CONF-830568--2

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ENERGY INTERACTIONS BETWEEN BUILDING-EQUIPMENT SYSTEMS*

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For Presentation at the
International Technical Appliance Conference
Purdue University
W. Lafayette, Indiana

May 17-19, 1983

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ENERGY INTERACTIONS BETWEEN BUILDING EQUIPMENT SYSTEMS

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ABSTRACT

The way in which an appliance is used or where the appliance is located affects its energy usage. The building-equipment system which usually is most affected by the efficiency and/or the manner of operation of other building-equipment systems (appliances) is the house heating and cooling (HVAC) system. This paper discusses two cases of energy interactions between appliances and the house HVAC and uses measured operating data to calculate the appliance energy usage including the HVAC interaction.

The first study involves the interaction between a heat-pump water heater (HPWH) and the house HVAC.[1] Since a HPWH extracts energy from the air in its surroundings and adds it to the water it is heating, the load on the house HVAC will be changed if the HPWH is located in a conditioned space.

The second study concerns the increased amount of infiltration air brought into a house caused by venting a clothes dryer to the outside.[2,3] All the increased infiltration air must be conditioned by the house HVAC if the dryer is located in a conditioned space.

Graphs and tables based on measured data are presented which show the estimated interaction of the house HVAC with a HPWH and a vented electric clothes dryer.

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*Research sponsored by the Office of Building Energy Research and Development, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

INTRODUCTION

In many instances the amount of energy entering an appliance via its electric cord and/or gas inlet line does not give the true energy usage of the appliance. Depending upon where the appliance is located and how it is installed and used, the appliance may interact with the house heating and cooling (HVAC) system and either increase or decrease the load on the HVAC. Two examples which illustrate this appliance-HVAC interaction are the outside venting of a clothes dryer and the operation of a heat pump water heater (HPWH). Figures 1 and 2 schematically illustrate these two processes.

1. Clothes Dryers

Although venting a clothes dryer inside the living area of a house is energy efficient during the heating season, the practice has several drawbacks. If the dryer uses a combustion process to heat the air as gas dryers do, potentially dangerous combustion products can permeate the house air; therefore, gas dryers should never be vented inside. Lint and excess moisture in the exhaust from both gas and electric dryers can also present safety and aesthetic problems if not effectively controlled. Thus, clothes dryers are usually vented outside. Venting the dryer outside, however, can increase the house air infiltration rate.

The rate at which this air enters or leaves a structure is an important factor in performing heating and cooling calculations for residences or other buildings. This air-flow rate is called the air infiltration rate and usually is expressed in units of air changes per hour (ACPH). Infiltration occurs through cracks around doors, windows, walls, floors, etc., and its magnitude is determined by the quality of materials and construction and by existing weather conditions.

EFFECT OF CLOTHES DRYER ON HOUSE INFILTRATION

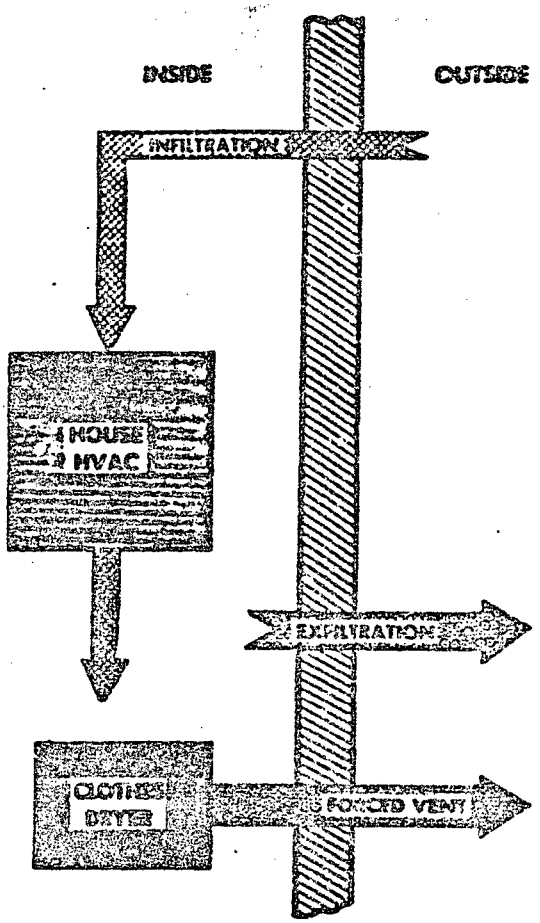


FIGURE 1

EFFECT OF HEAT PUMP WATER HEATER ON HOUSE HVAC

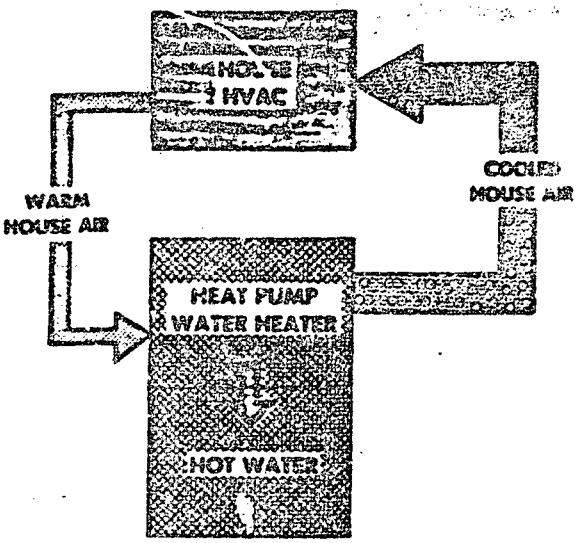


FIGURE 2

Some infiltration air is necessary; however, to replenish the oxygen supply in houses, deplete "used" air and contaminants, and furnish air to any fossil-fueled heating devices. In cases where infiltration air is inadequate to do these jobs, ventilation must be added to the house. In cases where infiltration air is too high, a penalty is paid in terms of increased space-conditioning costs and perhaps personal discomfort.

2. Air Infiltration

Both the measurement of and the prediction of air infiltration in residences and other buildings are receiving a great deal of attention these days because of the contribution that infiltration adds to the house heating and cooling loads and indoor air quality.

Quantitative measurements of air infiltration rates are presently best made using the tracer-gas decay technique which involves introducing a tracer gas, such as sulfur hexafluoride, ethane, nitrous oxide, etc., into a structure, monitoring its concentration versus time with a suitable instrument, and using this data to calculate the infiltration rate. The mathematical model used is that of a first-order decay rate — that is, the rate of loss of the tracer gas from a structure is proportional to the amount of the tracer gas present at any instant in time. Expressed mathematically,

$$-\frac{\partial c}{\partial t} = kc \ ,$$

where

c = the concentration of the tracer gas in the structure at any time t,

k = the infiltration constant.

When this equation is integrated with the initial boundary conditions at $t = 0$, $c = c_0$, the solution is

$$\ln \frac{c}{c_0} = -kt.$$

Plotting $\ln(c/c_0)$ versus t, in hours, results in a straight line going through the origin with a slope equal to -k, the infiltration rate in ACPH.

If sufficient measured infiltration and weather data are available for a given structure, the Achenbach-Coblentz method may be used to correlate the data and form a predictive infiltration equation. The Achenbach-Coblentz correlation uses an equation of the form:

$$\text{infiltration rate} = A + [B \times (\text{wind speed})] + [C \times |\text{house-to-ambient } \Delta T|] ,$$

where A, B, and C are empirical constants for the structure.

3. Heat Pump Water Heaters

Laboratory and field tests 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. Also, geography, house construction, type and efficiency of HVAC system, and hot-water usage will all affect the effective HPWH performance.

Figure 3 shows a schematic diagram of an HPWH system and Figure 4 shows the concept of the energy flows in a HPWH.

METHODOLOGY

The initial information needed to conduct the study was gained experimentally. For the dryer experiment, measurements of house air infiltration rates were made both with the dryer off (not operating) and with the dryer operating while venting its exhaust outside through a standard 4" diameter through-the-wall vent kit. Sixty-nine measurements were made over the course of 18 months, in order to encompass weather conditions from all the seasons. Regression analysis techniques were then applied to the measured data in order to obtain equations relating the increased amount of infiltration air brought into the house by operating the dryer and venting it outside as a function of the outside weather conditions.

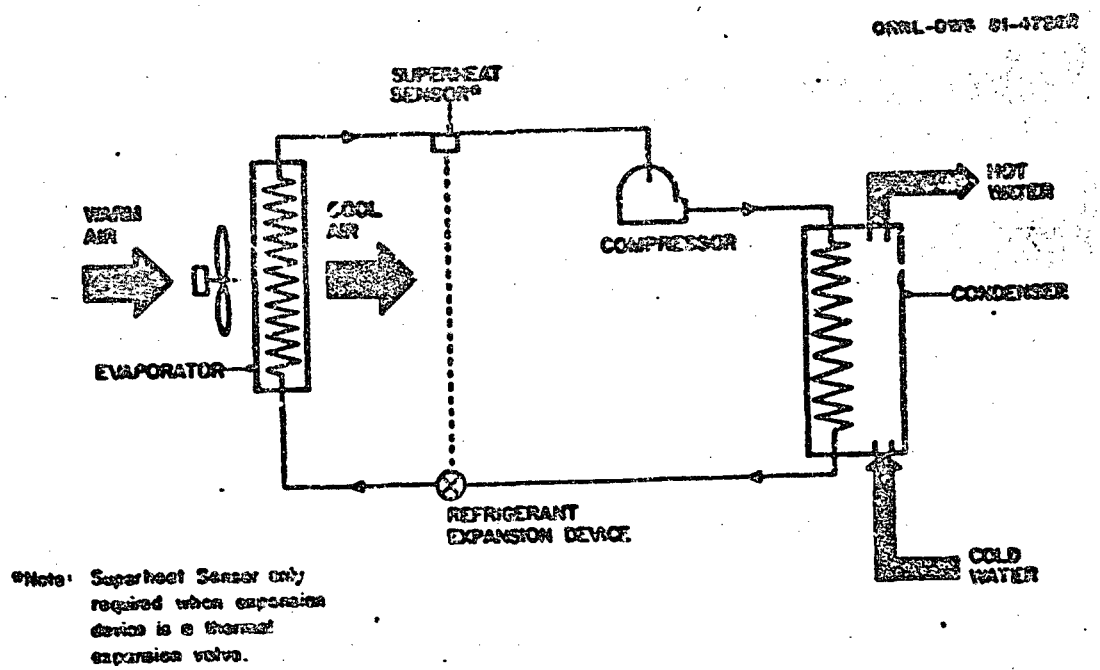


Fig. 3. Schematic of HPWH.

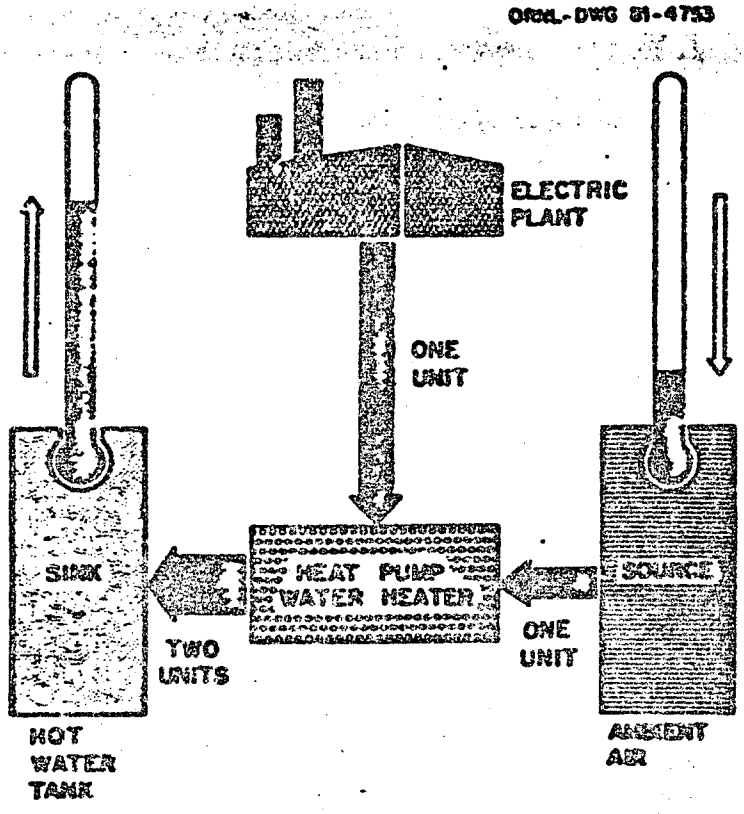


Fig. 4. Concept for HPWH showing approximate energy transfers

The experimental data for the performance of the heat pump water heater was obtained over a two-year period in the laboratory. A concurrent test of four water heaters was set up — two of the water heaters were integral-type (tank + HPWH form single unit) HPWH's, one was a separated-type HPWH, and one was a standard resistance water heater. All the water heaters used identical storage tanks. The water heaters were put on a daily draw schedule test of 64.3 gal/day which simulated actual average inhouse use.[1] A microprocessor controlled the experiment, gathered the data, and also reduced the data. The output of this testing was a set of equations describing the performance of the various water heaters as a function of ambient, inlet water, and delivery water temperatures.

Since the actual interaction between either appliance and the house HVAC would be extremely difficult to measure, a computer modeling approach was taken to analytically estimate the magnitude of each interaction. Therefore, a representative house was modeled as shown in Figure 5, which contains the heating and cooling load lines of the house as well as the performance and capacity data of a central heat pump HVAC. Weater data from several parts of the country in the form of monthly 5°F bins, average monthly wind speeds, and average monthly ground water temperatures were incorporated in the model. Monthly heating and cooling loads were calculated for the house both with and without the appliance-HVAC interaction. The interaction results were then calculated for a house with a heat pump HVAC and for the same house with resistance heat and electric air conditioning.

RESULTS

Vented Electric Dryer

Figure 6 is a plot of the experimentally measured data which shows the effect of forced ventilation (venting a dryer outside) on the house infiltration rate. The regression equation which best fit the data may be written in the form:

$$VI = NI + VR \times e^{-(NI/VR)},$$

where

VI = infiltration rate including dryer effect,

NI = normal infiltration rate (no dryer effect),

VR = vent rate of the dryer.

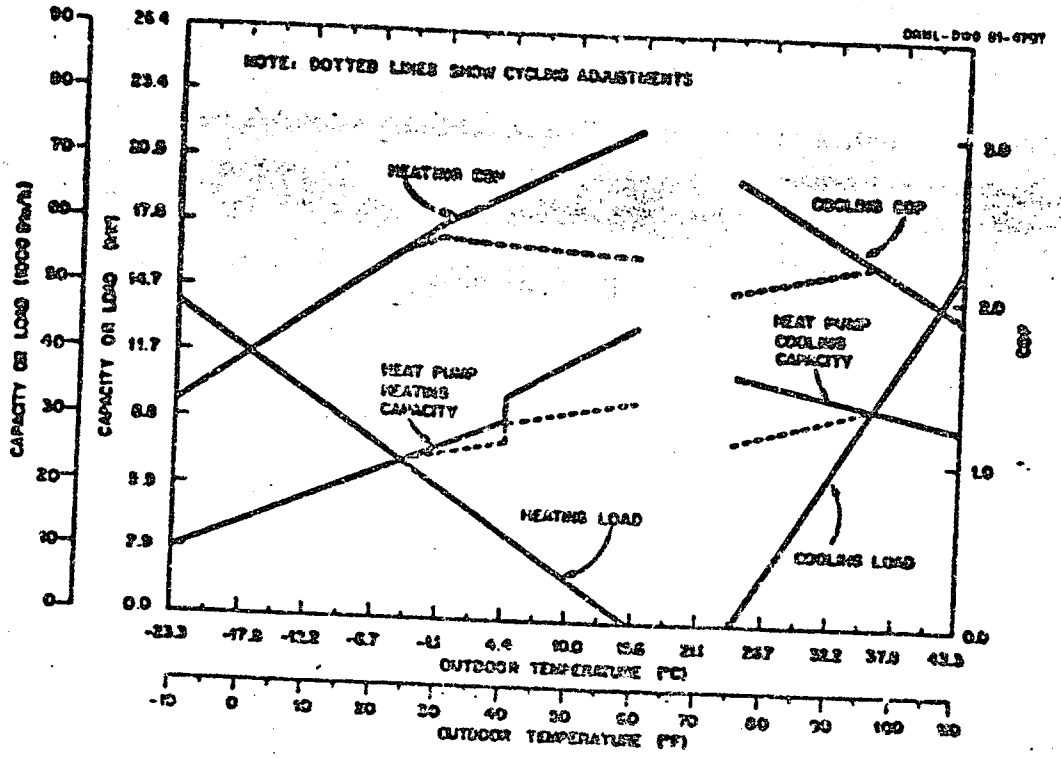


FIGURE 5 HEATING - COOLING DIAGRAM OF MODEL RESIDENSE

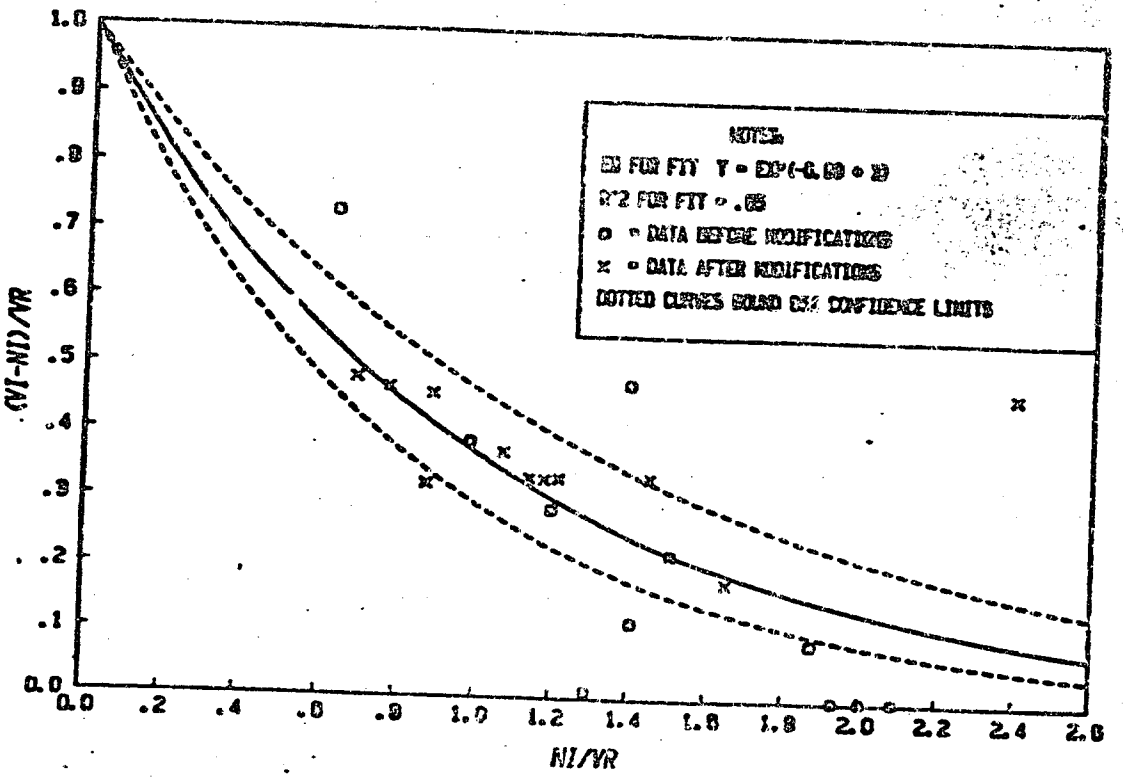


Fig 6 EFFECT OF FORCED VENTILATION ON [illegible]

Note from this equation that the increase in the house infiltration rate caused by venting the dryer outside is not simply the sum of the original house infiltration rate plus the dryer vent rate, but something less than that.

Assuming a monthly dryer usage of 34 loads per month and an average operation time of 45 minutes per load, the annual interaction effect of the dryer on the house central HVAC for several cities is shown in Table 1 for two types of HVAC systems. It should be kept in mind that an electric dryer will use about 1100 kWh/y under these conditions so that the maximum penalty paid for venting the dryer outside is about 68 kWh/y in a Seattle resistance heated house. This number is about 6% of the normal dryer input energy. Resistance-heated houses in most other geographical locations would only pay about a 4-1/2% penalty for venting the dryer outside, and only about 2% if the house had a heat pump HVAC. The penalty for a fossil-fuel-heated house would probably be 6 to 7% of the dryer input.

Heat Pump Water Heater

Table 2 shows the HVAC interaction for a HPWH located inside a house with a central heat pump HVAC, and uses the interaction penalties and gains to calculate the effective annual performance factor of the HPWH (HPWH PF). The column labeled "RES WH KWH IN" shows the annual energy that a resistance water heater would use in the same situation. Since the penalty paid during the heating season HVAC interaction is greater than the gains made during the summer season for all but the two Florida locations, the effective HPWH PF is lower than the measured PF of 1.94, which does not include the HVAC interaction. However, an overall energy savings averaging about 2300 kWh/y is obtained when compared to resistance water heating. This would amount to about a 40% savings.

Table 1

ANNUAL EFFECT OF VENTED DRYER ON TWO TYPES OF HVAC SYSTEMS

CITY	DELTA HVAC LOAD (KWH/YR) ELEC RES & A/C HOUSE			ELEC HEAT PUMP HOUSE		
	HEAT	COOL	TOTAL	HEAT	COOL	TOTAL
ALBUQUERQUE NM	47.8	3.7	51.5	25.3	3.7	29.0
ATLANTA GA	32.2	5.5	37.8	16.4	5.5	22.0
BOSTON MA	39.5	1.2	40.6	22.9	1.2	24.1
CHICAGO IL	49.3	2.2	51.5	29.5	2.2	31.8
DENVER CO	55.9	1.0	56.9	32.3	1.0	33.3
FT WORTH TX	22.9	7.2	30.1	11.6	7.2	18.9
KNOXVILLE TN	46.0	4.8	50.8	24.0	4.8	28.7
LOS ANGELES CA	38.1	0.0	38.1	18.0	0.0	18.0
MINNEAPOLIS MN	55.5	0.8	56.3	36.8	0.8	37.6
NEWARK NJ	46.4	2.5	48.9	25.0	2.5	27.4
PITTSBURGH PA	51.5	0.7	52.2	29.5	0.7	30.1
SAN FRANCISCO CA	47.5	0.0	47.5	22.5	0.0	22.5
SEATTLE WA	67.6	0.0	67.6	33.3	0.0	33.3
TAMPA FL	11.1	10.8	21.9	5.3	10.8	16.1
WASHINGTON DC	40.6	3.6	44.2	21.8	3.6	25.5
WESTHAMPTON NY	43.3	1.2	44.5	23.7	1.2	24.9
WILMINGTON DE	49.6	2.3	51.9	26.7	2.3	29.0

Note: Average Monthly Temperatures and Wind Velocities Used

Table 2

HPWH in House With High Efficiency Heat Pump

CITY	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
Albuq NM	3077	797	201	3672	6010	2337	1.64
Atlanta	3008	602	233	3377	5839	2462	1.73
Boston	3241	1181	128	4294	6424	2130	1.50
Chicago	3252	1147	147	4252	6453	2201	1.52
Denver	3232	1176	125	4283	6402	2119	1.49
Ft Worth	2868	491	301	3058	5498	2440	1.80
Houston	2801	341	372	2771	5339	2569	1.93
Knox Tn	3036	680	220	3496	5907	2412	1.69
LA Cal	2959	564	59	3464	5720	2255	1.65
Miami	2734	81	575	2240	5180	2940	2.31
Minn Mn	3335	1384	143	4576	6669	2093	1.46
Newark	3169	919	162	3927	6243	2316	1.57
Phoenix	2746	393	287	2852	5209	2357	1.83
Pitts Pa	3225	1075	132	4169	6385	2216	1.53
Ptlnd Or	3172	1014	56	4130	6248	2119	1.51
SF Cal	3063	904	31	3936	5976	2039	1.52
Seattle	3214	1044	40	4219	6356	2137	1.51
Tampa	2761	199	450	2509	5243	2734	2.09
Wash DC	3109	859	168	3800	6089	2290	1.60
Whstn NY	3169	1047	75	4141	6243	2101	1.51
Wilm Del	3149	918	158	3910	6191	2282	1.58

NOTES: The Following Assumptions Apply to the Above
1. HPWH Located in Conditioned Space of House
2. Daily Water Usage is 64.3 Gallons at 140 F
3. HPWH Performance Factor = 1.94 at 70 F and 60 F Water In

Table 3 is similar to Table 2, but applies to a house with a resistance heat and electric air conditioner HVAC. As would be expected, the savings for this case is less than that for a house with a heat pump HVAC.

Figures 7 through 10 depict the magnitude of the house heating and cooling loads both with and without a HPWH in the house for 21 different geographical locations.

Figures 11 and 12 show the effect of varying HPWH efficiency on the annual energy savings for five different cities for a heat pump HVAC and for a resistance heat with electric air conditioner HVAC.

CONCLUSIONS

Field measurements have shown that the increase in the house infiltration rate caused by venting a dryer outside is somewhat less than the measured ventilation rate of the dryer. The calculated HVAC interaction effect of the vented dryer is geography- and HVAC-dependent, and ranges from 2 to 6% of the dryer input of about 1100 kWh/y. Therefore, it can be concluded that venting a dryer outside is not very wasteful of energy.

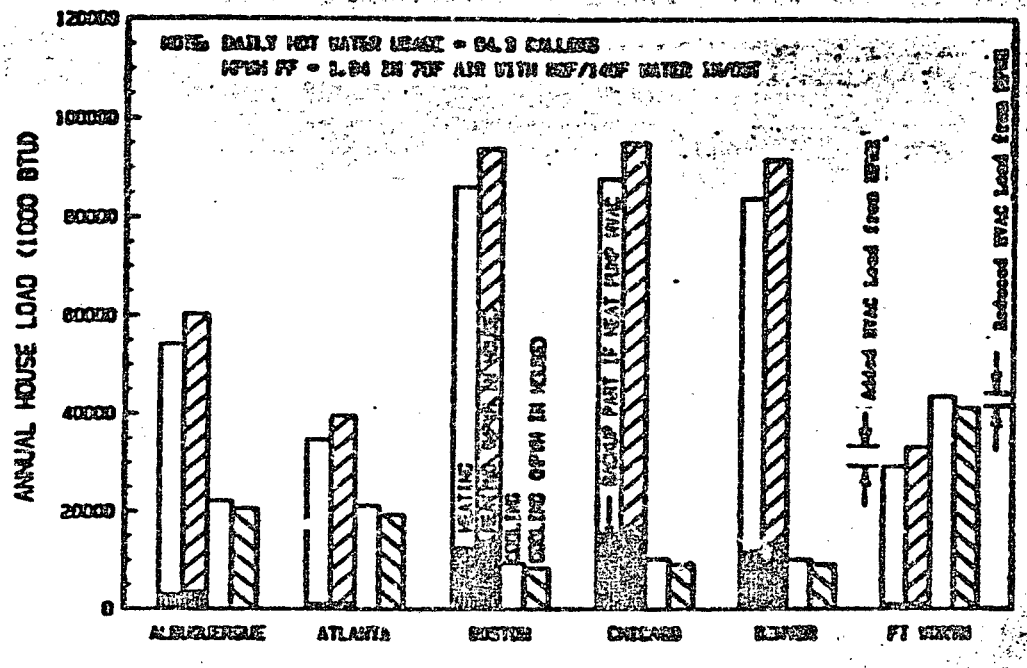
Although locating a HPWH inside a residence has a definite impact on the house heating and cooling load, the HPWH is still an energy conserving device, especially in the southern part of the country.

Table 3

HPWH in House With Resistance Heat & High Efficiency A/C

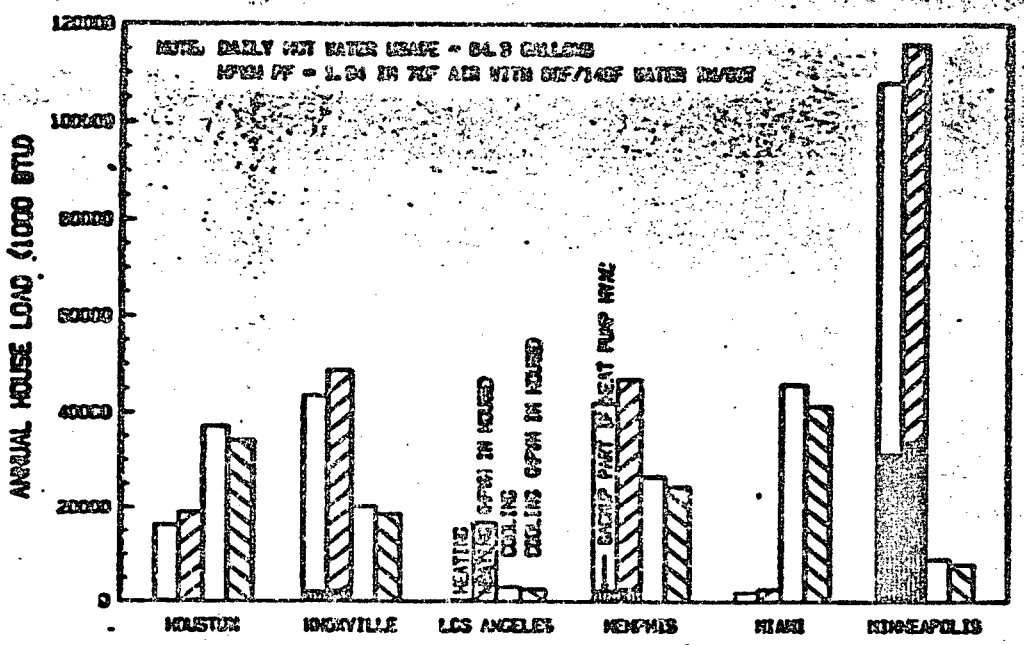
CITY	HPWH KWH IN	HTG SYS ADD KWH	CLG SYS KWH SVD	HPWH EQ KWH IN	RES WH KWH IN	ANNUAL KWH SVD	HPWH ANN PF
Albuq NM	3077	1780	201	4656	6010	1354	1.29
Atlanta	3008	1417	233	4192	5839	1647	1.39
Boston	3241	2286	128	5399	6424	1025	1.19
Chicago	3252	2176	147	5280	6453	1172	1.22
Denver	3232	2307	123	5413	6402	988	1.18
Ft Worth	2868	1155	301	3722	5498	1776	1.48
Houston	2801	822	372	3252	5339	2088	1.64
Knox Tn	3036	1562	220	4377	5907	1530	1.35
LA Cal	2939	1337	59	4238	5720	1482	1.35
Miami	2734	193	575	2352	5180	2828	2.[illegible]
Minn Mn	3333	2300	143	5492	6669	1177	1.21
Newark	3169	1996	162	5004	6243	1239	1.2[illegible]
Phoenix	2746	953	287	3412	5209	1797	1.5[illegible]
Pitts Pa	3225	2128	132	5221	6385	1163	1.2[illegible]
Ptlnd Or	3172	2439	56	5555	6248	693	1.1[illegible]
SF Cal	3063	2163	31	5193	5976	780	1.15
Seattle	3214	2537	40	5711	6356	645	1.11
Tampa	2761	475	450	2786	5243	2457	1.88
Wash DC	3109	1869	168	4810	6059	1280	1.27
Whstn NY	3169	2209	75	5303	6243	939	1.18
Wilm Del	3149	1995	158	4987	6191	1205	1.24

NOTES: The Following Assumptions Apply to the Above
1. HPWH Located in Conditioned Space of House
2. Daily Water Usage is 64.3 Gallons at 140 F
3. HPWH Performance Factor = 1.94 at 70 F and 60 F Water In



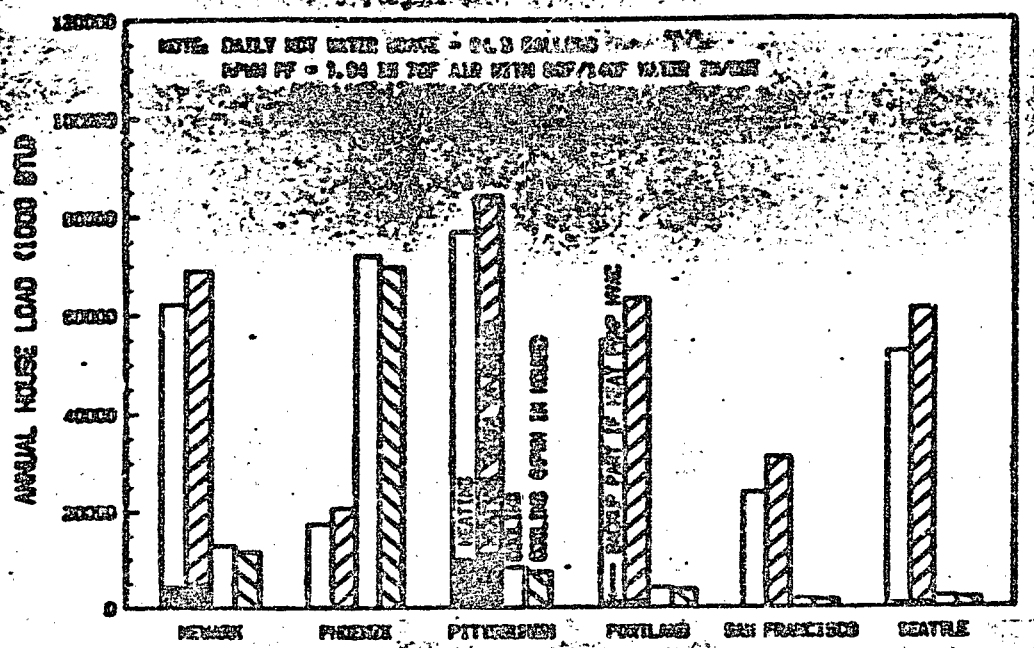
EFFECT OF HPWH ON RESIDENTIAL HEATING-COOLING LOADS

FIGURE 7



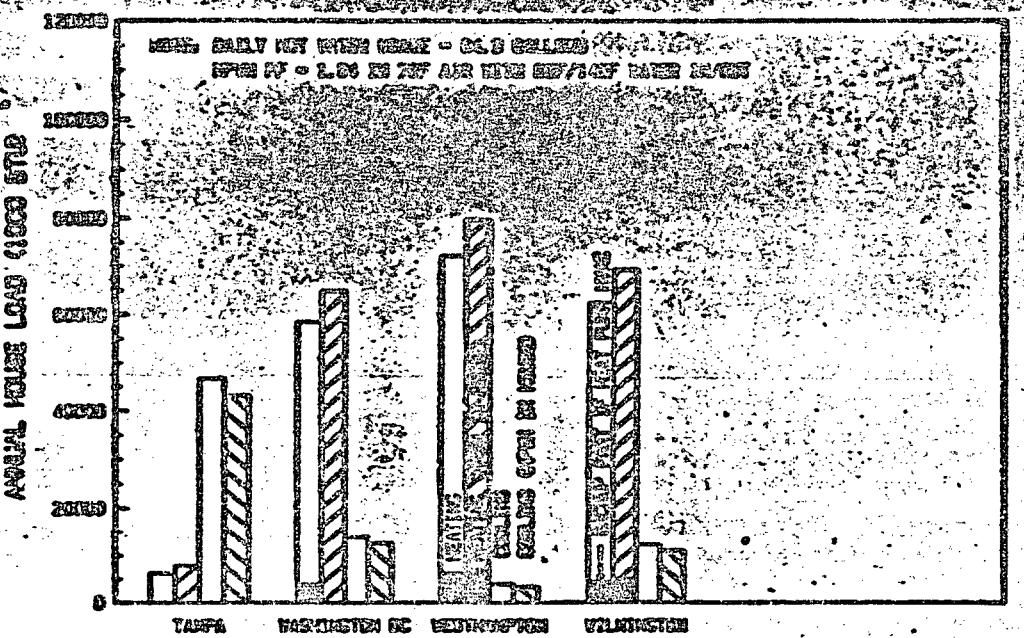
EFFECT OF HPWH ON RESIDENTIAL HEATING-COOLING LOADS

FIGURE 8



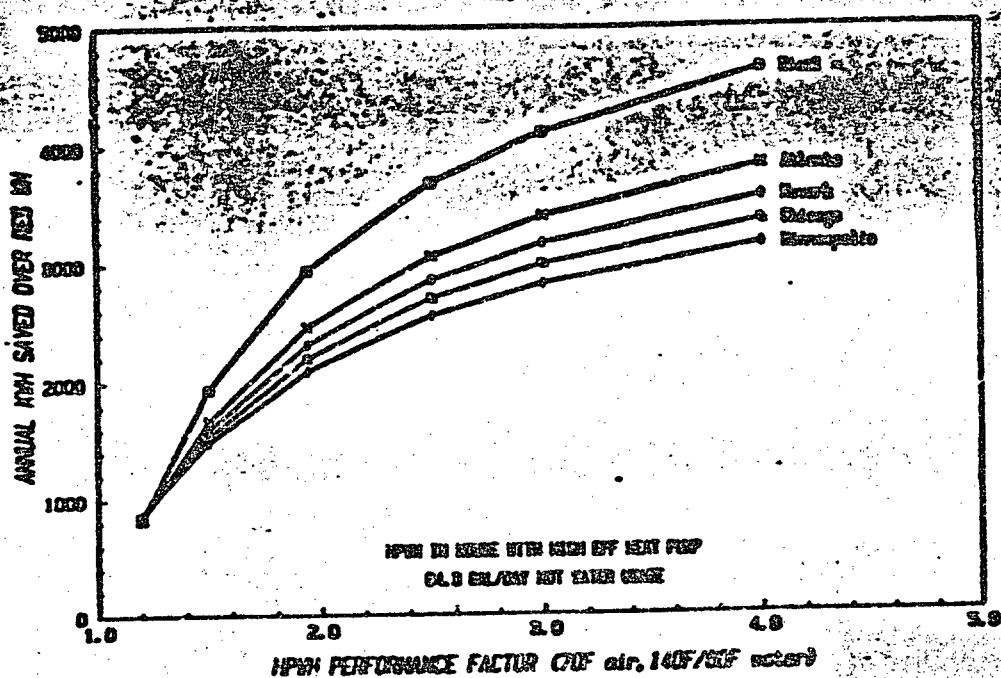
EFFECT OF HPWH ON RESIDENTIAL HEATING-COOLING LOADS

FIGURE 9



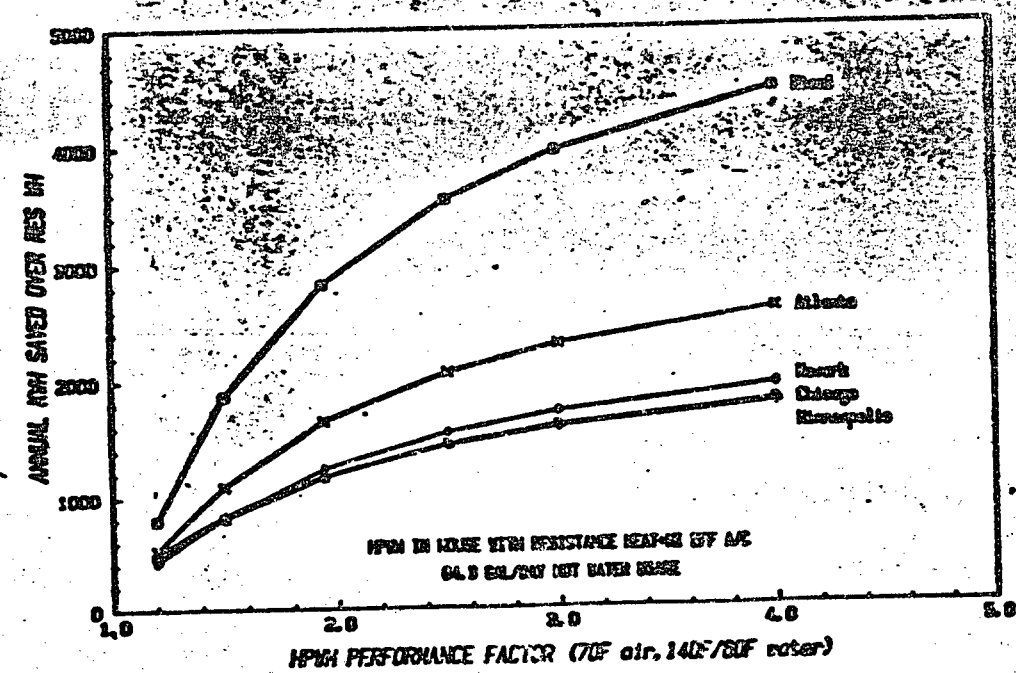
EFFECT OF HPWH ON RESIDENTIAL HEATING-COOLING LOADS

FIGURE 10



EFFECT OF HPWH EFFICIENCY ON ENERGY SAVED

FIGURE 11



EFFECT OF HPWH EFFICIENCY ON ENERGY SAVED

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