	125.73	223.54	225.64	227.72	118.29	119.41	120.51	269.59	272.14	274.64
LOS ANGELES	235.33	277.18	222.28	252.08	211.81	228.37	401.42	401.84	409.87	93.96	94.05	95.93	252.11	252.38	257.42
MINNEAPOLIS	213.04	247.93	197.31	239.89	230.81	185.87	331.02	341.16	338.91	134.63	138.75	137.84	288.72	297.56	295.60
NEWARK	260.37	317.73	264.61	285.53	261.88	244.12	432.54	440.78	441.92	208.22	212.18	212.73	289.76	295.28	296.04
PITTSBURGH	232.60	280.14	217.29	260.34	242.08	212.65	375.54	385.77	385.12	125.23	128.65	128.43	286.39	294.19	293.69
PORTLAND,OR	157.31	201.29	158.09	211.23	144.60	145.53	251.24	256.81	258.70	103.11	105.40	106.17	272.96	279.02	281.07
SAN FRANCISCO	200.49	252.54	192.35	239.04	171.99	185.66	320.11	322.49	328.85	101.09	101.84	103.85	261.05	262.99	268.18
SEATTLE	64.23	82.68	111.29	140.96	57.98	59.13	102.27	104.46	105.33	187.50	191.51	193.10	280.15	286.15	288.52
TAMPA	136.83	148.00	136.33	146.01	139.23	151.98	277.92	272.42	279.94	104.81	102.74	105.58	239.26	234.53	241.00
WASHINGTON DC	179.88	218.14	183.65	215.55	181.34	169.87	300.44	305.76	306.85	148.20	150.83	151.36	277.89	282.81	283.81
WESTHAMPTON,NY	264.94	325.02	271.33	291.73	267.18	241.17	421.56	433.30	432.74	215.41	221.41	221.12	287.32	295.33	294.94
WILMINGTON,DEL	190.01	232.07	201.27	225.81	191.38	178.00	314.52	320.90	321.65	182.81	186.52	186.95	277.72	283.36	284.01

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LITERS AT 60C
GAS WATER HEATERS ASSUMED TO BE 50% EFFICIENT
OIL WATER HEATERS ASSUMED TO BE 50% EFFICIENT
FUEL COSTS ARE LISTED IN TABLE B.13

Table 2 sums up the fuel cost economics of many water heating options available to a home owner. It is no surprise that gas-fired water heaters are the most economical system to operate in 17 of the 18 cities studied, even though the gas-fired water heater rivals the oil-fired water heater as the least efficient (point of use) system. 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 with other energy sources such as electricity, oil, coal, wood, solar, etc., with electricity being the overwhelming choice. For this case Table 2 shows the operating cost advantage of a HPWH over both a resistance water heater and an oil-fired water heater.

In many of the cities studied, especially in the south, differences in operating costs between HPWHs in heat pump-conditioned spaces and in unconditioned spaces are small. Also, HPWHs compare favorably with gas-fired water heating systems in both Atlanta and Knoxville.

The reader should keep in mind when interpreting the results of this report that they only apply to the models used and the assumptions made. All models and assumptions were, however, based on the best available information. The operating cost figures in Table 2 are sensitive to gas, oil, and electricity prices, and the system with the lowest cost in any city may vary as prices change. Differences in the performance of the various brands of HPWHs and the relative size of a heat pump HVAC to the house heating and cooling load will have a slight effect on the results. Also, Table B.14 shows how increased water usage results in greater savings for a HPWH over a resistance water heater.

REFERENCES

1. J. B. Chaddock, "Feasibility Study of the Heat Pump Water Heater," pp. 5–8 in *Joint AEIC-EEI Heat Pump Water Heater Subcommittee Research Contract No. PRF2420*, R. W. Herrick Laboratories, Purdue University, August 1961.
2. "Test Procedure for Water Heaters," *Fed. Regist.* **42**(192): Sect. B.6 (Oct. 4, 1977).
3. *Merchandising Magazine*, p. 54 (March 1976).
4. American Gas Association, *Gas Facts, 1975 Data*, 1975.
5. Census Bureau, Department of Commerce, *Statistical Abstract of the United States, 1979 Ed.*, p. 44.
6. R. P. Blevins, B. D. Sloane, and G. E. Valli, *Demonstration of a Heat Pump Water Heater*, **2**, Final Report, ORNL/Sub-7321/4 (June 1981).
7. Department of the Air Force, *Engineering Weather Data*, AFM 88-29 (July 1978).
8. L. A. Abbatiello, E. A. Nephew, and M. L. Ballou, *Performance and Economics of ACES and Alternative Residential Heating and Air Conditioning Systems in 115 U.S. Cities*, ORNL/CON-52 (March 1981).

Appendix A

DATA, ASSUMPTIONS, AND SAMPLE COMPUTER OUTPUT

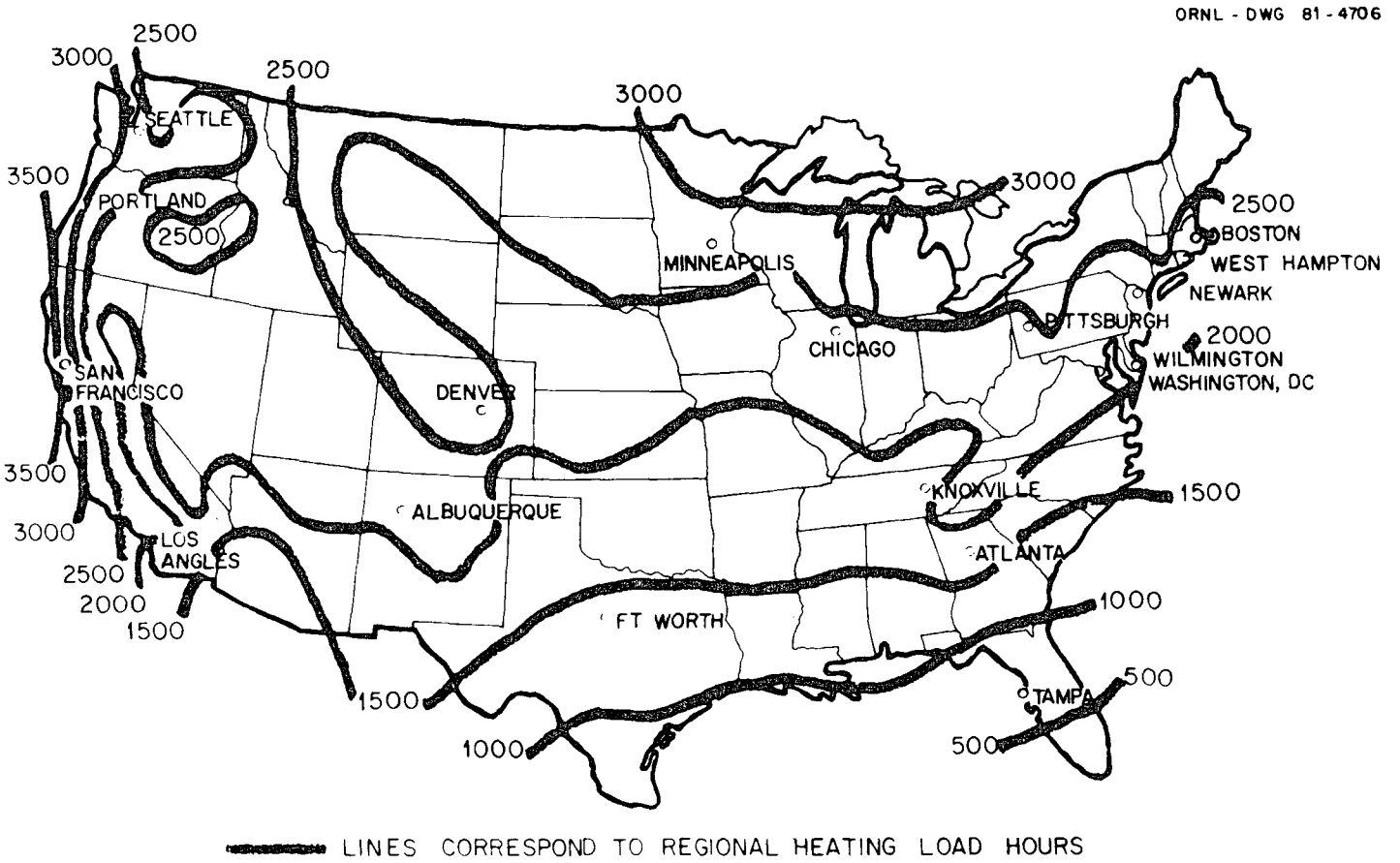


Fig. A.1. Locations of the 18 cities covered in HPWH study.

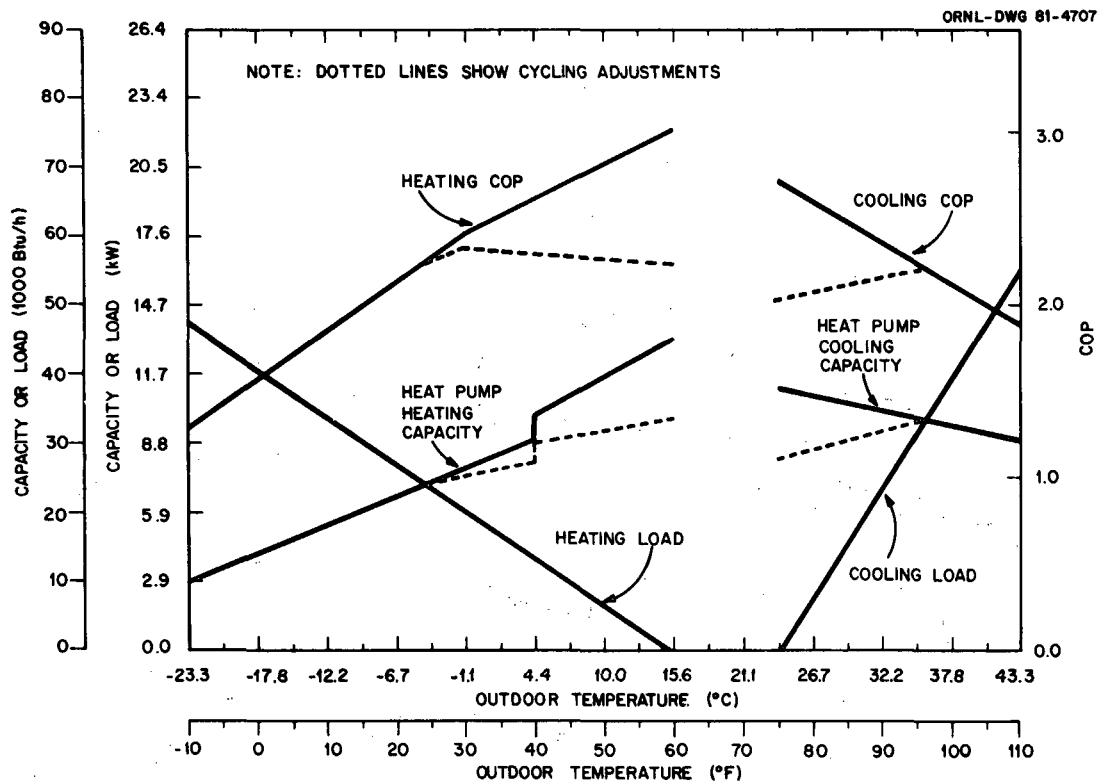


Fig. A.2. Heating-cooling diagram of model residence (no HPWH) and characteristics of the high-performance heat pump.

Table A.1. Computer models of house and heat pump

House model

Ranch house with finished basement and integral garage:
148.6 m^2(1600 ft^2) on main level
74.3 m^2(800 ft^2) in basement

Heating load line: kW = 5.43 − 0.362T (°C) [Btu/h = 40,412 − 685T (°F)]

Cooling load line: kW = 0.828T (°C) − 19.79 [Btu/h = 1,571.4T (°F) − 117,857]

Heat pump model

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

Data per Carrier catalog No. 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 min out of each 95 min 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-min defrost period to nullify the heat removed from the house by the heat pump

Medium performance: System COP assmed to be 90% of high-performance heat pump. Output identical to that of high-performance heat pump

Low performance: System COP assumed to be 81% of high-peformance heat pump. Output identical to that of high-peformance heat pump

Resistance heat model

System assumed to be 100% efficient

60% gas/oil furnace model

System assumed to be 60% as efficient as resistance heat model

Electric air conditioner models

Systems assumed to follow performance of high-, medium-, and low-efficiency heat pumps in cooling mode

TABLE A.2

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

NOTE: SOURCE OF DATA

NEPHEW,E.,ET AL,"PERFORMANCE AND ECONOMICS OF THE ACES AND ALTERNATIVE RESIDENTIAL HEATING AND AIR CONDITIONING SYSTEMS IN 115 US CITIES",ORNL/CON-52,MARCH,1981

Table A.3. Assumptions used for conditioned and unconditioned spaces

Assumptions common to all calculations

1. HPWH performance factor[a] = 1.754 + 0.0088C − 0.0022 (W − 15.5) where C = temperature (°C) in HPWH surroundings and W = inlet water temperature (°C) to HPWH
2. Hot water consumption = 243 L/d (64.3 gal/d) at 60°C (140°F)
3. HPWH and resistance water heater standby losses (watts) = 3.69 (60 − C)
4. HPWH runs continuously but at reduced levels to meet both hot water demand and standby losses
5. House temperature kept at constant 21.1°C (70°F) in heating mode and 23.8°C (75°F) in cooling mode

Additional assumption — house without heat pump water heater

1. I^2R water heater located in conditioned space of house

Additional assumptions — house with heat pump water heater

1. HPWH replaces I^2R water heater in house
2. HPWH extracts energy uniformly (at a constant rate) from house 24 h/d
3. House heating and cooling load lines include the hourly enthalpy extraction rate of the HPWH from the house

Additional assumptions — unconditioned attached garage

1. When T is greater than or equal to 18.3°C, $C = T$ where T = outside air temperature (°C)
2. When T is between −1.1°C and 18.3°C, $C = T + 5.5$
3. When T is less than −1.1°C, C = 4.4°C
4. When C = 4.4°C, HPWH operates in resistance mode

Additional assumptions — unconditioned basement

1. When T is greater than 21.1°C, C = 21.1°C.
2. When T is between 21.1°C and 12.8°C, $C = T$
3. When T is less than 12.8°C, C = 12.8°C

[a]Based on laboratory and field test data.

TABLE A.4 SAMPLE COMPUTER PROGRAM OUTPUT FOR HOUSE HVAC

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

	S U M M A R Y		H E A T I N G			C O O L I N G		
MON	TOTAL BTU	TOTAL KWH	BTU DLVRD	HTG KWH	HCOP	BTU REMVD	CLG KWH	CCOP
JUN	3.829E+06	523.5	5.175E+04	6.7	2.28	3.777E+06	516.9	2.14
JUL	5.271E+06	719.1	3.379E+03	0.4	2.27	5.268E+06	718.6	2.15
AUG	4.695E+06	641.3	5.068E+03	0.7	2.27	4.690E+06	640.6	2.14
SEP	2.792E+06	380.5	2.680E+05	34.3	2.29	2.524E+06	346.2	2.14
OCT	2.756E+06	362.5	2.294E+06	298.0	2.26	4.626E+05	64.5	2.10
NOV	6.803E+06	931.8	6.781E+06	928.7	2.14	2.240E+04	3.2	2.08
DEC	1.024E+07	1482.9	1.024E+07	1482.9	2.02	0.000E+00	0.0	0.00
JAN	1.045E+07	1550.6	1.045E+07	1550.6	1.98	0.000E+00	0.0	0.00
FEB	7.587E+06	1094.6	7.587E+06	1094.6	2.03	0.000E+00	0.0	0.00
MAR	6.683E+06	915.3	6.649E+06	910.4	2.14	3.415E+04	4.8	2.07
APR	3.137E+06	412.9	2.680E+06	349.2	2.25	4.571E+05	63.7	2.10
MAY	2.401E+06	324.9	6.146E+05	78.2	2.30	1.787E+06	246.7	2.12
TOT	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

	S U M M A R Y		H E A T I N G			C O O L I N G		
MON	TOTAL BTU	TOTAL KWH	BTU DLVRD	HTG KWH	HCOP	BTU REMVD	CLG KWH	CCOP
JUN	4.054E+06	552.1	3.297E+04	4.3	2.26	4.021E+06	547.8	2.15
JUL	5.564E+06	755.8	2.187E+03	0.3	2.25	5.562E+06	755.5	2.16
AUG	4.967E+06	675.6	3.281E+03	0.4	2.25	4.964E+06	675.2	2.15
SEP	2.897E+06	394.0	2.001E+05	25.8	2.27	2.697E+06	368.2	2.15
OCT	2.509E+06	333.1	1.988E+06	260.8	2.23	5.216E+05	72.3	2.11
NOV	6.246E+06	863.9	6.219E+06	860.2	2.12	2.670E+04	3.7	2.09
DEC	9.545E+06	1391.8	9.545E+06	1391.8	2.01	0.000E+00	0.0	0.00
JAN	9.738E+06	1453.2	9.738E+06	1453.2	1.96	0.000E+00	0.0	0.00
FEB	6.953E+06	1012.5	6.953E+06	1012.5	2.01	0.000E+00	0.0	0.00
MAR	6.079E+06	841.5	6.037E+06	835.5	2.12	4.241E+04	6.0	2.09
APR	2.853E+06	379.4	2.333E+06	307.3	2.22	5.200E+05	72.1	2.11
MAY	2.442E+06	330.9	4.915E+05	63.0	2.28	1.950E+06	267.9	2.13
TOT	6.385E+07	8983.8	4.354E+07	6215.2	2.05	2.030E+07	2768.6	2.15

Appendix B

TABLES OF RESULTS

Table B.1. Explanation of column headings used in Tables B.2 through B.10

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 resistance water heater kWh input (Res Wh kWh in) by the HPWH equivalent kWh input (HPWH eq kWh in)

TABLE B.2

HPWH IN HOUSE WITH HIGH PERFORMANCE HEAT PUMP

C I T Y	HPWH 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

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.3

HPWH IN HOUSE WITH MEDIUM PERFORMANCE HEAT PUMP

C I T Y	HPWH 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	670.6	166.0	3581.4	6009.6	2428.2	1.68
ATLANTA	3008.1	511.2	192.4	3326.9	5839.2	2512.3	1.76
BOSTON	3240.7	975.4	107.4	4108.7	6424.3	2315.6	1.56
CHICAGO	3251.7	943.8	124.3	4071.3	6452.7	2381.4	1.58
DENVER	3231.8	972.4	105.1	4099.1	6401.5	2302.5	1.56
FT WORTH	2867.9	414.6	245.8	3036.7	5498.4	2461.7	1.81
KNOX TN	3035.7	574.4	181.6	3428.5	5907.4	2478.9	1.72
LA CAL	2959.4	486.9	49.4	3396.9	5719.9	2323.0	1.68
MINN MN	3334.9	1120.3	121.9	4333.3	6668.5	2335.2	1.54
NEWARK	3169.4	772.7	135.1	3807.0	6242.5	2435.5	1.64
PITTS PA	3225.1	890.7	110.9	4004.9	6384.5	2379.6	1.59
PTLND OR	3171.7	866.5	47.3	3990.9	6248.2	2257.3	1.57
SF CAL	3063.1	780.8	25.9	3818.0	5975.5	2157.6	1.57
SEATTLE	3214.1	895.3	33.4	4076.0	6356.1	2280.1	1.56
TAMPA	2760.5	169.0	368.1	2561.4	5242.8	2681.4	2.05
WASH DC	3108.6	721.5	139.5	3690.6	6089.1	2398.5	1.65
WHMTN NY	3169.4	878.1	62.5	3985.1	6242.5	2257.4	1.57
WILM DEL	3149.2	771.9	130.9	3790.2	6191.4	2401.2	1.63

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.4

HPWH IN HOUSE WITH LOW PERFORMANCE HEAT PUMP

C I T Y	HPWH 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	726.3	182.2	3621.0	6009.6	2388.6	1.66
ATLANTA	3008.1	557.9	211.1	3354.8	5839.2	2484.4	1.74
BOSTON	3240.7	1038.3	117.9	4161.1	6424.3	2263.2	1.54
CHICAGO	3251.7	1002.3	136.4	4117.7	6452.7	2335.0	1.57
DENVER	3231.8	1036.7	115.4	4153.2	6401.5	2248.4	1.54
FT WORTH	2867.9	452.3	269.8	3050.5	5498.4	2447.9	1.80
KNOX TN	3035.7	624.5	199.3	3460.9	5907.4	2446.5	1.71
LA CAL	2959.4	534.4	54.2	3439.6	5719.9	2280.3	1.66
MINN MN	3334.9	1172.7	133.8	4373.8	6668.5	2294.7	1.52
NEWARK	3169.4	833.9	148.3	3855.1	6242.5	2387.4	1.62
PITTS PA	3225.1	950.6	121.7	4054.0	6384.5	2330.5	1.57
PTLND OR	3171.7	947.8	51.9	4067.6	6248.2	2180.6	1.54
SF CAL	3063.1	856.9	28.4	3891.6	5975.5	2084.0	1.54
SEATTLE	3214.1	980.6	36.6	4158.0	6356.1	2198.1	1.53
TAMPA	2760.5	185.4	404.0	2542.0	5242.8	2700.9	2.06
WASH DC	3108.6	778.9	153.1	3734.4	6089.1	2354.7	1.63
WHMTN NY	3169.4	944.4	68.6	4045.3	6242.5	2197.3	1.54
WILM DEL	3149.2	833.1	143.7	3838.7	6191.4	2352.7	1.61

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.5

HPWH IN HOUSE WITH RESISTANCE HEAT & HIGH PERFORMANCE A/C

C I T Y	HPWH 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

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.6

HPWH IN HOUSE WITH RESISTANCE HEAT & MEDIUM PERFORMANCE A/C

C I T Y	HPWH 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	166.0	4278.0	6009.6	1731.7	1.40
ATLANTA	3008.1	1088.1	192.4	3903.8	5839.2	1935.4	1.50
BOSTON	3240.7	1759.3	107.4	4892.6	6424.3	1531.7	1.31
CHICAGO	3251.7	1673.2	124.3	4800.6	6452.7	1652.0	1.34
DENVER	3231.8	1774.4	105.1	4901.1	6401.5	1500.5	1.31
FT WORTH	2867.9	881.1	245.8	3503.2	5498.4	1995.2	1.57
KNOX TN	3035.7	1198.1	181.6	4052.2	5907.4	1855.2	1.46
LA CAL	2959.4	1034.6	49.4	3944.7	5719.9	1775.3	1.45
MINN MN	3334.9	1769.3	121.9	4982.3	6668.5	1686.2	1.34
NEWARK	3169.4	1537.7	135.1	4572.1	6242.5	1670.4	1.37
PITTS PA	3225.1	1637.4	110.9	4751.6	6384.5	1632.9	1.34
PTLND OR	3171.7	1876.9	47.3	5001.3	6248.2	1246.9	1.25
SF CAL	3063.1	1674.4	25.9	4711.6	5975.5	1264.0	1.27
SEATTLE	3214.1	1954.4	33.4	5135.1	6356.1	1221.0	1.24
TAMPA	2760.5	362.7	368.1	2755.1	5242.8	2487.7	1.90
WASH DC	3108.6	1438.1	139.5	4407.3	6089.1	1681.9	1.38
WHMTN NY	3169.4	1699.7	62.5	4806.7	6242.5	1435.8	1.30
WILM DEL	3149.2	1537.0	130.9	4555.3	6191.4	1636.1	1.36

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.7

HPWH IN HOUSE WITH RESISTANCE HEAT & LOW PERFORMANCE A/C

C I T Y	HPWH 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	182.2	4261.8	6009.6	1747.9	1.41
ATLANTA	3008.1	1088.1	211.1	3885.0	5839.2	1954.2	1.50
BOSTON	3240.7	1759.3	117.9	4882.1	6424.3	1542.1	1.32
CHICAGO	3251.7	1673.2	136.4	4788.5	6452.7	1664.2	1.35
DENVER	3231.8	1774.4	115.4	4890.8	6401.5	1510.7	1.31
FT WORTH	2867.9	881.1	269.8	3479.3	5498.4	2019.2	1.58
KNOX TN	3035.7	1198.1	199.3	4034.5	5907.4	1872.9	1.46
LA CAL	2959.4	1034.6	54.2	3939.9	5719.9	1780.1	1.45
MINN MN	3334.9	1769.3	133.8	4970.4	6668.5	1698.1	1.34
NEWARK	3169.4	1537.7	148.3	4558.9	6242.5	1683.6	1.37
PITTS PA	3225.1	1637.4	121.7	4740.8	6384.5	1643.7	1.35
PTLND OR	3171.7	1876.9	51.9	4996.7	6248.2	1251.5	1.25
SF CAL	3063.1	1674.4	28.4	4709.1	5975.5	1266.5	1.27
SEATTLE	3214.1	1954.4	36.6	5131.8	6356.1	1224.3	1.24
TAMPA	2760.5	362.7	404.0	2719.2	5242.8	2523.6	1.93
WASH DC	3108.6	1438.1	153.1	4393.7	6089.1	1695.5	1.39
WHMTN NY	3169.4	1699.7	68.6	4800.6	6242.5.	1441.9	1.30
WILM DEL	3149.2	1537.0	143.7	4542.5	6191.4	1648.9	1.36

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.8

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

C I T Y	HPWH 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

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.9

HPWH IN HOUSE WITH 60% EFF GAS/OIL HEAT & MEDIUM PERFORMANCE A/C

C I T Y	HPWH 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	166.0	5189.4	6009.6	820.3	1.16
ATLANTA	3008.1	1813.5	192.4	4629.2	5839.2	1210.0	1.26
BOSTON	3240.7	2932.2	107.4	6065.5	6424.3	358.8	1.06
CHICAGO	3251.7	2788.7	124.3	5916.1	6452.7	536.6	1.09
DENVER	3231.8	2957.3	105.1	6084.0	6401.5	317.5	1.05
FT WORTH	2867.9	1468.5	245.8	4090.7	5498.4	1407.8	1.34
KNOX TN	3035.7	1996.9	181.6	4851.0	5907.4	1056.4	1.22
LA CAL	2959.4	1724.4	49.4	4634.5	5719.9	1085.5	1.23
MINN MN	3334.9	2948.8	121.9	6161.8	6668.5	506.7	1.08
NEWARK	3169.4	2562.9	135.1	5597.2	6242.5	645.3	1.12
PITTS PA	3225.1	2729.0	110.9	5843.2	6384.5	541.3	1.09
PTLND OR	3171.7	3128.2	47.3	6252.5	6248.2	-4.3	1.00
SF CAL	3063.1	2790.6	25.9	5827.8	5975.5	147.7	1.03
SEATTLE	3214.1	3257.4	33.4	6438.0	6356.1	-81.9	0.99
TAMPA	2760.5	604.5	368.1	2996.9	5242.8	2245.9	1.75
WASH DC	3108.6	2396.9	139.5	5366.0	6089.1	723.1	1.13
WHMTN NY	3169.4	2832.9	62.5	5939.9	6242.5	302.6	1.05
WILM DEL	3149.2	2561.6	130.9	5579.9	6191.4	611.4	1.11

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.10

HPWH IN HOUSE WITH 60% EFF GAS/OIL HEAT & LOW PERFORMANCE A/C

C I T Y	HPWH 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	182.2	5173.2	6009.6	836.4	1.16
ATLANTA	3008.1	1813.5	211.1	4610.5	5839.2	1228.8	1.27
BOSTON	3240.7	2932.2	117.9	6055.0	6424.3	369.2	1.06
CHICAGO	3251.7	2788.7	136.4	5904.0	6452.7	548.7	1.09
DENVER	3231.8	2957.3	115.4	6073.8	6401.5	327.8	1.05
FT WORTH	2867.9	1468.5	269.8	4066.7	5498.4	1431.7	1.35
KNOX TN	3035.7	1996.9	199.3	4833.3	5907.4	1074.1	1.22
LA CAL	2959.4	1724.4	54.2	4629.6	5719.9	1090.3	1.24
MINN MN	3334.9	2948.8	133.8	6149.9	6668.5	518.6	1.08
NEWARK	3169.4	2562.9	148.3	5584.1	6242.5	658.5	1.12
PITTS PA	3225.1	2729.0	121.7	5832.4	6384.5	552.1	1.09
PTLND OR	3171.7	3128.2	51.9	6247.9	6248.2	0.3	1.00
SF CAL	3063.1	2790.6	28.4	5825.3	5975.5	150.2	1.03
SEATTLE	3214.1	3257.4	36.6	6434.8	6356.1	-78.7	0.99
TAMPA	2760.5	604.5	404.0	2961.0	5242.8	2281.8	1.77
WASH DC	3108.6	2396.9	153.1	5352.4	6089.1	736.7	1.14
WHMTN NY	3169.4	2832.9	68.6	5933.8	6242.5	308.7	1.05
WILM DEL	3149.2	2561.6	143.7	5567.2	6191.4	624.2	1.11

NOTES: ALL FIGURES BASED ON DAILY USAGE OF 243 LTRS AT 60C
HPWH LOCATED IN CONDITIONED SPACE OF HOUSE
HOUSE KEPT AT 21.1C IN HTG AND 23.8C IN CLG

TABLE B.11

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	6092.1	3564.2	2527.9	1.71
ATLANTA	15.4	5874.4	3225.5	2648.8	1.82
BOSTON	9.7	6640.5	4268.3	2372.2	1.56
CHICAGO	9.4	6668.0	4299.5	2368.5	1.55
DENVER	9.9	6619.2	4226.7	2392.5	1.57
FT WORTH	18.7	5472.0	2970.1	2501.9	1.84
KNOXVILLE	14.7	5968.3	3369.1	2599.2	1.77
LOS ANGELES	16.6	5725.9	3018.1	2707.8	1.90
MINNEAPOLIS	7.3	6949.5	4726.6	2222.9	1.47
NEWARK	11.4	6373.2	3791.3	2581.9	1.68
PITTSBURGH	10.0	6585.2	4142.3	2442.9	1.59
PORTLAND, ORE	11.4	6389.2	3598.6	2790.7	1.78
SAN FRANCISCO	14.1	6020.0	3210.6	2809.4	1.88
SEATTLE	10.3	6493.5	3604.7	2888.8	1.80
TAMPA	21.2	5139.1	2626.5	2512.5	1.96
WASHINGTON, DC	12.9	6208.0	3686.3	2521.7	1.68
WESTHAMPTON, NY	11.4	6433.5	3973.5	2460.0	1.62
WILMINGTON,DEL	11.9	6328.8	3779.1	2549.6	1.67

NOTES: T=OUTSIDE AIR TEMPERATURE (C)
C=TEMPERATURE (C) IN UNCONDITIONED SPACE
W=INLET WATER TEMPERATURE (C)
HPWH PF=1.754+0.0088*C-0.0022*(W-15.5)
WHEN T IS GREATER THAN 18.3, C=T
WHEN T IS LESS THAN 18.3, C=T+5.5
WHEN C=4.4 WATER HEATER OPERATES IN RES MODE
C NEVER GETS BELOW 4.4

TABLE B.12

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
FT 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, ORE	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: T=OUTSIDE AIR TEMPERATURE (C)
C=TEMPERATURE (C) IN UNCONDITIONED BASEMENT
W=INLET WATER TEMPERATURE (C)
HPWH PF=1.754+0.0088*C-0.0022*(W-15.5)
WHEN T IS GREATER THAN 21.1, C=21.1
WHEN T IS BETWEEN 21.1 AND 12.8, C=T
WHEN T IS LESS THAN 12.8, C=12.8

TABLE B.13

ENERGY COSTS (JAN,1981) USED IN PREPARATION OF TABLE 2

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

NEPHEW,E.,ET AL,"PERFORMANCE AND ECONOMICS OF THE ACES AND ALTERNATIVE RESIDENTIAL HEATING AND AIR CONDITIONING SYSTEMS IN 115 US CITIES",ORNL/CON-52,MARCH,1981

US NEWS AND WORLD REPORT,P57 (FEB 9,1981)

US DEPT OF ENERGY,"TYPICAL ELECTRIC BILLS-JAN 1,1979", DOE EIA-0040(79),OCT 1979

TABLE B.14

EFFECT HOT WATER CONSUMPTION ON ANNUAL KWH SAVINGS OF HPWH OVER RESISTANCE WATER HEATER

	ANNUAL KWH SAVED BY HPWH LOCATED											
	IN HI EFF HP HOUSE				IN RES HT+A/C HOUSE				IN UNCONDIT GARAGE			
	LTRS/DAY HOT WATER				LTRS/DAY HOT WATER				LTRS/DAY HOT WATER			
CITY	0	132	243	379	0	132	243	379	0	132	243	379
ALBUQUERQUE	548	1610	2469	3548	410	1160	1715	2464	562	1632	2528	3619
ATLANTA	578	1667	2541	3644	464	1301	1916	2750	588	1710	2649	3793
BOSTON	489	1530	2369	3426	335	1022	1521	2205	513	1525	2372	3405
CHICAGO	496	1563	2429	3512	353	1088	1640	2374	505	1519	2369	3403
DENVER	489	1524	2358	3410	331	1003	1490	2162	516	1538	2393	3434
FT WORTH	599	1637	2476	3528	503	1340	1971	2807	570	1621	2502	3575
KNOXVILLE	566	1643	2512	3605	442	1242	1837	2635	579	1679	2599	3721
LOS ANGELES	554	1591	2367	3409	455	1285	1770	2579	610	1752	2708	3873
MINNEAPOLIS	466	1520	2377	3446	342	1099	1674	2431	450	1415	2223	3207
NEWARK	529	1611	2485	3584	381	1117	1657	2392	564	1662	2582	3702
PITTSBURGH	504	1570	2430	3511	358	1087	1622	2347	527	1570	2443	3507
PORTLAND, OR	497	1531	2336	3384	298	889	1242	1821	617	1800	2791	3998
SAN FRANCISCO	508	1511	2233	3243	341	991	1261	1884	621	1812	2809	4025
SEATTLE	493	1546	2364	3431	288	873	1218	1789	628	1859	2889	4144
TAMPA	666	1767	2662	3776	628	1654	2451	3480	573	1629	2513	3590
WASHINGTON DC	535	1592	2443	3516	395	1129	1668	2401	561	1628	2522	3610
WESTHAMPTON, NY	496	1509	2319	3347	333	976	1430	2069	552	1590	2460	3520
WILMINGTON, DEL	528	1592	2451	3533	379	1098	1623	2341	563	1644	2550	3653

NOTE: ALL FIGURES BASED ON HOT WATER TEMPERATURE OF 60C

INTERNAL DISTRIBUTION

1. V. D. Baxter
2. J. W. Boyle
3. N. S. Cardell
4. S. M. Cohn
5. N. E. Collins
6. R. D. Ellison
7. S. K. Fischer
8. R. J. Friar
9. W. Fulkerson
10. C. A. Gallagher
11. C. C. Gilmore
12. R. E. Goodson, Consultant
13. V. O. Haynes
14. K. E. Heidenreich
15. E. L. Hillsman
16. H. E. Hinkle
17. E. Hirst
18. D. E. Holt
19. D. Hunsaker
20. W. T. Jewell
21. G. Kamp
22. C. R. Kerley
23. J. O. Kolb
24. T. R. LaPorte, Consultant
25. W. P. Levins
26. E. R. Marshall
27. H. A. McLain
28. L. N. McCold
29. V. C. Mei
30. J. W. Michel
31. R. E. Minturn
32. W. R. Mixon
33. L. I. Moss, Consultant
34. F. S. Patton, Jr.
35. H. Perez-Blanco
36. A. M. Perry
37. J. H. Reed
38. C. K. Rice
39. T. Rizy
40. R. C. Robertson
41. A. Rose
42. K. N. Spurgeon
43. J. P. Stovall
44. I. A. Tag
45. L. F. Truett
46. E. A. Vineyard
47. T. Vineyard
48. T. J. Wilbanks
49. Emergency Technology Library

50–51. Central Research Library

52. Document Reference Section
53. Energy Information Library
54. Laboratory Records — RC

55–57. Laboratory Records Department

58. ORNL Patent Office

EXTERNAL DISTRIBUTION

59. C. A. Allen, Energy Information Administration, EI-60, Federal Building, 1200 Pennsylvania Avenue N.W., Washington DC 20461
60. Carmen Anzalone, Fedders Corporation, Design Engineering, Edison, NJ 08817
61. Howard Barkley, Duo-Therm, 509 S. Poplar Street, LaGrange, IN 46761
62. E. K. Bastress, Energy Conversion & Utilization Technology Division, CS-142, Forrestal Building, Department of Energy, Washington DC 20585
63. Reason Biddle, Public Service Indiana, 1510 Stafford Road, Plainfield, IN 46168
64. Rob Blevins, EUS, 201 Seco Road, Monroeville, PA 15146
65. Peter Bodett, Duo-Therm, 509 S. Poplar Street, LaGrange, IN 46761
66. J. Calm, EPRI, P.O. Box 10412, Palo Alto, CA 94303
67. J. J. Cuttica, Energy Conversion Equipment Branch, CE-113.2, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
68. G. D. Duffy, Air Conditioning News, 700 East Maple, Birmingham, MI 48011
69. J. N. Eustis, Department of Energy, Office of Industrial Programs, CE-121.1, 1000 Independence Avenue, S.W., Washington, DC 20585

70. R. J. Fiskum, Energy Conversion Equipment Branch, CE-113.2, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
71. Eben V. Fodor, Energy Systems Eng., American Gas Association, 1515 Wilson Blvd., Arlington, VA 22209
72. G. M. Freedman, 49 Sample Bridge Road, Mechanicsburg, PA 17055
73. J. H. Gibbons, Office of Technology Assessment, U.S. Congress, 600 Pennsylvania Avenue S.E., Washington DC 20510
74. Urban Gibson, Texas Power & Light Company, 1511 Bryan, P.O. Box 226331, Dallas, TX 75266
75. Victor Goldschmidt, Ray W. Herrick Laboratories, Purdue University, W. Lafayette, IN 47907
76. D. E. Grether, Friedrich Air Conditioning & Refrigeration, P.O. Box 1540, San Antonio, TX 78295
77. G. C. Groff, Research Division, Carrier Corporation, Syracuse, NY 13201
78. R. A. Grot, National Bureau of Standards, Bldg. 226, Washington, DC 20234
79. M. J. Harms, A. O. Smith Corporation, P.O. Box 28, Kankakee, IL 60901
80. James Harnish, York Division of Borg Warner, P.O. Box 1592, York, PA 17405
81. D. J. Harrje, Princeton University, Mechanical Engineering Department, Princeton, NJ 08540
82. Ian Harry, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94066
83. R. J. Hemphill, Gas Research Institute, 8600 Bryn Mawr Avenue, Residential & Commercial Util., Chicago, IL 60631
84. Larry Hobart, American Public Power Association, 2000 Virginia Avenue N.W., Washington DC 20037
85. Tina Hobson, Building Equipment Division, CE-113.2, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
86. Charles Howard, 14631 Crossway Road, Rockville, MD 20853
87. Leonard Hull, Indianapolis Power & Light, 25 Monument Circle, Indianapolis, IN 46206
88. H. Jaster, General Electric Corporate Research & Development, General Electric Company, P.O. Box 43, Schenectady, NY 13201
89. C. W. Jennings, Tennessee Valley Authority, 205 Sheraton Bldg., Chattanooga, TN 37401
90. P. L. Johnson, Oak Ridge Associated Universities, Executive Office, Administration Building, Oak Ridge, TN 37830
91. Tom Johnson, Hobart Corporation, World Headquarters, Troy, OH 45374
92. W. R. Jones, Ontario Hydro, Research Division, 800 Kipling Avenue, Toronto, Canada M8Z5S4
93. F. R. Kalhammer, Energy Management and Utilization Division, Electric Power Research Inst., 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303
94. T. Kapus, Consumer Products Branch, Department of Energy, CS-11, 1000 Independence Avenue, Washington, DC 20585
95. R. W. King, Manager, Advanced Engineering, Copeland Corporation, Sydney, OH 45365
96. Arvo Lannus, Residential & Commercial Applications, Electric Power Research Inst., 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303
97. D. C. Lim, Energy Conversion Equipment Branch, CE-113.2, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
98. H. P. Luckett, Editor in Chief, Popular Science, 380 Madison Avenue, New York, NY 10017
99. R. Macriss, Institute Gas Technology, Energy Division Center, 4201 W. 36th Street, Chicago, IL 60632
100. Hugh Maguire, Cincinnati Gas & Electric, P.O. Box 960, Cincinnati, OH 45201
101. Jim McCallum, Executive Editor, Air Cond. & Refrig. Bus., 614 Superior Avenue W., Cleveland, OH 44113
102. Pamela McKeever, Public Service New Mexico, P.O. Box 2267, Albuquerque, NM 87103
103. J. P. Millhone, Office of Buildings Energy Research & Development, CE-11, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
104. Louise Morrison, Denver Processing Center, 910 15th Street, Denver, CO 80202

105. F. H. Morse, Office of Solar Heat Technologies, CE-31, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
106. T. Ratchford, Committee on Science and Technology, Subcommittee on Energy R & D, House of Representatives, Washington DC 20515
107. Bill Riley, Advance Development, Heil Quaker Corporation, 647 Thompson Lane, P.O. Box 40566, Nashville, TN 37204
108. J. Rizzuto, New York State Energy Research & Development Auth., Agency Building No. 2, Empire State Plaza, Albany, NY 12223
109. Glenn Robinson, ETECH, 2403-C Johnson Ferry Rd., Atlanta, Georgia 30341
110. H. Ross, Office of Buildings and Community Systems, Department of Energy, 20 Massachusetts Ave., NW, MS-2221C, Washington, DC 20545
111. J. H. Rothenburg, Utilities Systems, Department of Housing & Urban Development, 451 Seventh Street S.W., Washington DC 20410
112. J. D. Ryan, Energy Conversion Equipment Branch, CE-113.2, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
113. L. A. Sarkes, American Gas Association, 1515 Wilson Boulevard, Arlington, VA 22209
114. M. L. Savitz, Deputy Assistant Secretary for Conservation, CE-10, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
115. J. L. Schulze, General Electric Company, Appliance Park, Louisville, KY 40225
116. Mack Sheldon, Oregon Water Heater Company, 8190 S.W. Nimbus Avenue, Buildings, Progress, Oregon 97005
117. T. Sheldon, Tennessee Valley Authority, 205 Sheraton Bldg., Chattanooga, TN 37401
118. D. E. Sherpereel, Research and Engineering Center, Whirlpool Corporation, Benton Harbor, MI 49022
119. J. A. Smith, Test and Evaluation Branch, CE-113.2, Department of Energy, 1000 Independence Avenue S.W., Washington DC 20585
120. Douglas Solley, Thermodyne, P.O. Box 1007, West Columbia, SC 29171
121. R. Sondenreger, Lawrence Berkeley Laboratory, Berkeley, CA 94720
122. E. W. Spannhake, White Consolidated Industries, Inc., 11770 Berea Road, Cleveland, OH 44111
123. W. F. Stoecker, Department of Mechanical & Industrial Engineering, University of Illinois, Urbana, IL 61801
124. W. D. Syniuta, Advanced Mechanical Technology, Inc., 141 California Street, Newton, MA 02158
125. C. C. Thiel, Jr., Division of Advanced Technology Applications, National Science Foundation, 1800 G Street N.W., Washington DC 20550
126. W. H. Thielbahr, Energy Conservation Branch, Department of Energy, Idaho Operations Office, 550 Second Street, Idaho Falls, ID 83401
127. S. S. Waddle, Oak Ridge Operations Office, Department of Energy, Oak Ridge, TN 37830
128. D. J. Walukas, Foster-Miller Associates, Inc., 795 Oak Ridge Turnpike, Oak Ridge, TN 37830
129. David Young, Ontario Hydro Research, 800 Kipling Avenue, Toronto, Canada
130. Thomas Zawacki, Institute of Gas Technology, 3424 S. State Street, Chicago, IL 60616
131. Congressional Information Service, Research Building 83, Kodak Park, Rochester, NY 14050
132. Edison Electric Institute, 8th Floor, 1111 19th Street N.W., Washington DC 20036
133. Office of the Assistant Manager for Energy R & D, U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, TN 37830
134. National Energy Information Center, Library, Room 1404, 12th & Pennsylvania Ave. N.W., Washington DC 20461

135–161. Technical Information Center, Department of Energy, P.O. Box 62, Oak Ridge, TN 37830

162–398. External Energy Conservation Distribution, Oak Ridge National Laboratory, Building 9102-2, Rm. 112, Oak Ridge, TN 37830

☆U.S. GOVERNMENT PRINTING OFFICE: 1981-546-067/368