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ENERGY CONSERVATION

RESEARCH and DEVELOPMENT of a HEAT-PUMP WATER HEATER

VOLUME 1
FINAL SUMMARY REPORT
AUGUST 1978

Work Performed by
ENERGY UTILIZATION SYSTEMS, INC.
for
OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U. S. DEPARTMENT OF ENERGY

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FINAL SUMMARY REPORT

August 1978

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for the

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FOREWORD

This is a report of work performed to date by Energy Utilization Systems, Inc. (EUS), covering Phase I of the research and development of an electric heat pump water heater on which U.S. letters patents for prior work have been applied for. The work is being sponsored by the Buildings and Community Systems Division of the Department of Energy (DOE) through the Oak Ridge National Laboratory (ORNL).

Volume 1 contains a summary of the Phase I program. Volume 2 contains the final reports of the three major tasks performed in Phase I.

- a Market Study which identifies the future market and selects an initial target market and channel of distribution based on an analysis of the parameters affecting feasibility of the device and the factors that will affect its market acceptance.
- a Design and Test Program that provides final heat pump designs for both new water heaters and for retrofit of existing water heaters.
- a Development Plan for an extensive field demonstration involving use in actual homes.

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ABSTRACT

EUS has designed an electric heat pump water heater with an operating efficiency, E_R, of 2.5 in average conditions of 70-75^{o}F ambient air and 55-60^{o}F supply water. With losses taken into account, the Coefficient of Performance is 2.8 or within ten percent of the design objective. Separate heat pump designs are available for new water heaters and for retrofitting of existing ones. For both models, the compressor, evaporator, fan and controls are mounted in a round cabinet set on top of the water heater. The condenser is a dual tube direct immersion type which enters the tank through a special four-inch hole in the top of new tanks. For retrofit units, the condenser is in the form of a helix and is screwed into the tank through the hole normally used by the lower resistance element.

Early estimates for the cost of the device are between 200 and 250 dollars more than for an electric resistance water heater. Using this estimate, the payback for many applications will be between one and two years with some being less than one year. The payback period is more dependent on the amount of hot water consumption and the price of electricity than it is on the level of COP achieved, given a minimum average COP of 2. More accurate costs will be available as a result of the demonstration project.

In warm climates, the benefit/cost ratio will be improved by higher efficiency from warmer ambient air and by the value of free air conditioning and dehumidification provided while the unit is operating. In colder climates, the improved efficiency from colder supply water and the higher operating savings from higher kilowatt-hour use because of the colder water tend to offset the effect of the less favorable climate.

The potential market for the heat pump water heater is estimated as growing to seven million units per year by 1985. Recognizing that potential will be constrained by restraints on electric utilities from state regulatory agencies, the introduction of a new technology (refrigeration) into the normal water heater sales and service organizations, physical installation limitations and possible labor unit jurisdictional disputes.

To help overcome those constraints and to assure the device does not suffer at the start from misapplication and poor installation and servicing, the device will be marketed initially through merchandising electric utilities. Twenty of these utilities will participate in Phase II of the development--the field demonstration of one hundred units. Each utility will purchase, install and service five units, and install, service and monitor instrumentation packages supplied by DOE. Instrumentation will be designed to determine the annual COP of the unit including allowance for its impact on the heating and cooling load of the house.

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1.0 Introduction

The recent rapid rise in the cost of electricity, going from a national average of 3.18¢/kWh in 1973 to 3.45¢/kWh in 1976, and the increasing imports of foreign oil and gas have focused new attention on how our society uses energy. That attention has identified water heating as usually being the second largest user of energy in the home.

For electric water heating, average energy use is some 5000 kWh per year per dwelling unit. That average comes from an integration of single family homes, rural homes, urban apartments and mobile homes. Taken separately, single family and rural homes would average higher than that, somewhere between 5,000 and 10,000 kWh per year. (Consumers Reports[1] uses a consumption of 10,000 kWh for a typical suburban home.)

So electric water heating may be a much larger factor in the electric bill than the homeowner is aware of. In a total electric home, water heater consumption would amount to 20% of the total but it's consumption and its cost are hidden by, and blamed on, space heating. In homes without electric space heating, water heating would represent between 30 and 40% of the total and be blamed on lighting, appliances or air conditioning. Where air conditioning is not used, lighting and appliances are blamed where water heating could be as much as 60% of the total.

In the past, none of this mattered because electric rates in general were low and declining each year. Most utilities offered promotional rates for space and water heating that were as little as one-half regular rates -- a saving of about one cent per kWh. But now, that reduction of one cent per kWh is not very meaningful when normal rates are between 3 and 7 cents per kWh.

From all of this, it seems that electric water heating is costing a family of four somewhere between $150 (5,000 kWh at 3¢) and $525 (7,500 kWh at 7¢). A large family may be spending as much as $700 (10,000 kWh at 7¢) annually.

Of even greater concern to society as a whole, is the amount of our energy resources being used. For 5,000 kWh at the point of use requires the equivalent of 9.5 barrels of oil to be burned at the generating station.

To put that into perspective, 9.5 barrels of oil is the equivalent of 400 gallons of gasoline or enough to drive a compact (even some mid-size) car getting 20 mpg a total of 8,000 miles per year. A family using 10,000 kWh per year, could drive 16,000 miles per year. The national average mileage per car in 1973 was only 9,800 miles. In other words, an electric water heater uses more primary energy than the average compact or mid-size automobile.

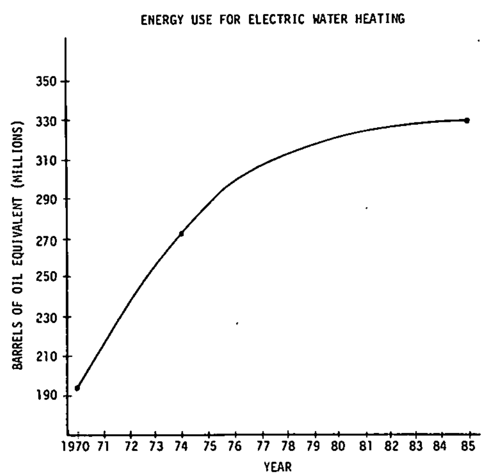
Much of that high primary energy consumption results from the relative inefficiency of the electric water heater. For while at the point of use, it can be considered close to 100% efficient, losses in the production and transmission of electricity reduce that to 30%.

Adding further to the energy inefficiency of the electric water heater is the high level of hot water consumption during those hours coincident with the peak load of the electric utility. For example, the hours between five and seven p.m. normally show coincident functions of food preparation, cooking, laundry, bathing and dishwashing. The hours of 7 to 9 a.m. are somewhat similar. These four hours account for 60% of hot water consumption.(2) So a major part of hot water may be provided from electricity generated in the utility's less efficient peaking plants.

In 1974, some 28,000,000(3) electric water heaters consumed an estimated 470 trillion BTU at the point of use or 1.6

quadrillion BTU when the losses in production and transmission are included. That is the equivalent of 270 million barrels of oil, a figure that is projected to increase to 330 million by 1985. See figure 1.1. But that projection does not reflect the possible effect of the shortfall in domestic supplies of oil and natural gas which could increase the future use of electric water heaters.

Figure 1.1



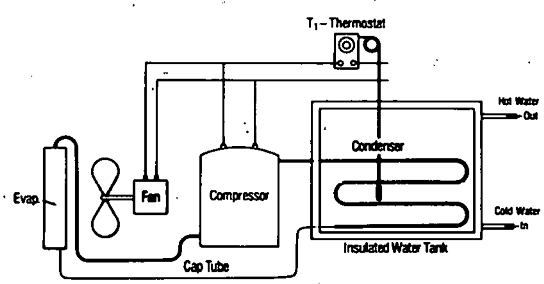
Obviously, electric water heating is an energy use offering great potential for energy savings. This potential has been noted and is being pursued in the DOE program for increasing appliance efficiency which concentrates on making energy conservation a primary criterion for water heater design. Even greater potential for reducing energy use is offered by the use of the thermodynamic principle in a heat pump water heater.

The heat pump type of water heater, with an average seasonal COP of three, would reduce the kWh use, and thus the cost to one-third of present levels. At an estimated installed cost of $200 more than for a conventional electric water heater, the payback period would be one year or less in most cases.

The heat pump water heater works much like a window air-conditioner except that it pumps heat into the water tank rather than outdoors and is expected to pump it from otherwise waste heat in an unconditioned space such as the basement, garage, utility room or attic.

In the summer, the device would be cooling and dehumidifying the enclosed space. At ambient temperatures between 70 and 90 degrees, it would be expected to operate at efficiencies in the range of three times that of a straight resistance water heater. It is expected that these high efficiencies would be offset to some degree in the winter because the unit would be using heat that would have to be replaced by the home heating system. Thus the energy efficiency of the total system for providing heat for hot water would be no better than the efficiency of the heating system.

Figure 1.2
Schematic of Heat Pump Water Heater



The heat pump water heater is shown schematically in figure 1.2. The major components are the compressor, evaporator, fan and the direct immersion condenser. Other components would include electrical controls and an expansion valve and a case.

The concept of a heat pump water heater is not new. Two firms manufactured and marketed them in the 1950's.[4] They met with little success because the cost of electricity was low and declining and/or the performance achieved from the then state of the art of heat pumps was minimal. One type used a refrigeration tube brazed to the outside of the water tank. The second used a single-tube direct immersion condenser. In field tests, the COP ranged from 1.26 to 1.39 for the first type and from 1.7 to 2.5 for the second.

In 1961, feasibility studies run at Purdue University by Dr. J. B. Chaddock, sponsored by the Association of Edison Illuminating Companies,[4] indicated a technical feasibility with a COP of 3 being attainable. But the economics of the device were unfavorable because of the low and still declining cost of electricity.

In 1976 EUS designed a heat pump water heater using a double tube direct immersion condenser. Many building codes now require a double wall separation between any toxic substance and potable water.* Condenser designs have been created for new units and for retrofitting existing water heaters.

* Although the fluorocarbon refrigerant is normally considered nontoxic, a small amount of lubricant oil accompanies the refrigerant through the system.

Since May of 1977, development has continued under the sponsorship of DOE through the Oak Ridge National Laboratory. Phase I of the DOE project has involved:

- an analysis of the various parameters that could be expected to affect the feasibility of the device
- the development of a final design for use in a field test of some 100 units
- laboratory tests of six units including sensitivity and life tests
- a study of the potential market
- the development of a "Phase II Plan" for the field demonstration of 100 units

All but the last of these efforts were carried out, somewhat simultaneously over a period of a year. For that reason, some of the early laboratory test units were considerably dissimilar to the final design, the parametric analysis had to use assumed performance characteristics and the market study was based on preliminary cost and performance estimates. At the same time, the final design was being evolved through an iterative series of design modifications and performance tests.

In this report, the efforts listed above are summarized separately but with appropriate notation of interaction between them.

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2.0 Parametric Analysis

The economic feasibility of the heat pump water heater is a function of the ratio of its added installed and annual maintenance costs to its annual cost savings as compared to a standard electric resistance water heater.

The annual operating cost savings are affected by several variables including:

- Efficiency of the heating system
  - Coefficient of performance of the heat pump
    - Ambient air temperature
    - Supply water temperature
    - Delivery water temperature
    - Availability of waste heat
- The energy to heat the water
  - Family size (hot water consumption)
  - Supply water temperature
- Fuel prices
  - Projected increases
  - Rate structure

2.1 Heating System Efficiency

In the case of water heaters, efficiency is expressed as E_R which is the ratio of the heat in the water coming from the tank (which excludes tank losses) to the heat input to the unit during the test period. The ratio between the E_R of the heat pump water heater and the E_R of resistance heating is a measure of the COP of the heat pump. Thus if the E_R is 0.8 for a resistance-heated unit and is 2.4 with a heat pump on the same tank, then the heat pump COP is 2.4 ÷ 0.8 or 3.

The COP of the heat pump can also be derived by adding the tank losses to the heat energy output and then dividing by the electrical energy input. Losses from the 82 gallon tanks used in the EUS laboratory have been measured at 590 BTU/hour. In a representative eight-hour cycling test involving draws of 5, 15 and 25 gallons as shown in Table 2.1, the total energy output, as drawn hot water, was 25,989 BTU. Adding heat losses during the test gives a total heat pump condenser output of 30,329 BTU for a COP of 3.05.

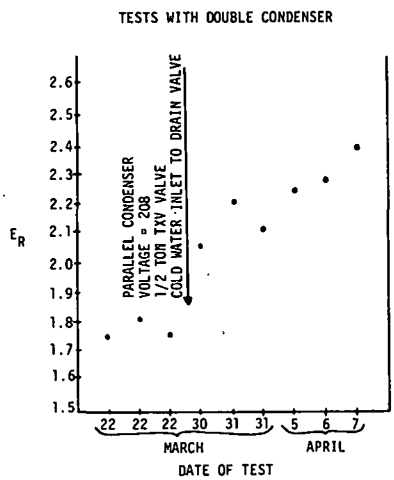
TABLE 2.1

Heat Pump Water Heater Performance from Eight-Hour Cycling Tests

	25 Gal.	15 Gal.	5 Gal.	Total
Output - BTU	14,438	8,663	2,888	25,989
Input - BTU	5,160	3,280	1,501	9,941
E_R	2.8	2.64	1.92	2.61
Losses - BTU				4,340
Output Plus Losses - BTU				30,329
COP				3.05

The COP of 3.05 would meet the objective of 3.0 for an average application of 70°F ambient, 70°F supply water temperature and 140°F delivery water temperature.

Figure 2.1



This level of COP has not been consistently achieved throughout the Phase I development period. Rather, it was not until April of 1978 that an E_R of 2.4 was reached indicating a COP of 2.8 is attainable. This is demonstrated in figure 2.1 which shows a dramatic improvement in the E_R during April. This was not caused by one major modification but rather by several minor ones including:

- moving the cold water input from the top mounted tube to the bottom drain hole
- the use of a new design chimney type condenser to improve refrigerant to water heat transfer
- optimizing the refrigerant charge

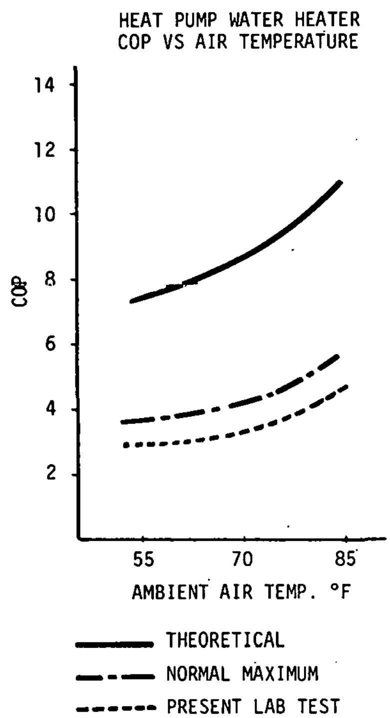
Subsequent to April, yet another chimney type condenser design has increased the E_R to above 2.5 and the COP to between

2.9 and 3.0. These values have been achieved under average conditions which will vary considerably in actual use. The sensitivity of the E_R to each of the major variables has been tested. A discussion of these variables and the results of the sensitivity tests follows.

2.1.1 Effect of Ambient Air Temperature

The theoretical COP of a Rankine cycle heat pump is a function of the difference between heat source temperature (in this case, ambient air temperature) and delivery temperature (in this case, 140°). In figure 2.2, the top curve is the theoretical COP based on delivery temperature of 140°F with source temperature varying between 55 and 85°F. In practice, the Rankine cycle COP generally runs 40 percent of the theoretical COP. The second curve is 40 percent of the theoretical curve which represents about the maximum that can be expected from the heat pump water heater. But the units tested at EUS have achieved less than that as shown by the bottom curve.

Figure 2.2

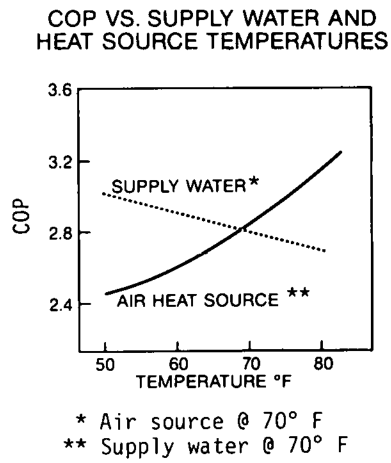


From the shape of the curve, it is apparent that the device can be expected to achieve better performance in the warmer climate in the South than in the North. As will be shown later, some of this effect is offset by the effects of other variables.

2.1.2 Effect of Supply Water Temperature

The efficiency of the heat pump water heater is higher when heating water starting at lower temperatures because of the better heat transfer between condenser and water which results in a lower condensing temperature.

Figure 2.3

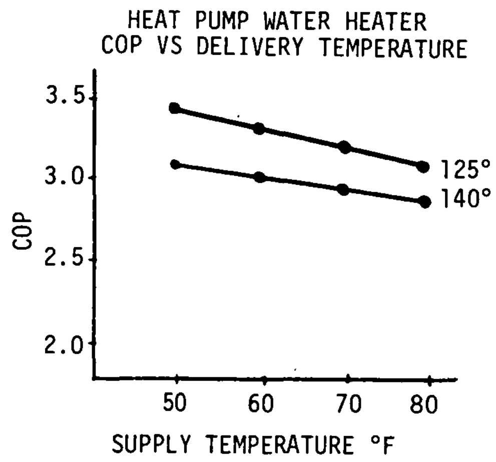


The net effect is seen to be a seven percent improvement in COP when supply temperature decreases from 70°F to 50°F. That seven percent will offset some of the disadvantage of the colder climate in the North. That is portrayed in figure 2.3 which shows the relative impact of air and supply water temperatures.

2.1.3 Effect of Delivery Water Temperature

Because the COP for the Rankine cycle is a function of the delivery and source temperatures, the question arises as to what improvement in COP can result from reducing the delivery

Figure 2.4

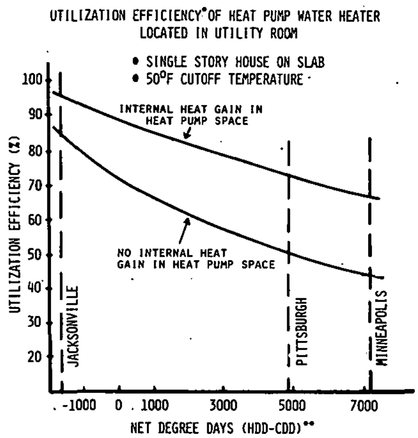


temperature. Figure 2.4 which shows results from a series of cold start tests, indicates a 10 percent improvement in the COP as the delivery temperature is reduced from 140^{o} to 125^{o}F. To lower the delivery temperature that amount would require increasing the tank size by 23 percent to maintain the same heat storage capacity. Analyses of the added costs and operating savings have shown payback periods ranging from 7 to 3-1/2 years for different levels of electricity prices and hot water consumption. However, the lower temperatures would have some effect on sanitizing of dishes and clothes where those appliances do not have booster heaters.

2.1.4 Availability of Waste Heat

The theory of the heat pump water heater is based on recovering that would otherwise by considered waste heat. This raises the question of just where and how much waste heat is available. For as heat is pumped from any given space, it must be replaced if the heat pump is to continue operating. Otherwise, the ambient temperature will be reduced to a point where the unit can no longer function.

Figure 2.5



SOURCE: REFERENCE 5

A unit operating outdoors, in a ventilated attic or in a carport, would have an unlimited heat source as long as the ambient temperature remained above the evaporator's icing temperature. Recent tests have determined that temperature to be between 45^{o} and 50^{o}F.

A unit operating indoors would be limited to heat flowing through walls, floor, ceiling and windows in an unheated space. In utility rooms, furnace rooms and basements, heat is available from the dryer, washer, furnace jacket losses, duct losses, the water tank jacket losses and the effluent water from bath, laundry and kitchen.

The effect of the availability of waste heat on utilization efficiency* was examined by General Energy Associates (GEA)[5] using a computer simulation of heat gains and losses based on daily weather data and simulated profiles of heating, cooling, water heating and other house loads. The availability of heat

* Utilization efficiency is defined as the percent of time there is an adequate heat source.

** Heating degree days minus cooling degree days.

for use by the heat pump water heater increases the utilization efficiency by:

- 11% in Jacksonville (from 84% to 95%)
- 25% in Pittsburgh (from 50% to 75%)
- 23% in Minneapolis (from 45% to 68%)

While the GEA study only covered one scenario of loads, it does identify the need for knowledgeable application of the heat pump water heater if it is to achieve economic justification.

2.2 Energy to Heat the Water

2.2.1 Hot Water Consumption

Because annual operating savings of the heat pump water heater are a direct function of the amount of hot water it provides, there is in each application some level of use above which the device will have a satisfactory payback period and below which it will not. Some knowledge of consumption will be required for future application of the device and for estimating market potential.

Very little has been done, or at least reported, in recent years toward determining patterns of hot water use. The latest data available are from the early and mid-sixties when the AEIC Load Research Committee (Reference 6, 1967-68) sponsored tests by several utilities to study the effect of varying supply water temperature on kWh consumption. The results showed average usages between four and five thousand kWh per year and appear consistent with estimates (7 and 1) as shown in Table 2.2 for an average family of three persons based on heating water to 140°F.

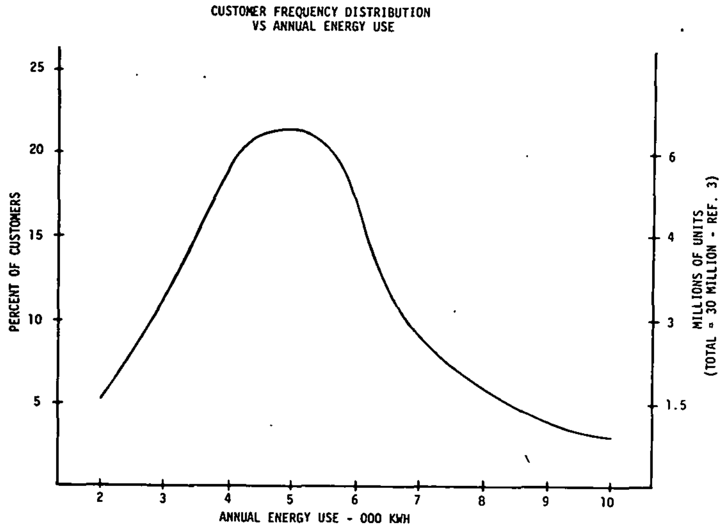
TABLE 2.2

Daily Hot Water Consumption Versus Family Size (Gals/day @ 140°F)

Family Size	3[1]	4	6
Food preparation	3	4	6
Hand dishwashing	4	5	8
Auto. dishwasher	15	15	22
Clothes washer	21	28	42
Shower or bath	15	20	30
Face and hands	2	3	4
TOTAL	45/56	60/70	90/104
kWh/Year	3970/4940	5300/6200	7950/9200

Based on our extrapolation, energy consumption for heating water would increase to 7,950 kWh/year for a family of six without an automatic dishwasher and to 9,200 for that family with a dishwasher. With the increase of saturation of dishwashers since the AEIC tests in the sixties from some 10 percent to today's 40 percent, the average annual consumption should be above 5,000 kWh.

Figure 2.6



SOURCE: REFERENCE 6, PAGE L-130

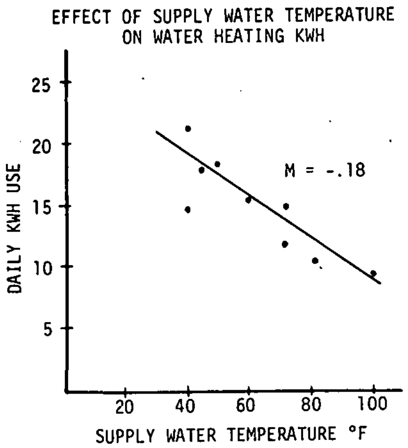
Based on this average and a typical customer frequency distribution as shown in figure 2.6, the annual kWh use of the 30 million electric water heaters in service in 1976 would be distributed as shown on the right side ordinate of that figure. Of the total 30 million electric water heaters installed, 19.3 million use 5,000 kWh per year or above.

Projecting the future average consumption per household requires estimating some offsetting influences. Any further increase in the saturation of dishwashers and clothes washers would significantly increase the average consumption. Conversely, the Department of Energy program on appliance efficiency will call for lower jacket losses from new units sold and existing units will be retrofitted with insulation, both of which will lower average kWh consumption.

2.2.2 Effect of Supply Water Temperature on Energy Use

In 1963-64, the Association of Edison Illuminating Companies ran tests in four cities which compared the kilowatt-hours used for domestic water heating with the temperature of the

Figure 2.7



SOURCE: REFERENCE 6

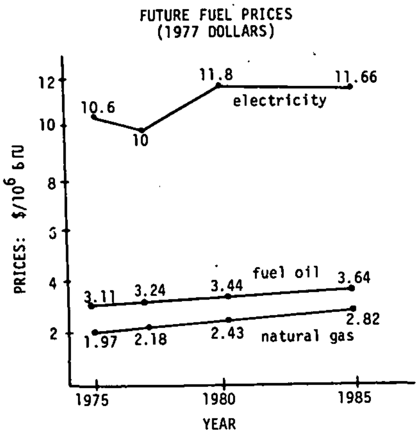
water supplied from the municipal water system. The results are presented in figure 2.7. On the average, each degree F of increase in supply water temperature lowers the daily electricity use by 0.18 kWh. With a difference of 20°F between the annual average supply temperatures of the South and the North, annual consumption will vary about 1300 kilowatt hours.

This effect tends to offset the higher system efficiency in the South from warmer ambient air (see section 2.1.1) when calculating payback periods. However, it adds to the effect of higher system efficiency in the North from colder supply water.

2.3 Price of Fuels

The marketability of the heat pump water heater will depend on its capability for generating operating cost savings compared to other types of water heaters. Those savings will vary directly as the price of electricity and to the relationship between the price of electricity and the price of oil and gas. In figure 2.8 are shown projected prices of electricity, gas and oil.

Figure 2.8



SOURCE: AVERAGED FROM FEDERAL REGISTER[8]

These projections were made in the summer of 1977 before the effect of foreign oil imports on the value of the U. S. dollar was widely recognized. Any tax imposed on foreign oil and/or deregulation of domestic natural gas prices would increase the future gas and oil prices with some lesser effect on electricity prices.

But even without that, prices of gas and oil are projected to increase faster than electricity so the ratio between the price of electricity and the prices for fossil fuels will be reduced. Table 2.3 shows the reduction between 1970 and 1985.

Table 2.3

RELATIVE PRICE OF ELECTRICITY VERSUS GAS AND OIL

1 Year	2 Electricity $/MMBTU	3 Gas $/MMBTU	4 Ratio (2÷3)*	5 Oil $/MMBTU	6 Ratio (2÷5)*
1970	6.2	1.05	5.9	1.3	4.8
1975	10.6	1.97	5.4	3.11	3.4
1980	11.8	2.43	4.9	3.44	3.4
1985	11.66	2.82	4.1	3.64	3.2

* Numbers indicate column numbers

When the ratio drops below four, the heat pump water heater would cost less to operate than the fossil-fired water heater. This is derived by assuming an E_R of 2.8 for the heat pump water heater and 0.7 for the fossil units. With the ratios down to 4.1 and 3.2 by 1985, the heat pump water heater will be competitive on an operating cost basis. But that is somewhat academic unless the supply of natural gas and oil improves because this would force greater use of electricity for residential use, including water heating. So the greatest impact on the market acceptance of the heat pump water heater may actually come from the future price of electricity which will, to a great degree, determine the payback period of the device compared to a resistance type electric water heater.

Projecting the future cost of electricity as it will pertain to water heating is complicated by the possibility of the use of special time-of-day (TOD) rates (rates that are lower during off-peak hours) which would substantially reduce the cost of water heating if it is restricted to off-peak hours.

However, the heat pump water heater provides an alternative for reducing the demand of electric water heating on the utility facilities without requiring the costly metering and control equipment associated with TOD rates, which account for much of the reluctance of electric utilities to return to TOD rates.

A current trend that will increase the cost of electric water heating is that of states encouraging, if not forcing, utilities to abandon all promotional rates including special water heating and total electric home rates.

In summary, TOD rates could reduce the economic justification of the heat pump water heater. Conversely, the heat pump water heater could reduce the economic justification of TOD rates applied to water heating.

Coupled with the anticipated reluctance of utilities to return to TOD rates and controlled water heating, the reduction in demand of the heat pump water heater will enhance its chance for acceptance and promotion by electric utilities at the regular residential rate. As regular rates increase, to whatever degree, the feasibility will be yet further enhanced.

2.4 Payback Period

It is generally agreed that in the deep South the heat pump water heater could provide hot water at one-third the normal cost and practically year round. At the same time, it would be providing free air conditioning and dehumidification. But the practicability of the device in the North (at least in the winter) is not as evident because it would be taking heat from the house that would have to be replaced by the house heating system. This would seem to indicate that the most feasible application will be in the South.

But the availability of waste heat in a furnace or utility room and the effect of colder supply temperatures on the heat pump's efficiency and on the total kWh consumption tend to offset the effect of ambient air temperature.

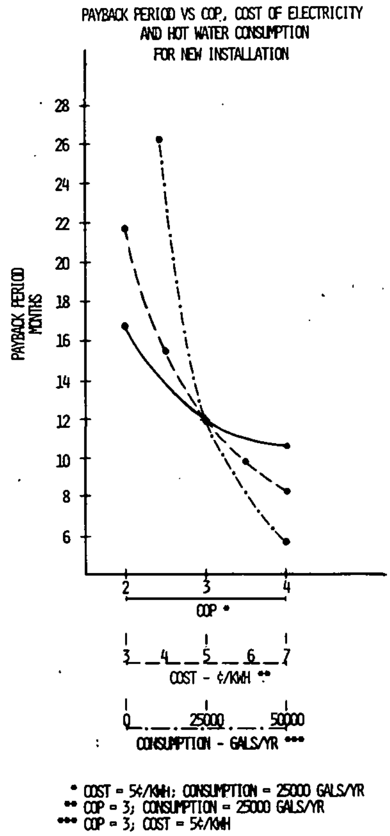
Even in the worst case in the North, assuming no waste heat is available, the heat pump can be turned off in the winter and the water heated by electric resistance with a COP of one. Assuming equal seasons and a COP in summer of three, the annual average is 1.5, reducing consumption by 33 percent.

A COP of two increases the savings to 50 percent compared to a resistance unit. Going from there to a COP of three only reduces it another 17 percent. A COP of four cuts only another 8 percent. So the consumer's payback period is reasonably insensitive to COP, at least not as sensitive as payback period is to the level of hot water consumption and the price of electricity.

Figure 2.9 compares the payback period for three variables (COP, price of electricity and annual consumption) for what are considered reasonable limits for each variable. The common point is for a COP of 3, a price of 5 cents per kilowatt-hour and an annual consumption of 25,000 gallons.

Examination of the data shows that the length of the payback period is relatively insensitive to the COP, improving about

Figure 2.9



36 percent between a COP of 2 and one of 4. Increasing electricity prices lower the payback period in excess of 60 percent going from 3¢ to 7¢ per kWh. Increased usage lowers the payback period by more than 50 percent as water heating requirement goes from 25,000 to 50,000 gallons per year.

So the conclusion can be drawn that the most attractive applications will be those involving large families and in areas with high electricity rates, somewhat regardless of the climate and other variables affecting the COP.

However, this analysis does not give credit for providing free air conditioning and dehumidification.

2.5 Air Conditioning and Dehumidification

When running, the heat pump water heater will provide over 1/4 ton of air conditioning and dehumidification. Assuming the unit operates ten hours per day, the air conditioning would save 5.6 kWh or at 5¢/kWh, it would be worth 28¢/day. In warm climates this could amount to as much as $75 per year.

And in the North, there is some value for homes with basements which have high humidity in summer and can require dehumidifiers ranging in electricity rating from 300 to 600 watts. Running continuously for five months, a dehumidifier would use between 1080 and 2160 kilowatt-hours per season. At electricity prices between three and seven cents per kWh, the annual energy cost is between $32 and $151. The heat pump water heater could provide the greater majority, if not all, of the dehumidification required. Thus it could eliminate both the installed cost and the annual operating cost of the dehumidifier.

2.6 Conclusion

The heat pump water heater as it is now conceived can provide an energy efficient and cost effective substitute for an electric resistance water heater. This conclusion is based on certain assumptions:

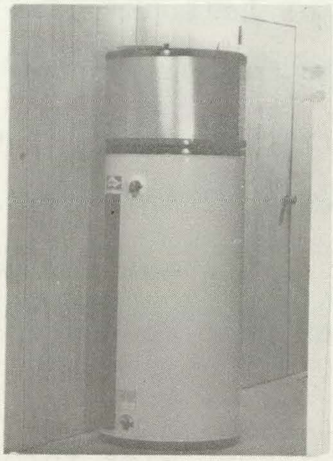
- it is installed in an appropriate location in the home
- the unit achieves a COP of 3 under average conditions
- the annual cost of electric resistance water heating would be $250 (5,000 kWh at 5¢/kWh or 10,000 kWh at 2.5¢/kWh) or more.

The payback period is more sensitive to hot water consumption and the price of electricity than it is to climate. Thus the unit can be cost effective in all climates. But if credit is given for air conditioning and dehumidification, feasibility would be greater in warm climates.

3.0 Final Design of the Heat Pump Water Heater

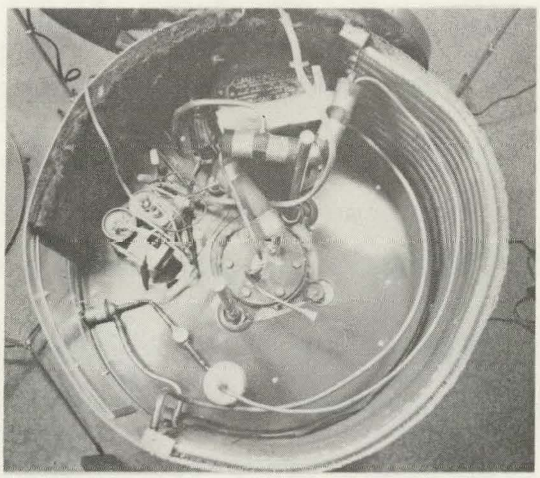
The final design for units to be built for field demonstration for either a new unit or for retrofitting to an existing unit is in a 24" diameter round housing sized to match the diameter of an 82 gallon energy saver electric water heater tank manufactured by Mor-Flo Industries.

Figure 3.1
Heat Pump Assembled to
82-Gallon Water Tank



The housing contains the compressor, evaporator, expansion valve, sight glass, drier, electrical controls and fan.

Figure 3.2
Heat Pump Unit
with Cover Removed



The top and bottom of the housing are the same as the top used for the water heater tank itself. Thus an aesthetic match between heat pump and tank is achieved and at a cost savings because the covers are already in mass production.

The compressor for a new unit is a standard one horsepower, 230 volt, R-22 model. In this application, the refrigerant is changed to R-12 because of the high discharge pressures associated with the systems discharge temperature of 200°F. This derates the compressor by approximately one-third providing an output of 8,000 BTU per hour. A 230 volt unit was selected to match the voltage of the 2,500 watt resistance element provided for quick recovery or in event of heat pump failure.

For the retrofit design, a 3/4 horsepower compressor is used with an output of 6,000 BTU per hour because this provides a closer match to the reduced heat transfer capability of the retrofit condenser as compared to the new unit condenser.

The evaporator is 11 inches high and 36 inches wide formed in a radius to fit the tank top and covering the rear half of the housing. It is constructed of a single row of 3/8" copper tubing with 10 aluminum fins per inch. The size is based on sufficient evaporator capacity to provide 6,000 BTU per hour. That provides a recovery rate of nine gallons per hour or enough to provide the average daily requirement of 63 gallons in less than seven hours. The advantage of oversizing the evaporator is two fold. A smaller fan and fan motor may be used which reduces power consumption, and the fan blade air noise is much more acceptable at lower blade tip speed.

The expansion device is a thermostatic expansion valve, factory adjustable, rated at 1/2 ton R-12.

There are three basic types of refrigeration restriction-expansion devices available for these units. Maximum control over a wide range of conditions is provided by the thermostatic expansion valve available, not field adjustable, for \$6.50. Minimum control, but lowest in OEM cost, is the capillary tube, widely used in central and room air conditioners. The size and length required would cost approximately \$1.

Moderate control with anti-frost protection for the evaporator at ambients down to 40°F or less is provided by a constant pressure valve at a cost of \$4.70. However, at low ambients this device permits liquid refrigerant to flood the compressor when its adjustment is optimized at 70°F ambient. If a significant amount of flooding does occur, it can seriously damage the compressor. If the device is set to restrict the flow at low ambients, performance (COP) at higher, more normal household ambients is sacrificed.

Due to the extreme range of conditions, 50°F to 90°F ambients, and 40°F to 140°F water, the capillary tube was not considered practical.

The thermostatic expansion valve was therefore selected for optimum COP and compressor life for new and retrofit units.

Figure 3.3
Chimney Type Condenser for New Water Heater

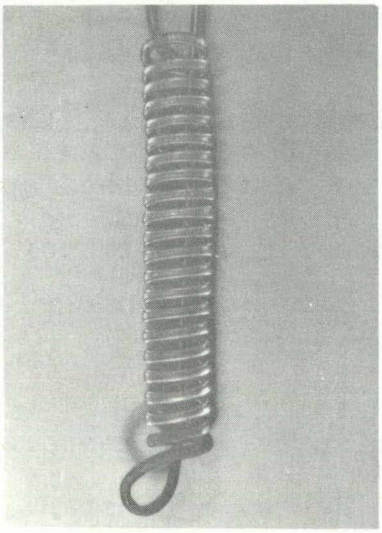


Figure 3.4
Tubing Used in Condenser for New Units

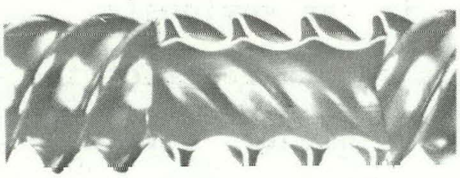
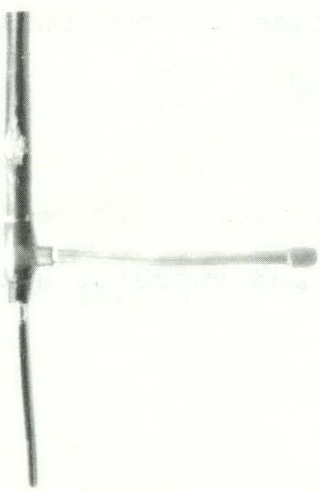


Figure 3.5
Annulus Cap



The condenser for new units is a "chimney" type coil having 19 4.25-inch diameter coils spaced 1/2 inch apart. The chimney design increases convective flow and achieves a maximum heat transfer.

The copper is tin plated to protect the tank anode. The coil is wound from 20 feet of 3/4" double copper tubing with fluting (see figure 3.4) to improve the heat transfer between refrigerant and water. Space is left between tubes (the annulus) for providing a barrier between toxic refrigerant compounds and the potable water.

The annulus is filled with colored water and sealed with a pressure relief cap to provide a visual indication of failure if increased pressure from a hole in either tube forces the dyed water from the annulus (see figure 3.5).

The tank selected for new units is a standard Mor-Flo 82 gallon energy saver tank except that a special top cover with a 4-1/2 inch hole is used to allow entry of the condenser.

The larger the hole diameter, the larger may be the condenser coil diameter. Therefore, with fewer coils, it will have most of its heat transfer area at the very bottom of the tank where the water is lowest in temperature.

Limitations to the size of the hole are the standardized industry hot and cold water connections 8" apart on centerline. The entry hole must be centered so that any added flange will not interfere with existing major Mor-Flo tooling. It has been resolved that a 6" outside diameter flange is the largest that can be welded to the tank top without interfering with tooling and water connections.

The weld flange will therefore be a 6.0" diameter, 0.5" thick mild steel with a 4.5" hole in it. It will have six drilled and tapped 3/8" NFT holes spaced 60^{o} apart. The weld flange will be heliarc or submerged arc welded on its I.D. and O.D. to provide a water-tight seal. After welding it must be flat $\pm$ 0.005. Mor-Flo is to test each tank assembly in accordance with standard electric water heater pressure test procedures.

Figure 3.6

Condenser Tubing for Retrofit Units

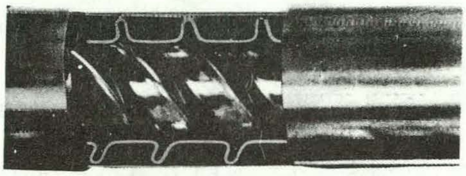
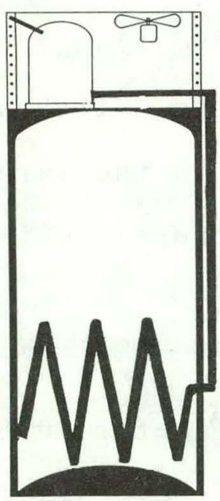


Figure 3.7

Sketch of Retrofit Unit



For retrofitting existing electric water heaters, the condenser will consist of 20 feet of fluted copper refrigeration tubing inside a 1/2 inch smooth copper sheath with a special double wall return bend having an O.D. of less than 1-1/8 inch (see figure 3.6).

The condenser is in the shape of a 12 inch diameter spiral helix, 22 inches long, in order to "screw" it into the hole left by removal of the lower resistance element. External insulated "risers" will be used to make field connections of the precharged lines to the heat pump.

The seal to the tank required two solutions, one for a bolt plate seal, the other for a 1-1/8" (1" pipe size) threaded hole. In both instances the adapter plate is braced to the sheath. Retrofit condensers must be ordered with a differentiation determined by type of seal.

Connections to the heat pump system are made by way of a 3/8" compressed gas line and 1/4" liquid line, both insulated, external to the tank and jacket, extending from the condenser up to the heat pump cabinet.

Precharged condenser and system lines will be sealed with Aeroquip 3/8" connectors, similar to split system central air conditioning system connections. This permits installation of the separate condenser and the heat pump on top of the tank with the added task only of connecting the two sealed precharged systems.

A low ambient cut-off control will be used to shut the compressor off at temperatures below 45^{O}F, in which case the upper resistance heater would automatically provide the water heating.

Both a run capacitor and a start capacitor with relay will be used to permit expected quick restarts, as when hot water is drawn from the tank just after the compressor has cycled off.

The fan is rated at 1/30 horsepower, 230 volts, 1550 rpm using a 40^{o} pitch blade to move 750 cfm at 300 FPM. This lower than standard fan speed results in quieter operation from reduced blade tip speed.

Operation of the heat pump in conjunction with backup resistance elements can be in various combinations using none, one or two elements, with wattages from 1500 to 4500 watts and controlled to be interlocked with or to operate in parallel with the heat pump.

Units to be built in the pilot run will have a 2500-watt upper element. Normally, only the heat pump will be used to heat the water. However, on start-up, or on withdrawal of all or most of the hot water, the resistance element will automatically operate in parallel with the heat pump for fast recovery. Total wattage will be approximately 3200 watts while providing effective heating of 4500 watts. This parallel operation is achieved by eliminating the normal electrical interlock between top and bottom thermostat.

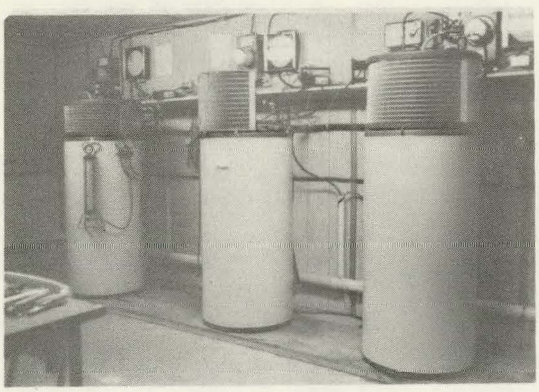
In the event of failure of the heat pump or when it is cut off in below 45°F ambients, the upper element will supply hot water. Normally the upper element will only heat 25 percent of the tank, but EUS and Mor-Flo have designed an element to bend down into the tank to achieve heating of as much as one-half of the tank.

4.0 Test Results

Over a period of twelve months, eight heat pump water heaters have been built and tested, one bench model, four new type units and three retrofit units. One of the new type and one retrofit have been tested by an independent test laboratory. Three new type and two retrofit have been tested by EUS.

To perform its tests, EUS built a test room with the capability of controlling temperature, humidity, voltage and supply water temperature; automatically controlling withdrawal cycles; and recovering the heat from hot water as it is withdrawn. The test room (figure 4.1) is 12 x 24 feet.

Figure 4.1
EUS Test Room



Tank water inlet and outlet temperatures are measured and recorded on TRERICE disc chart recorders. The temperature probes are located in the water flow path.

Room ambient temperatures and humidity are recorded on a BACHARACH servex disc recorder located four feet off the floor, five feet away from the nearest tank.

Tank water temperatures are measured with OMEGA 10 point digital readouts with iron-constantine thermocouples. The points measured are centerline 1/6, 2/6, 3/6, 4/6 and 5/6 down from the top of the tank along with three inches from the bottom and the top. A thermocouple is also located at the lower tank thermostat. (This usually reads 3^{O}F lower than the average tank water temperature at shut off).

Heat pump system temperature measurements, also using OMEGA 10 point digital readouts, are taken at (1) discharge line six inches from compressor for super heat, (2) return liquid line at condenser exit from tank, (3) liquid line just before expansion devices, (4) evaporator refrigerant gas inlet, (5) evaporator air outlet, (6) evaporator refrigerant gas outlet.

Discharge pressure and condensing temperature, suction pressure and temperature, and system pressure drops, are measured with SUPERIOR refrigeration pressure-temperature gauges.

Power supply is controlled with 230 volt variable transformers.

Laboratory heating is accomplished by collecting the 140^{O}F tank withdrawal water in a 175 gallon insulated tank. This water is then pumped through a fan coil in the laboratory as the room thermostat calls for heat.

Cooling is supplied (down to 45°F) by the heat pump water heater evaporators as they run on their various tests. Additional cooling is provided when required by a through-the-wall air conditioner.

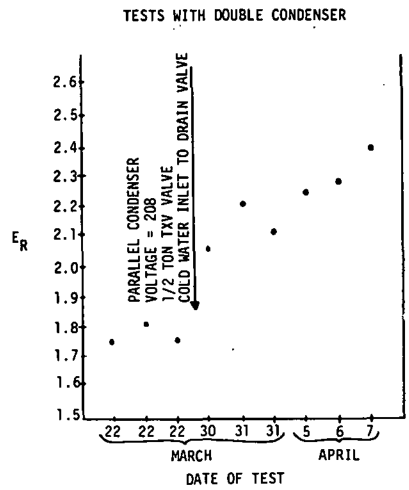
All tanks are mounted on 3/4-inch plywood platforms resting on 2" x 4"'s laid flat.

After consultations with Oak Ridge National Laboratory and the National Bureau of Standards, a heat pump water heater test procedure was developed. It is essentially the same as the proposed procedure published in the Federal Register, dated April 27, 1977, Part II, pertaining to water heaters. The revisions were only those necessary to assign the proper energy equations to the heat pump water heater. A copy of this test procedure is included in Volume 2. Tests performed by EUS (and the subcontractor, Associated Test Laboratories) have followed the guidelines established in this test procedure since it was approved.

4.1 Performance Tests

Performance tests have been run starting in August of 1977. The results over the complete twelve months are not comparable as the design was being constantly modified to incorporate improvements and as test procedures and instrumentation were being changed.

Figure 4.2



As shown in figure 4.2, the test results showed a dramatic improvement in the E_R in early April of 1978. This improvement was achieved by a series of minor modifications in design. Two 20 ft. condensers were connected in parallel where they had been in series. Tests had shown when in series, all the condensing had been done in the first section. Voltage was reduced from 230 to 208 volts. (Later tests of voltage sensitivity showed the optimum to be 220 volts). The expansion valve was changed from a constant pressure type to a thermal expansion type. The cold water inlet was moved to the bottom of the tank through the normal drain valve.

Subsequent to these tests, a new chimney type condenser was built that would operate lower in the tank where it sees colder water. It has achieved an E_R of 2.5.

4.2 Sensitivity Tests

Also during April, sensitivity tests were run on the then latest design.

Figure 4.3

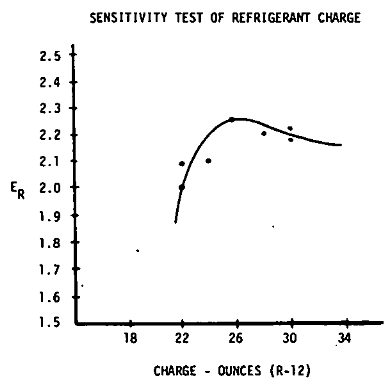


Figure 4.4

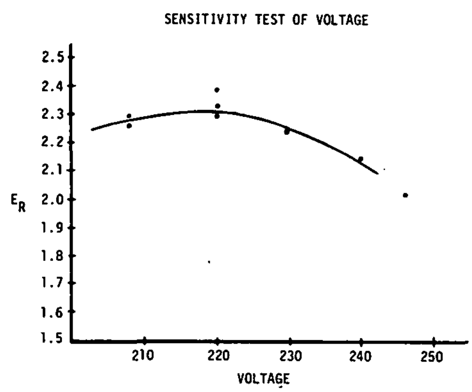
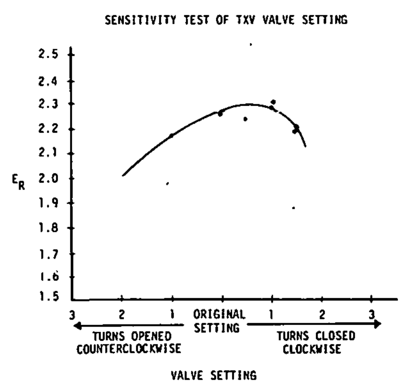


Figure 4.5



For a new unit, the optimal refrigerant charge is 26 ounces for operation in a 70°F ambient. The optimal charge for the retrofit unit is the same.

The optimum voltage is 220 volts which is 10 or 12 volts below the usual utility normal or average voltage. In production units, compressors will be modified to raise the optimum voltage.

Various types and sizes of expansion valves have been tested. The best one is a 1/2-ton thermal expansion valve (TXV) set one turn toward closed from the setting as received from the supplier.

Sensitivity tests of ambient air temperature, supply water temperature and delivery water temperature were performed.

Figure 4.6

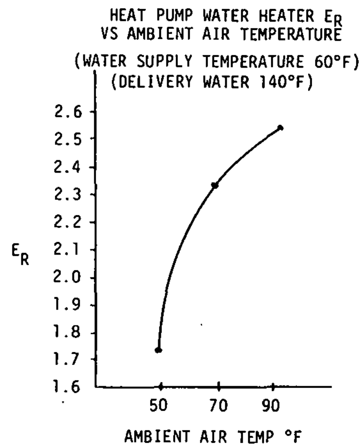
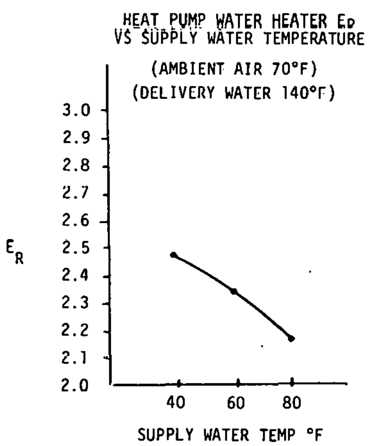


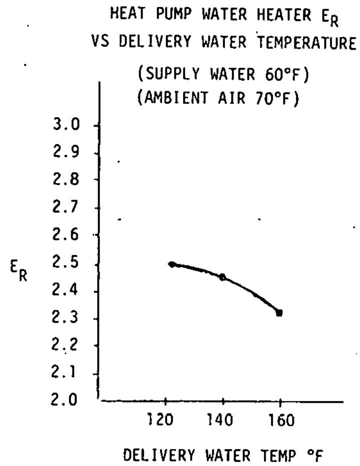
Figure 4.7



The efficiency improves by 47 percent from an ambient air temperature of 50°F to one of 90°F. These are separate tests where the unit in each case is optimized for that temperature. But in actual operation, if the unit is optimized at 70°F, the E_R at 90°F would be lower than at 70°F because the amount of refrigerant used would be more than optimal for 90°F.

Conversely, the E_R improves as supply water temperature declines. As discussed in section 2, this offsets the ambient air advantage in warmer climates where supply water is also warmer. The improvement from 80°F to 40°F supply water temperature is 7 percent.

Figure 4.8



As the thermostat and thus the delivery water temperature is reduced from 140°F to 120°F, the E_R improves by 6 percent. But as noted in section 2, this requires an increase in tank size to maintain an equivalent heat storage capacity. Further, the lower temperature may not provide adequate sanitizing of clothes and dishes.

4.3 Life Tests

Three new and two retrofit heat pump water heaters have been on life test for varying lengths of time up to one year. The units operate on a continuous cycling schedule seven days a week, heating 55-60°F supply water to 135-140°F in a 70-75°F ambient. On June 1, 1978 the thermostats were reset to 160°F to accelerate the life test (E_R dropped from 2.4-2.5 to 2.1). So far one compressor failed after 24 hours because of a faulty bearing; and one thermostat failed at night in the closed position, allowing the tank temperature to reach 173°F by morning or just below the safety shut-off at 175°F. The unit suffered no damage.

4.4 Conclusions

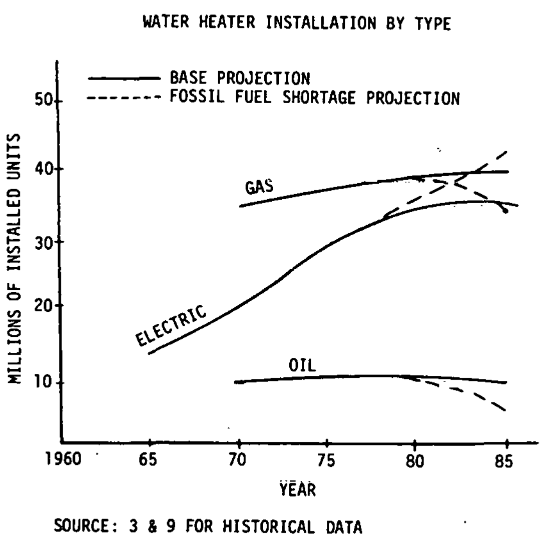
The heat pump water heater as now designed has demonstrated a performance very close to the design objective of a COP of 3. Sensitivity tests on the most recent designs have led to maximized performance. The device will perform satisfactorily over an expected range of ambient temperatures and supply water temperatures. There is reason to believe the device will operate satisfactorily for several years.

5.0 Market Study

5.1 Potential Market

In figure 5.1 are shown curves (solid lines) of current projections of the number of dwelling units with water heaters -- gas, oil or electric. These projections are based on extrapolation of the past trends of water heater purchases. Thus, they assume no significant change caused by shortages of domestic supplies of gas or oil.

Figure 5.1



At the other extreme are the dotted line curves in figure 5.1 which represent what could happen if increasing prices and/or shortages of fossil fuels do cause a rapid switch to electric water heaters. The actual projection will probably fall somewhere in between these two extremes.

In section 2 it was determined that the payback period (the primary criteria for determining the value of the heat pump water heater) is relatively insensitive to COP. At least it is not as sensitive to COP as it is to the cost of electricity and to the amount of hot water consumed. In the case of the

COP, the payback period (which is measured as the ratio of the additional installed cost to the monthly operating savings, including maintenance costs, compared to resistance type water heating) increases 57 percent between a COP of 4 and one of 2. These are practicable limits for the device. In the case of the cost of electricity, the payback period increases 161 percent between the limits of seven and three cents per kilowatt-hour. For hot water consumption, payback period increases by 110 percent between 50,000 gallons per year which is representative of a typical rural or suburban family and the national average of 25,000 gallons per year. Thus, the device will prove to be economic in many homes in the North, where both hot water use and the cost of electricity are above average, as well as in locations with moderate climates. So it is practicable to view the entire United States as the potential market.

With 30 million electric water heaters now in use, there would appear to be a large market for the heat pump for retrofitting these existing units. But the majority of these are either too old or too small to justify retrofitting or are eliminated by some accessibility or space limitation. Thus, the estimated potential for retrofitting existing water heaters is 2,400,000 units. Existing water heaters, gas, oil and electric, are being replaced at the rate of 3,500,000 units per year. These represent a much greater potential for replacing with a heat pump type electric unit than they do for retrofitting.

New units for new dwelling construction represent the most immediate potential as large home builders adopt the heat pump water heater and use it as a selling point because of its low operating cost.

Over the next five years, more than three million electric resistance type water heaters will be installed each year. Most of those will soon represent retrofit potential, a potential that will be enhanced as the price of electricity continues to rise, shortening the payback period.

Aggregating the above market segments shows a potential market growing to seven million units by 1982 as shown in Table 5.1.

TABLE 5.1

Potential Market for Heat Pump Water Heaters
(in millions)

Year	New Units (new houses)	Existing Retrofit	Retrofit New Units	Replace Existing Units	Total
1978	1.5	2.4		2.5	6.4
1979	1.8			2.7	4.5
1980	2.0		1.0	3.0	6.0
1981	2.0		1.2	3.2	6.4
1982	2.0		1.5	3.5	7.0
1983	2.0		1.7	3.7	7.4

5.2 Constraints to Achieving Market Saturation

Realizing all the potential market will be difficult because of many technical and institutional constraints that will impede the market acceptance. A significant need is to train plumbing installers who normally install water heaters to apply, install and service a refrigeration system. Without that training, customer complaints would be multiplied and the device would get a bad image at the start.

To reduce that possibility, electric utility people, each of whom will have people trained by EUS, will participate in the demonstration program described in section 6. Once the product is in production, the initial target market will be rural and suburban single family homes in areas served by merchandising utilities or utilities who select a reliable dealer, train dealer personnel and supervise the application, installation and servicing of heat pump water heaters for some initial marketing period.

Only after enough field experience is gained to create a comprehensive application, installation and service training program, will personnel and organizations throughout the normal channels of distribution of water heaters be selected to expand the application, installation and maintenance of the device.

Other constraints that will impede the full commercialization of the heat pump water heater will include:

- the need for compliance with different regulations of Federal, state and local safety, health and code authorities.
- price competition and consumer resistance. Despite the attractive payback periods, experience with other energy conservation products suggests that this economic incentive will be slow to change the normal buying habits of the public who normally buy on price.
- reluctance of present water heater manufacturers to become involved in a new technology.
- the restraint by public utility commissions of electric utility promotion of new load.
- a possible jurisdictional dispute between plumbers, electricians and refrigeration installers as to which one or ones will be responsible for the device.
- the normal unwillingness of architects and home builders to try something new if it means adding to the cost of a new house.

- the lack of appropriate space for a heat pump water heater in new or existing homes.

5.3 Target Market

As stated previously, the original target market will be rural and suburban single family homes, in areas served by merchandising utilities and in those areas with warm climates and/or high electric rates. This has been derived by a building disaggregation study which concluded that little potential exists in major types of commercial buildings because the hot water demand is too high or is for water at temperatures of $160^{\circ}F$ to $180^{\circ}F$, which are above the anticipated delivery temperature of the heat pump water heater. In urban dwelling units (apartments), hot water use is generally below the national average and in most cities natural gas is presently available.

5.4 Conclusions

A large market for heat pump water heaters exists, particularly in the suburban and rural single family housing sectors and in those areas where the cost of electricity is high and gas is unavailable. Initial marketing should be through merchandising utilities to avoid misapplication and poor installation and servicing of this new technology and to help overcome other institutional and technical constraints that threaten to restrict the market acceptance of the device.

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6.0 Field Demonstration Plan

In section 2, the summary of the parametric analysis performed by EUS concluded that the heat pump water heater can be cost effective in all climates, assuming the device meets the design performance objective and that it is properly applied and installed in the home. Above average hot water use and cost of electricity improve the economics.

To prove that conclusion in actual field use, 100 units will be installed, serviced and monitored for 12 months by electric utility personnel trained at the manufacturer's location. From this program, it is hoped that enough field experience will be gained to create a comprehensive application, installation and service training program for the training of personnel throughout the normal channels of distribution of water heaters.

To accomplish that objective will require a program which can:

- determine the average performance of the device in different climates, locations in the house, types of houses, modes of control and water quality.
- determine application, installation and maintenance problems and costs

- determine actual payback period

The above information can also be used to:

- promote the heat pump water heater as a cost and energy saving device
- encourage other manufacturers to manufacture and market the device
- provide publicity for electric utilities for their part in providing lower cost electric water heating.

As envisioned, the plan would involve the manufacture of 113 units by a combination of EUS and Mor-Flo.

Eighty-five units would be for new installation with tank and heat pump assembled, tested and shipped in one carton. The tank and shipping carton would be supplied by Mor-Flo. The tanks would be standard units but modified to use special covers to accommodate installation of the direct immersion condenser. EUS will build the heat pump units, assemble them to the tanks, test and ship via Mor-Flo's in-house fleet of trucks.

Twenty-five units would be the heat pump only for retrofit to existing tanks. They would be produced and shipped by EUS.

Three units would be new type for test by Underwriters Laboratory. Ten units (five of each type) would be held by EUS for replacement of defective units over the course of the test. Thus, 80 new units and 20 retrofit units will be installed and tested.

Five units will be shipped to each of 20 utilities. A preliminary list of utilities and the number and type they are expected to install is shown in Table 6.1. The list will be finalized after discussion with the utilities.

TABLE 6.1

Participating Utilities

Utility	Type	Installation Location	Quantity
Valley REC, Huntingdon, PA	New	Basement	5
Somerset REC, Somerset, PA	New	Basement	5
Indianapolis Power & Light	New	Basement	5
Public Service of Indiana	Retrofit	Basement	5
NRECA	New	Basement	5
Kansas Gas & Electric	New	Garage	5
Kentucky Association of Electric Coops	New	Garage	5
Ohio Edison	Retrofit	Basement	5
Toledo Edison	Retrofit	Basement	5
Mississippi Power & Light	New	*	5
South Carolina Gas & Electric	New	Utility Room	5
Duke Power	New	Garage	5
Florida Power & Light	New	*	5
Southern California Edison	New	Outdoors	5
Gulf Power	New	Utility Room	5
Hawaiian Electric	New	Outdoors	5
Arizona Public Service	New	*	5
Portland General Electric	New	Utility Room	5
Eugene Water Board	New	Utility Room	5
Bonneville Power Admin.	Retrofit	Basement	5
		Total	100

* Not determined.

Specific parts of the plan are listed in detail in Volume 2. Stated briefly, EUS and Mor-Flo will design and produce the units. Electric utilities will be expected to:

1) purchase the heat pump water heaters at $200 for retrofit units and $371 for new units complete with tank (estimated to be ultimate retail price);
2) attend a training session in Pittsburgh;
3) install and service the water heaters and instrumentation;
4) collect data each month, including service/maintenance experience, and mail to EUS; and
5) provide liability insurance or indemnify the contracting agencies.

DOE/ORNL will provide costs of:

1) prototype units in excess of prices paid by utilities;
2) instrumentation;
3) data reduction and analysis; and

4) spare parts or replacement units.

The test is scheduled to run for 12 months with a possible extension to be determined later.

7.0 References

1. Consumers Reports, March 1976.

2. 1973 Systems Handbook, ASHRAE, Page 37.17, Table 7.

3. Bureau of Census, Statistical Abstracts, 1975.

4. Chaddock, Dr. J. B., "Feasibility Study of the Heat Pump Water Heater," Purdue University, August 31, 1961. From work sponsored by Association of Edison Illuminating Companies.

5. Personal communication from Dr. B. B. Hamel and Dr. H. L. Brown, General Energy Associates, November 1977, of subcontract work for this project.

6. Association of Edison Electric Illuminating Companies, Load Research Committee, Annual Report.

7. ASHRAE, Systems Handbook, 1973, Page 37.17, Footnote C and Page 37.18, Table 8.

8. Federal Register, Volume 42, No. 125, June 29, 1977.

9. Gas Facts, 1976, American Gas Association.

APPENDIX A

Scope of Work

Task I.1

Submit a detailed project plan for review and approval by the ORNL TM. This plan shall indicate, in more detail than the proposal program plan, final allocation of financial and personnel resources, timing of principal events that are to occur during execution of the project, decision points and progress milestones, technical approach, and other items of direct relevance to timely and successful accomplishment of the project objectives.

The Contractor shall not proceed with Task I.2 or beyond until this plan is approved by the ORNL TM. No changes shall be made to the approved plan without approval of the ORNL TM.

Task I.2

Perform the studies necessary to determine the potential market for the heat pump water heater for both retrofit and new applications. These studies should address both the residential and commercial sectors in a disaggregated (by type of building and region) manner, as appropriate. Size of units, purchasers, and end user should be identified. All problems which impede commercialization of the improved water heater are to be identified, along with the solutions planned to overcome the problems. These problems should include, but not be limited to, the anticipated selling price or price differential, and to institutional and other factors that have a strong effect on buyer acceptance, manufacturer capital requirements, applicability to conventional manufacturing and installation practice, maintenance, safety, and regional factors. Determine the effect of the heat pump water heater on the living space conditioning when placed in various conditioned spaces (basement, garage, utility room, crawl space, etc.) in three different cities: Minneapolis, Pittsburgh, and Jacksonville. Develop and apply a rating method to indicate the best target market(s) for demonstrating the improved water heater. Rating criteria should include the potential for national energy savings, the time schedule on which such energy savings might realistically be achieved, and the difficulty of solving the problems impeding commercialization.

Task I.3

Perform the R&D necessary to develop, fabricate, and test heat pump water heaters both for new and retrofit applications which are optimized for the target market identified in Task I.2. Evaluations should be made of the tradeoff between size of equipment and energy storage capability, the reliability and cost-effectiveness of components, and the modifications required to adapt the equipment to other portions of the potential market. Testing should be performed under conditions which are realistic to the target market and which are compatible with NBS-FEA-FTC[a] testing and labeling requirements for water heaters to the greatest extent possible. An independent laboratory shall verify the performance test results for both the retrofit and new applications heat pump water heaters.

Task I.4

Submit, for review and approval by the ORNL TM, a detailed Phase II project plan for demonstration of the heat pump water heaters for both retrofit and new applications in practical field applications, including the plan for production of the demonstration units to be tested and evaluated. The plan for production of these units should be in a manner that can be readily scaled to commercial production size. The plan for demonstration should be adequate to obtain credible information on energy consumption and efficiency, reliability, performance, safety, cost, and other aspects determined to be important to promoting use of the units. Energy efficiency and cost information should be consistent with NBS-FEA-FTC labeling and efficiency rating methods.

The plan must include definitive commitments for the partici-

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[a]National Bureau of Standards - Federal Energy Administration - Federal Trade Commission.

pation of users and for the manufacturers' participation in a nontrivial, cost-sharing effort.

This plan shall indicate, in more detail than the Task I.1 plan, the allocation of financial and personnel resources, timing of principal events that are to occur during execution of the project, decision points and milestones, technical approach, additional plans to further promote the heat pump water heaters through use of the project-generated information, and other items of direct relevance to timely introduction of the equipment into the marketplace.

Task I.5

Prepare a final summary report covering all aspects of the Phase I work, reflecting resolution of comments from the ORNL TM based on review of draft copy (allows 2 weeks for the ORNL review). Include deliverables 2F, 3F, and 4F as backup to the summary report.