ENERGY

CONSERVATION

ORNL/Sub-7321/3

# DEMONSTRATION of a HEAT-PUMP WATER HEATER

VOLUME 1
DESIGN REPORT

DECEMBER 1979

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

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# DEMONSTRATION
# OF A
# HEAT PUMP WATER HEATER

Volume 3

DESIGN REPORT

December 1979

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# ABSTRACT

Energy Utilization Systems, Incorporated, under work sponsored by Buildings and Community Systems Division of the United States Department of Energy, through the Oak Ridge National Laboratory, has developed a heat pump water heater for residential installations.

This report describes work performed during the pilot run manufacturing and laboratory testing stages of the contract. A general description of the heat pump water heater is provided, as are detailed discussions of individual components. Also included is a description of the pilot run manufacturing facility and experience, laboratory operations and laboratory test data.

# FOREWORD

This is a report of work performed to date by Energy Utilization Systems, Inc. (EUS), covering part of Phase II, the field demonstration of an electric heat pump water heater on which United States letter patents for prior work have been granted. 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).

This Volume 1, a continuation of a series of reports on a heat pump water heater [1,2], contains a description of the pilot run production and testing effort as defined in the first four major tasks included in Phase II. These tasks are:

- Task 1 - Development of final specifications and engineering design of the heat pump water heater and of the pilot run manufacturing facility.
- Task 2 - Preparation of facility for pilot run production.
- Task 3 - Construction of prototypes for laboratory testing and Underwriters' Laboratory approval.
- Task 4 - Manufacture of pilot run heat pump water heaters and instrumentation packages.

Results of heat pump installation and data monitoring will be presented in a later report.

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# INTRODUCTION AND SUMMARY

Energy Utilization Systems, Incorporated (EUS), under work sponsored by the Buildings and Community Systems Division of the United States Department of Energy (DOE), through the Oak Ridge National Laboratory (ORNL), has developed a heat pump water heater for residential installations. The work for this contract (UCC number 7321) was divided into two phases. Phase I covered the research and development of the heat pump water heater, designated TEMCOR. Work performed under Phase I included conceptual design and engineering and was completed in August 1978 [1,2].

Under Phase II of the contract, a pilot run facility for assembly and testing of 100 units was designed and constructed. After assembly and shipment, these 100 units were placed in customers' homes by 20 electric utility companies in order to demonstrate the capabilities of the heat pump water heater. The performance of the units is being monitored for one year by these utilities; the data will be forwarded to EUS and will be presented in a final report.

This report is a summary of work performed during Task 1 through Task 4 of Phase II.* A general description of the heat pump water heater is provided, as are more detailed discussions of the individual components, pilot run manufacturing facility and experience, laboratory and testing operations, and demonstration unit test data. The units provided 140°F (60°C) water under a cyclic water draw schedule with 36 to 50% of the energy that would have been required from resistance heaters over a wide range of source water and ambient temperatures. Information concerning the field demonstrations and conclusions regarding the performance of the units in field sites will be provided in a later report.

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* A summary of the work scope for each task in Phase II is provided in Appendix A.

# 1. HEAT PUMP WATER HEATER DESCRIPTION

## 1.1 GENERAL DESCRIPTION

A heat pump water heater is a device which pumps heat from either a conditioned space (such as a laundry or utility room) or an unconditioned space (basement, garage or attic) into a water tank, and which operates in a manner similar to that of an air conditioner. In the case of the heat pump water heater, heat from the room is transferred into the water tank rather than outdoors. Because only a portion of the total heat energy transferred to the water by the heat pump must be supplied electrically (as opposed to a standard electric water heater in which all the energy must be supplied by electrical resistance heating), the device offers a great potential for energy savings. It is currently estimated that only about one-half to one-third the electric energy used by resistance heating units to heat water would be needed for a heat pump unit.

The heat pump water heater is shown schematically in Figure 1-1. The major components are the compressor, evaporator, fan and direct-immersion condenser. Other components include electrical controls, expansion valve, refrigerant filter dryer and heat pump housing.

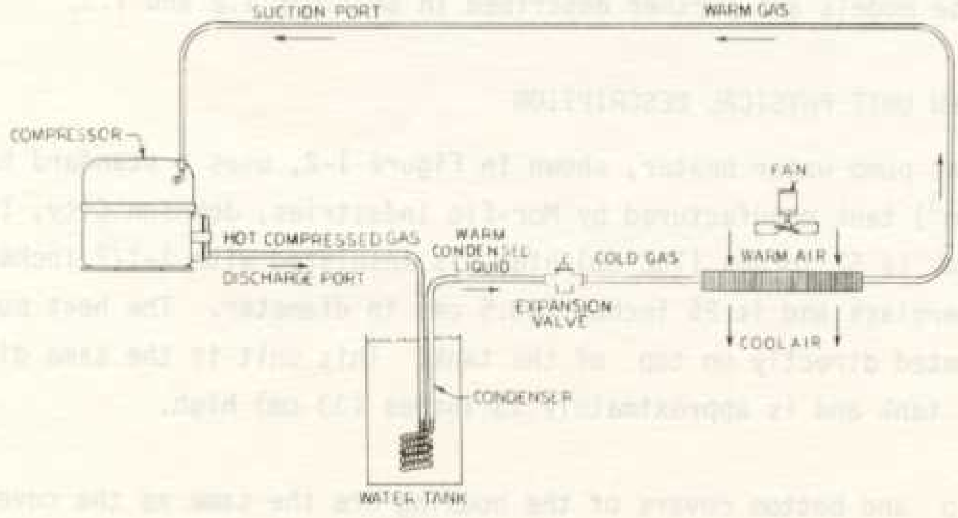


Figure 1-1. Heat Pump Water Heater Schematic

During operation, high pressure liquid refrigerant (R-12) passes through the expansion valve where it undergoes a phase change from a liquid to a vapor. The heat of vaporization and superheat are supplied by room air as it is blown across the finned tubes of the evaporator by the fan. The warmed vapor enters the compressor where it is compressed to a higher pressure and correspondingly higher temperature. This hot gas passes through the condenser where it gives up heat to the water in the tank. The cycle repeats until the thermostat setpoint is reached and the unit shuts off.

The thermodynamics of the above cycle are such that, for every unit of heat energy provided by electrical energy to the compressor, more than one unit of heat energy is released to the water in the tank. The amount of heat released depends on the ambient air temperature and water temperature. The additional heat energy is extracted from the air in the room. Because the room air is cooled 5°F-10°F (2.8-5.6°C) as it passes through the evaporator, the heat pump also provides a limited amount of cooling and dehumidification of the enclosed space.

Two heat pump water heater models have been developed. One model is designed as a complete unit, consisting of a heat pump assembly mounted atop an 82-gallon (0.31-$m^3$) water tank. The second model is a retrofit unit, designed to be used with an existing water heater installation. Both of these models are further described in Sections 1.2 and 1.3.

## 1.2 NEW UNIT PHYSICAL DESCRIPTION

The heat pump water heater, shown in Figure 1-2, uses a standard 82-gallon (0.31-$m^3$) tank manufactured by Mor-Flo Industries, Johnson City, Tennessee. The tank is 52 inches (132 cm) high, is insulated with 1-1/2 inches (3.8 cm) of fiberglass and is 25 inches (63.5 cm) in diameter. The heat pump unit is mounted directly on top of the tank. This unit is the same diameter as the tank and is approximately 13 inches (33 cm) high.

The top and bottom covers of the housing are the same as the cover used for the water heater tank. Use of these covers provides an aesthetic match between the heat pump and the tank as well as a cost savings because the covers are already in mass production.

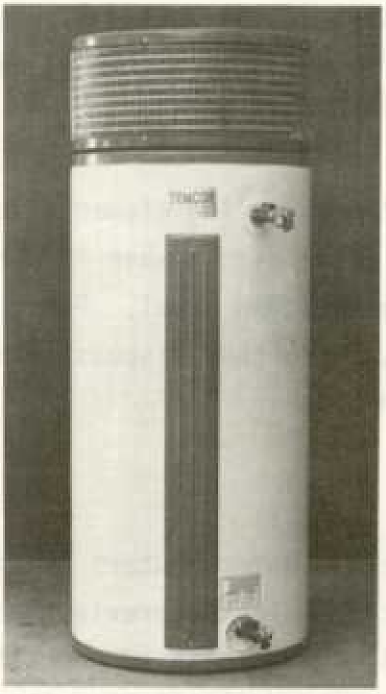

Figure 1-2. Heat Pump Assembled to 82-Gallon Tank

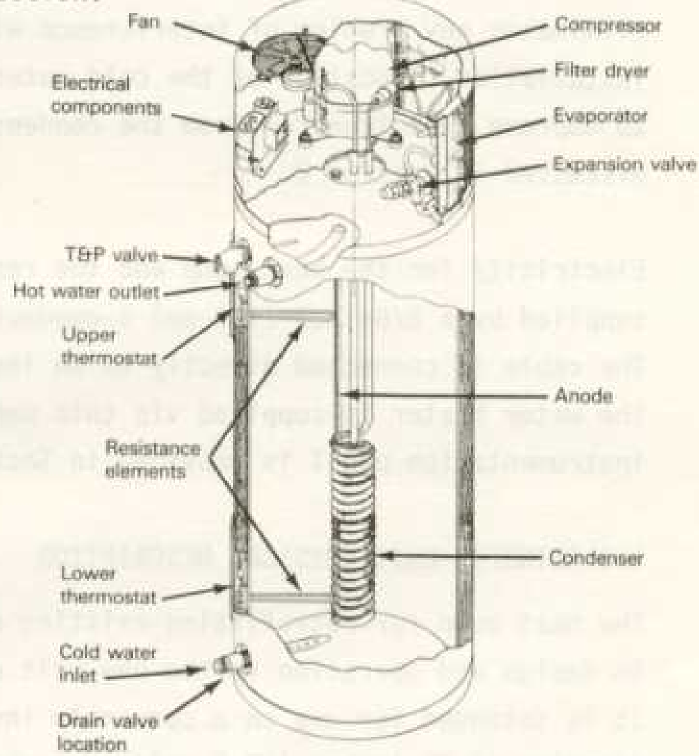


Figure 1-3. Cutaway View of Heat Pump Water Heater

Figure 1-3 shows a cutaway view of the entire unit. Individual heat pump components are described in Section 2 of this report. The tank contains two 2500-watt standard resistance heating elements. The upper element is designed to operate in conjunction with the heat pump whenever the water temperature, as measured by the upper themostat, drops below a preset temperature. This provides a rapid heat recovery rate when necessary, as during startup or following withdrawal of a large quantity of hot water.

The lower resistance heating element is included as a backup in the event of a failure of the heat pump. It also supplies energy on resistance heating days during the test program in order to provide a standard with which the heat pump will be compared. A separate thermostat is provided for controlling this element. The water inlet and outlet nozzles do not enter the tank from the top, as they do on standard electric water heater designs. The cold water inlet is at the bottom of the tank and the hot water outlet is on the side of the tank near the top. This configuration eliminates any problem of interference with the heat pump unit during installation. Location of the cold water inlet at the bottom also serves to improve heat transfer from the condenser to the water, as will be discussed in Section 2.

Electricity for the heat pump and the resistance heating elements is supplied by a 5/8-inch (1.6-cm) 6-conductor cable with number 10 wire. The cable is connected directly to an instrumentation panel. Power for the water heater is supplied via this panel. A further discussion of the instrumentation panel is provided in Section 3.

## 1.3 RETROFIT UNIT PHYSICAL DESCRIPTION

The heat pump for retrofitting existing electric water heaters is similar in design and operation to the new unit described in the previous section. It is intended for use on a currently installed tank with an overall diameter of 25 inches (63.5 cm) and a capacity of at least 50 gallons (189 liters) of water.

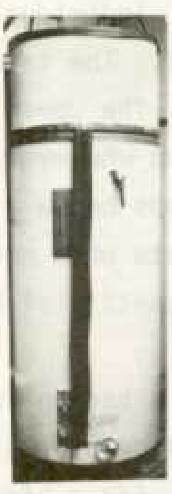

Figure 1-4. Retrofit Unit

The retrofit unit is shown in Figure 1-4. The heat pump compartment is 13 inches (33 cm) high and is mounted on top of the existing tank. There are two holes in both the base and the lid of the heat pump unit. These holes are located in positions matching the industry standard cold water inlet and hot water outlet pipe locations for electric water heaters. The hot water outlet pipe position is not changed following installation of the heat pump, but the cold water inlet pipe is relocated to the bottom of the tank, entering through the fitting originally used for the tank drain valve. The new fitting has a drain valve installed.

For existing tanks which have a temperature-pressure (T&P) safety valve installed on the side of the tank, no further piping modification is required and the remaining hole (the original cold water inlet) on top of the tank is plugged. If the original tank has a T&P valve mounted on top, this valve is relocated to the top cold water inlet hole after the cold water dip tube is removed, a hose is connected between the valve and a drain, and the original valve hole is plugged. The purpose of moving the valve is to allow a standardized heat pump assembly design with no requirements for drilling holes during field installation.

The most significant difference between the new and retrofit units is the condenser design [1]. The retrofit condenser enters the tank through the hole previously used for the lower resistance element rather than through the top of the tank as in the new unit. Two insulated copper lines running along the outside of the tank jacket connect the condenser to the heat pump unit. The retrofit assembly (both cabinet and condenser) is supplied precharged with refrigerant. After installation in the tank, the condenser lines are connected to the refrigeration system using one-time quick-connect puncture connectors.

Electricity is supplied via an instrumentation panel. The connections are similar to those described for the new units, but employ a much simpler panel, as described in Section 3.

# 2. COMPONENT DESIGN MODIFICATIONS

## 2.1 GENERAL DISCUSSION

The component design work for the TEMCOR heat pump water heater was performed under Phase I of ORNL contract number 7321 and was completed in 1978. Thermal and hydraulic design information is unchanged from that presented in the original report [1]. However, because the unit developed during Phase I was a prototype, new physical layout work had to be done to manufacture the unit. Therefore, only the physical design of the heat pump components and modifications made to the original designs are reported here.

Several design changes were made; these changes were made specifically to improve the unit's performance. Among the more significant modifications are:

- elimination of the low-temperature cutoff switch
- elimination of the suction-line heat exchanger
- redesign of the chimney condenser

These modifications are described in the following section. The discussion of component changes applies to both the new unit and retrofit models with one exception, i.e., the retrofit model condenser required no changes from the description provided in reference 1.

A list of all major components included in the new unit model is given in Table 2-1. Major components included in the retrofit units are listed in Table 2-2. The component manufacturer and component specifications or drawing numbers are also listed for each item.

Table 2-1

NEW MODEL COMPONENTS

| Component | Supplier | Model | Specifications |
|---|---|---|---|
| Compressor | Copeland Corp. | JRL4-0100-PAV | R-22 1-ton |
| Condenser Tubing | Turbotec Products | N/A | EUS Drawing B-141-17 |
| Filter Dryer | Sporlan Valve Co. | C-032-S | R-12 1/2-ton |
| Expansion Valve | Singer Controls Div. | TXV223FA 1/2 | R-12 1/2-ton |
| Evaporator | Bohn Heat Transfer | M-6712*36x10 | EUS Drawing B-141-16 |
| Fan Motor | Fasco Industries | 006330V05-534 | 1/20-1/30 h.p. 220v |
| Fan Blade | Air Drive, Inc. | N/A | 9-3/4" ccw #9-pitch |
| Condensate Drip Pan | F.B. Wright & Co. | N/A | EUS Drawing B-141-30 |
| Unit Base | Mor-Flo Industries | N/A | EUS Drawing B-141-23 |
| Unit Top | Mor-Flo Industries | N/A | EUS Drawing B-141-2 |
| Fan Mount | EUS, Inc. | N/A | EUS Drawing B-141-21 |
| Unit Wrapper | Follansbee Metals | N/A | EUS Drawing B-141-14 |
| Evaporator Screen Guard | Vollwein Wire Co. | N/A | EUS Drawing B-141-15 |
| Tank Weld Flange | R. C. White Co. | N/A | EUS Drawing B-141-2 |
| Condenser Assembly Flange | R. C. White Co. | N/A | EUS Drawing B-141-3 |
| Flange Gasket | Mor-Flo Industries | N/A | EUS Drawing B-141-4 |
| Condenser Assembly | EUS, Inc. | N/A | EUS Drawing B-141-18 |

Table 2-2

RETROFIT MODEL COMPONENTS

| Component | Supplier | Model | Specifications |
|---|---|---|---|
| Compressor | Copeland Corp. | JRL4-0075-PAV | R-22 3/4-ton |
| Condenser Tubing | Noranda Tubing | N/A | EUS Drawing A-141-51 |
| Filter Dryer | Sporlan Valve Co. | C-032-S | R-12 1/2-ton |
| Expansion Valve | Singer Controls Div. | TXV223FA 1/2 | R-12 1/2-ton |
| Evaporator | Bohn Heat Transfer | M-6712*36 x 10 | EUS Drawing B-141-16 |
| Fan Motor | Fasco Industries | 006330V05-534 | 1/20, 1/30 h.p. 220v |
| Fan Blade | Air Drive Inc. | N/A | ccw-#9 pitch hub on suction size |
| Condensate Drip Pan | F. B. Wright & Co. | N/A | EUS Drawing B-141-30 |
| Unit Base | Mor-Flo Industries | N/A | EUS Drawing B-141-23 |
| Unit Top | Mor-Flo Industries | N/A | EUS Drawing B-141-2 |
| Fan Mount | EUS, Inc. | N/A | EUS Drawing B-141-21 |
| Unit Wrapper | Follansbee Metals | N/A | EUS Drawing B-141-14 |
| Evaporator Screen Guard | Vollwein Wire Co. | N/A | EUS Drawing B-141-15 |
| Tank Mounting Flange | Mor-Flo Industries | N/A | EUS Drawing A-141-85 |
| Tank Sealing Ring | Mor-Flo Industries | N/A | EUS Drawing A-141-86 |

## 2.2 SIGNIFICANT MODIFICATIONS

### 2.2.1 Elimination of Low-Temperature Cutoff Switch

A low-temperature cutoff switch was included in the original design. This switch was intended to protect the heat pump from evaporator freezeup* at low ambient air temperatures by disconnecting the power to the unit when the air temperature dropped below a predetermined setpoint. However, commercially available switches designed to perform this function would have been extremely expensive if special ordered to meet our specifications. Those available directly off the shelf have a deadband of 10°F and a guaranteed setpoint accuracy of ± 5°F. These specifications are unacceptable since in many instances the unit would turn off for the entire winter. This switch was therefore eliminated from the pilot run design and installation locations for the demonstration units will be selected to preclude freezeup.

### 2.2.2 Elimination of the Suction-Line Heat Exchanger

The original design included a compressor suction-line heat exchanger consisting of six inches (15.2 cm) of the suction line soldered to the liquid refrigerant line. The purpose of this heat exchanger was to insure that the refrigerant vapor entering the compressor was superheated enough to meet the compressor manufacturer's specifications. After the final selection of the expansion valve was made, it was found that the fluid leaving the evaporator was sufficiently superheated without the heat exchanger. With the heat exchanger and the new valve in the system, the additional superheat reduced the performance of both the compressor and the condenser.

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* Evaporator freezeup is a condition which results when the air passing over the evaporator coils is cooled sufficiently to cause the moisture in the air to freeze onto the coils. The ice formed blocks the flow of air and reduces the efficiency of the unit.

Compressor volumetric efficiency is based on the amount of fluid moved per compression stroke. As the fluid temperature increases, its density decreases so that, for a given volume entering the compressor, there is less mass to be compressed. Therefore, at higher temperatures the compressor must do more work to move the same amount of fluid, reducing its efficiency.

If the vapor entering the condenser is too highly superheated it does not become liquid until it reaches a location in the condenser which is too high up in the tank to take full advantage of the stratification of water temperature. This situation can result in both reduced heat transfer in the tank and improper operation of the thermostat.

Because of these problems, the suction-line heat exchanger was eliminated from the design.

### 2.2.3 Redesign of the Chimney Condenser

The condenser for new unit models is designed in a cylindrical coiled shape in order to heat the cold water as it enters the bottom of the tank and allow the heated water to rise to the top due to convection. This chimney-effect coil was modified for the pilot run units in order to improve condenser efficiency.

Figure 2-1. Original Condenser Coil Design

The original condenser assembly had a large loop at the bottom which held the condenser coil four to five inches (10 to 13 cm) above the bottom of the tank as illustrated in Figure 2-1. The coil was relatively long because it was rather small in overall diameter.

It was recognized that the condenser

coil would perform more efficiently if it were placed closer to the bottom of the tank where the coldest water would offer maximum temperature differential. The condenser design was therefore modified to eliminate the bottom loop and to reduce the height and increase the diameter of the coil as shown in Figure 2-2. This new configuration allows a larger portion of the condenser coil to reside in the cold water at the bottom of the tank, thereby increasing condenser efficiency. This modification also increases the amount of hot water in the tank (and available to the user) because the unheated volume at the bottom is greatly reduced.

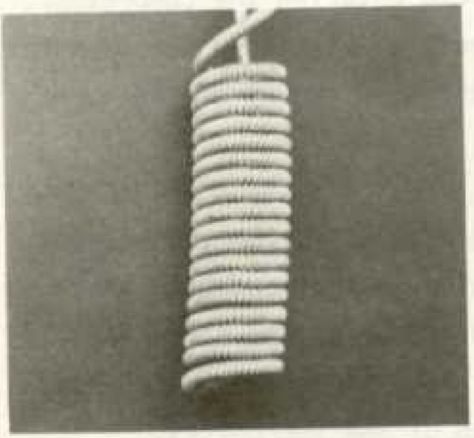


Figure 2-2. Modified Condenser Coil Design

# 3. INSTRUMENTATION PACKAGE

## 3.1 INSTRUMENTATION REQUIREMENTS

In order to determine the performance of the heat pump water heater, it is necessary to examine various operating parameters under controlled conditions. An instrumentation package was developed for use in controlling heat pump operation and for providing operating data during the field demonstration program.

Three major areas to be investigated during the field test program are:

- Water heating energy usage by the heat pump as compared with the resistance heating elements.
- Effects on house heating and air conditioning loads as caused by the heat pump water heater.
- Performance of the heat pump as a function of ambient air temperature, delivery water temperature and supply water temperature.

The requirements for the instrumentation package, in order to facilitate the above investigations, include:

- Capability for controlling heat pump and resistance heating elements on a regular schedule.
- Provisions for monitoring and recording energy used by the heat pump and by the resistance heating elements.
- Provisions for monitoring and recording house heating and air conditioning loads.
- Provisions for monitoring and recording temperatures of ambient air, supply water and delivery water.
- Provisions for monitoring and recording amount of water used.

The equipment chosen to meet these requirements is described in the following section.

## 3.2 NEW UNIT INSTRUMENTATION PACKAGE DESIGN

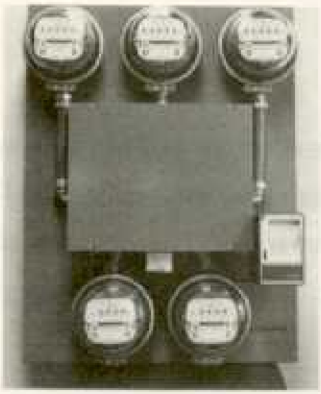


Figure 3-1. New Unit Instrumentation Package

The instrumentation panel is shown in Figure 3-1 and is designed to provide the data needed to meet the requirements listed in Section 3.1. In addition to the instrumentation panel as shown, a standard residential water meter is included with each water heater to complete the instrumentation package.

Instrumentation panel components are as follows:

- three standard watthour meters (Westinghouse Model 510C910G10)
- two current-transformer watthour meters (Westinghouse Model 510C910G52)
- one 14-day timer (Mid-Tex Model 620-7958)
- one single-pole double-throw (SPDT) 10-amp relay (Allen-Bradley Model 700)
- two double-pole double-throw (DPDT) 30-amp relays (Struthers Dunn Model 425XBX)
- one dual-track temperature recorder (Rustrak Model 2155A/F137)
- one single-track temperature recorder (Rustrak Model 2155A) - provided only for installations at which supply water temperature is measured.

This instrumentation is shown schematically in Figure 3-2.

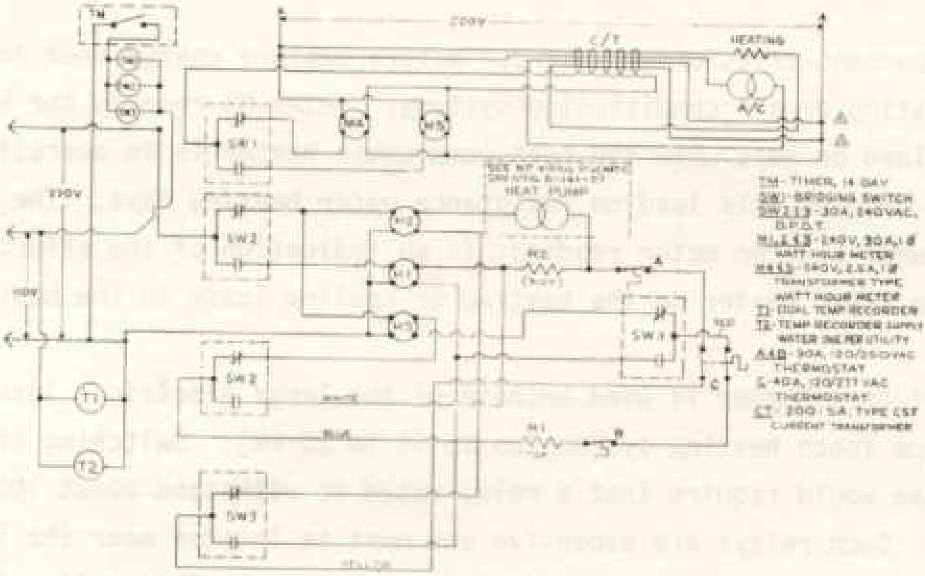



Figure 3-2. New Unit Instrumentation Package Schematic

The timer operates relay switches to allow alternate operation of the heat pump and the resistance heaters.

The two DPDT relays (SW2 and SW3) control the electric current to the heat pump and to the resistance elements as determined by the timer. These relays also switch the proper meters into the circuit for each mode of operation. Relay SW1 switches the current from the current transformer (placed around the heating/air conditioning system wiring) to either M4 or M5, depending on the operating mode. This relay contains an overlap cartridge to prevent arcing when switching between M4 and M5.

During heat pump operation, one of the standard watthour meters (M1) measures the energy used by the heat pump systems and a second standard watthour meter (M2) measures the energy used by the upper resistance heating element for fast recovery. During resistance heating only operation, the third standard watthour meter (M3) measures the total amount of energy used by the upper and lower resistance elements. The total electrical load for either mode of operation can be determined using these three meters.

The two current-transformer watthour meters measure energy used for the house heating or air conditioning systems. Meter M4 records the heating/cooling load on days when the heat pump water heater is in operation; meter M5 records this load on resistance water heating days. The difference between the two meter readings is an indication of the effect of the heat pump water heater on the heating or cooling loads in the house.

A current-transformer is used because of the large electrical load in a resistance space heating system (up to 15 to 20 kW). Switching of this large load would require that a relay rated to withstand about 100 amperes be used. Such relays are expensive and must be located near the load, which would have required additional remote wiring. The cooling load would have necessitated an additional heavy-duty relay and wiring, thus further complicating the installation of the instrumentation package. The current-transformer, installed at the main junction box of the house, requires only two wires for connection to the instrumentation panel.

Ambient air temperature in the water heater location and temperature of the heated water are recorded on the dual-track temperature recorder (T1). The single-track temperature recorder (T2) is used to monitor supply water temperature and is supplied one per utility, since local water temperature is usually constant throughout the supply system. An additional water temperature recorder is provided when more than one water source is used within the service area of the participating utility company. One standard water meter (Hershey American Model 430), supplied as part of the package, is installed in the cold water supply line.

Standard water heater control and protection, which is not part of the instrumentation package, consists of two control thermostats, a safety thermostat, and a temperature and pressure (T&P) safety valve, all mounted on the tank. Thermostat A controls the heat pump or the lower resistance heating element, as appropriate. Thermostat B controls the fast-recovery upper resistance element. Thermostat C is the safety thermostat which cuts off all electricity to the water heater whenever the water temperature exceeds 190°F (88°C). The T&P valve is installed on the hot water outlet pipe and is a standard water heater protection device.

## 3.3 RETROFIT UNIT INSTRUMENTATION PACKAGE DESIGN

The instrument panel for the retrofit units is less complex than the new unit panel because the cycling between heat pump and resistance heating modes is not required. Equipment used on the panel includes:

- two standard watthour meters (Westinghouse Model 510C910G10)
- one dual-track temperature recorder (Rustrak Model 2155A/FB7)
- one single-track temperature recorder (Rustrak Model 2155A)

The instrumentation is shown schematically in Figure 3-3.

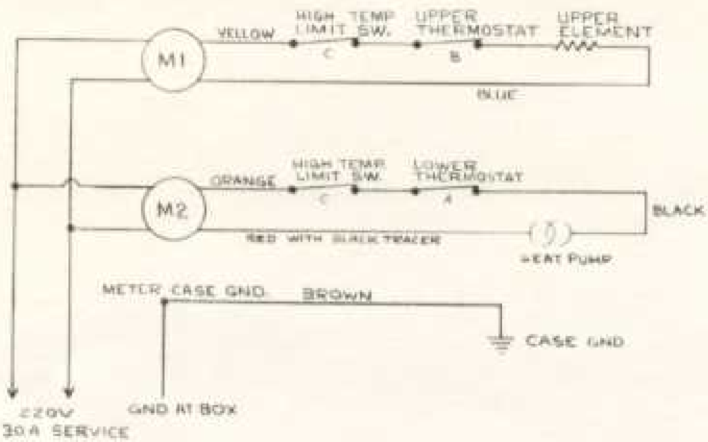



Figure 3-3. Retrofit Unit Instrumentation Package Schematic

Meter M1 records energy used by the retrofit heat pump unit. Meter M2 records energy used by the fast-recovery heating element (R1). Thermostat A controls the heat pump. Thermostat B controls the fast-recovery resistance heater. The temperature recorders operate as described for the new units.

# 4. PILOT RUN MANUFACTURING FACILITY AND TOOLING

## 4.1 MANUFACTURING FACILITY DESCRIPTION

The pilot run manufacutring facility was built at the EUS plant in Pittsburgh, Pennsylvania. The 3500 square-foot facility was designed to allow production of three new units with instrumentation panels per day by three workers. Component fabrication capability was also allowed for in the design.

### 4.1.1 Facility Layout

A diagram of the pilot run facility is shown in Figure 4-1. Major forming equipment (described in more detail in the following section) includes an evaporator forming press, a condenser coil winding machine and a sheet-metal brake; these items are located along the rear wall of the work area.

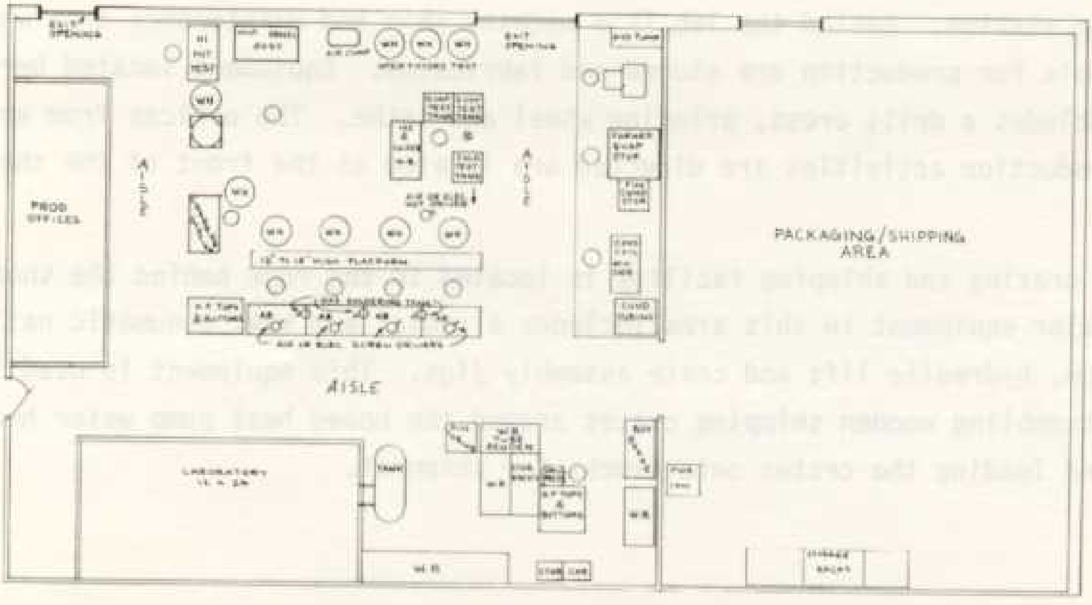



Figure 4-1. Pilot Run Facility Layout

The testing area is located in front of the forming area. Condensers and evaporators are tested here prior to installation. Completed heat pump water heaters are also run-tested in this area. Equipment located here includes the evaporator test tanks, the condenser test tank and the operating and hydro-testing equipment.

The area near the center of the shop is used for heat pump assembly. Each assembly station is furnished with tube-soldering equipment and hand tools. Next to the assembly benches is a platform for use during installation of the heat pumps on top of the water tanks. A refrigerant charging station is also located in this area.

Electrical testing and instrumentation panel assembly stations are located along the side wall near the hydro-testing area. The electrical testing equipment includes a high-potential dielectric strength (hi-pot) test apparatus.

A testing laboratory is located along the wall opposite the electrical testing station. Behind the lab is a machine shop and maintenance area where tools for production are stored and fabricated. Equipment located here includes a drill press, grinding wheel and lathe. The offices from which production activities are directed are located at the front of the shop.

A crating and shipping facility is located in the room behind the shop. Major equipment in this area includes a radial arm saw, pneumatic nail gun, hydraulic lift and crate assembly jigs. This equipment is used for assembling wooden shipping crates around the boxed heat pump water heaters and loading the crates onto trucks for shipment.

## 4.2 PILOT RUN TOOLING

The majority of the tooling for the pilot run project consisted of hand tools and small capital equipment items including:

- bench punch
- 1/2-inch drill press
- bending brake
- radial arm saw
- bench grinder
- air compressor
- hydraulic lift
- pneumatic nail gun
- electrical metering equipment

In addition, a number of devices for manufacturing and testing were either purchased or specially fabricated. These are described in the following sections.

### 4.2.1 Special Manufacturing Equipment

Three drill jigs were constructed for use in drilling holes in the heat pump base, top and wrapper. An evaporator bending press and a condenser coiling machine were also designed and built.

The evaporator bending press is shown in Figure 4-2 in position to begin operation. An unbent evaporator lies flat on a canvas webbing suspended between two movable arms. The canvas serves to move the arms inward as the press die moves down. The bending is done by the force exerted by the die and the movable arms on the evaporator.

Figure 4-3 is a photograph taken of the device after most of the bending

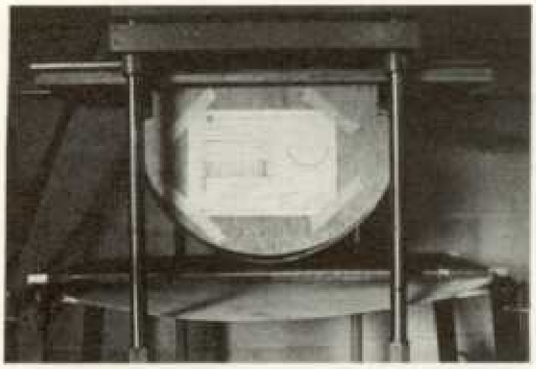


Figure 4-2. Evaporator Bending Press Ready for Operation

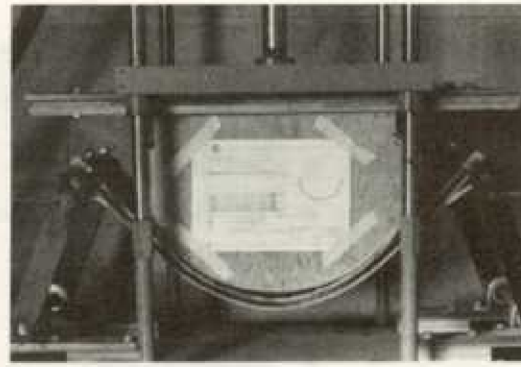


Figure 4-3. Evaporator Bending Press During Operation

operation has been completed. The fins of the evaporator are not damaged during the bending operation because the force used to bend the evaporator is always exerted in a direction normal to the fins.

The hydraulically-operated press descends at a rate of approximately one inch (2.54 cm) per second. At this rate, 100 evaporators can be made per 8-hour shift.

The condenser coil-winding tool is shown in Figure 4-4. It is essentially a long, motor-driven pipe (2 1/2-inch schedule 40) with an end-die of EUS

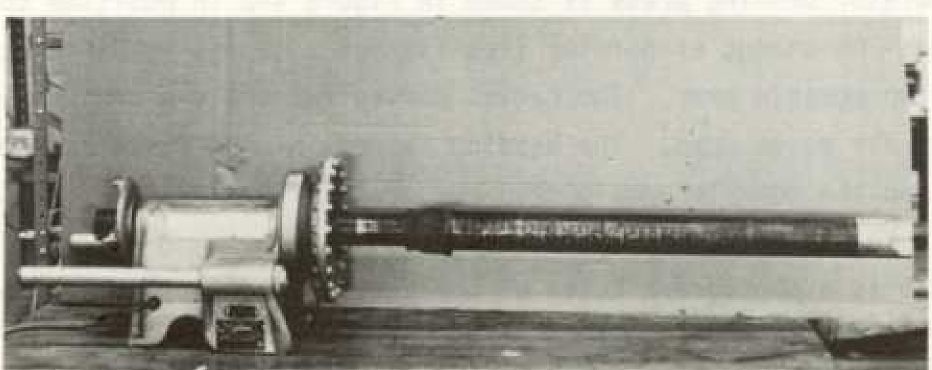


Figure 4-4. Condenser Coil-Winding Tool

design (Figure 4-5). During the condenser coil-winding operation, a straight length of condenser tubing is fed through the pipe and manually formed around the end-die in order to create the return bend. The machine is then turned on and the remainder of the coil is wound about the pipe mechanically. This operation allows the formation of the coil around the center tube without overbending. The machine is shown with a condenser coil in place in Figure 4-6.

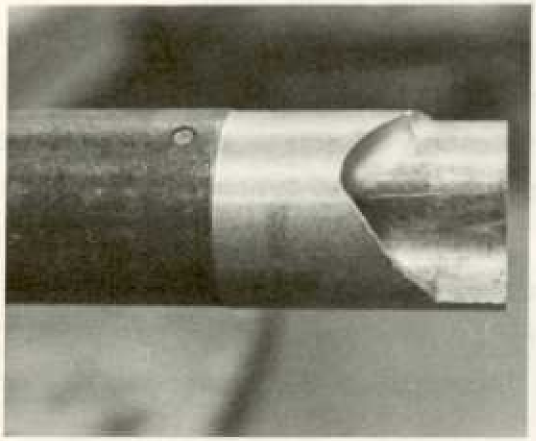


Figure 4-5. Condenser Coil Winder End-Die

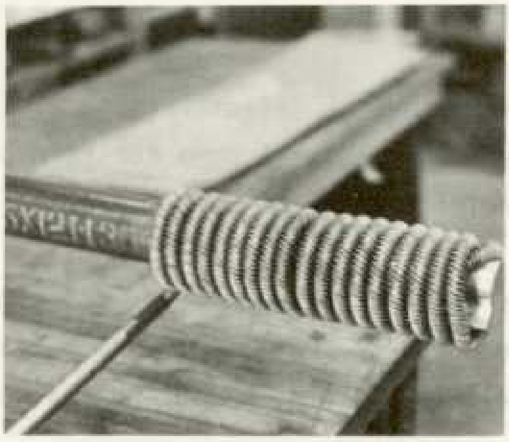


Figure 4-6. Condenser Coil on Winder

Two refrigeration-charging devices were purchased for the project. Each device consists of a vacuum pump, valves and gauges for measuring vacuum and refrigerant pressures. The device is used to charge the heat pump system with refrigerant in the following manner: the vacuum pump is used to evacuate the unit to an absolute pressure of 500 microns of mercury (pump-down operation) and the system is then flushed with refrigerant to remove moisture and contaminants. Both of these operations are repeated; a final pump-down to an absolute pressure of 200 microns of mercury is performed; and the unit is charged with the proper amount of refrigerant.

### 4.2.2 Special Testing Equipment

A number of quality control tests are conducted on the heat pump system and its components, both during and after assembly of the unit; these tests are further described in Section 4.4.

Equipment used for the condenser and evaporator leak tests consists basically of a large water tank and nitrogen charging system. Tank pressure testing is done using a positive-displacement pump.

A halogen leak detector (General Electric Model H-10) is used to test the completed heat pump for refrigerant leaks. The detector can measure a refrigerant leak rate as low as one-half ounce (14.2 grams) per year.

The electrical circuits of the completed unit are tested for adequate grounding and component insulation using a Hypot Junior high-potential dielectric strength testing instrument (Associated Research, Inc.).

Operational testing equipment includes three watthour meters (Duncan Model EM-100), three wattmeters (Simpson 0 to 3000W), temperature-recording equipment (Rustrack Model 2155A) and ground-fault circuit interrupters for safety.

## 4.3 ASSEMBLY PROCEDURE

The pilot run heat pump water heaters were assembled from a number of sub-assemblies which were built and tested concurrently. This allows for more efficient use of the shop equipment.

The evaporator, procured in a flat configuration, is bent into a 25-inch (36.5-cm) diameter arc to fit the contour of the heat pump cabinet. The evaporator bending press is used for this operation. Evaporator inlet tubes are bent to shape and soldered into place. This assembly is then pressure-tested in the evaporator test tank.

The condenser tubing [2] is supplied as a long, straight length which must be formed into a coil using the condenser coil-winder. After forming, the necessary flanges are brazed on and the indicator fluid used to detect refrigerant leakage in the condenser, is inserted. The condenser assembly is then tin-plated and pressure-tested.

Condenser assemblies are mounted in the tanks in the tank assembly area next to the platform near the center of the shop. The tanks are placed on movable carts behind the platform. The platform allows easy access to the tops of the tanks and the carts allow the tanks to be moved throughout the shop for further assembly and testing. Each tank is pressure-tested after the condenser is mounted in place to insure that there are no leaks around the top flange.

Heat pump units are built at the assembly benches, as shown in Figure 4-7. All heat pump components with exception of the condenser are installed. This assembly is mounted on top of the tank after the pressure-test has been passed. Final solder joints to the condenser tubing are made and the water heater is moved to the charging station for leak testing and refrigerant charging.

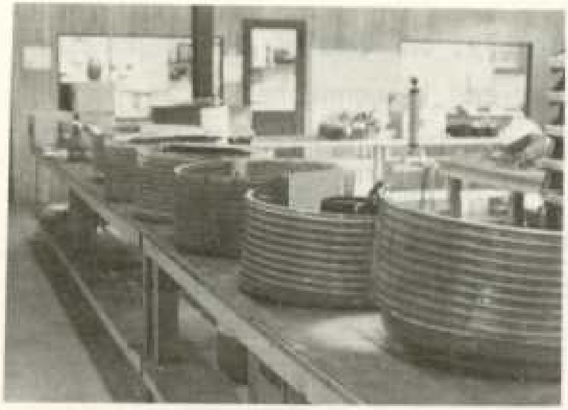


Figure 4-7. Heat Pump Assembly Benches

Electrical wiring and testing are completed while the unit is being charged. The completed water heater is filled with water and moved to the operational testing area for a final checkout of the unit's performance.

After operational testing and draining, the unit is taken to the packing and shipping area where it is put into a box and crated for shipment. Small components needed for installation (e.g. drain valves, condensate drain tubing, hose clamps, hot and cold water valves) are also packaged here.

The instrumentation package is assembled and tested while the heat pump is being built. This assembly is also packaged and crated in the shipping area.

Retrofit unit assembly operations are similar to new unit operations with the exception of tank mounting. Following heat pump assembly, these units are temporarily mounted on a water heater tank for operational testing. Then the heat pump, separate condenser and instrumentation package are crated for shipment.

## 4.4 TESTING PROCEDURES

A number of component and unit tests are conducted during and after assembly of the heat pump water heaters in order to insure that the units to be shipped will operate properly. An additional measure of quality assurance was introduced by selecting several production units for additional laboratory testing. The laboratory tests have been previously described in the task 3 report of reference 2; the additional tests are described here.

### 4.4.1 <u>Evaporator Leak Test</u>

Following completion of evaporator assembly, one end of the evaporator tubing is temporarily sealed. The other end is connected to an inert gas supply and pressurized to about 140 psi ($9.7 \times 10^5$Pa). The assembly is immersed in a large tank of water. If no bubbles appear, the evaporator is passed for installation. If bubbles do appear, the leaking portion can be identified, repaired if possible, and retested.

### 4.4.2 <u>Condenser Leak Test</u>

The condenser is tested to insure that there is no leakage either from the refrigerant tube to the annulus or from the annulus to the water tank. The two ends of the refrigerant tube are temporarily capped. Then the line normally used for leak detection during operation is connected to the high-pressure nitrogen supply. The condenser assembly is then immersed in a water tank. If bubbles appear around the outside of the condenser tubing, there is a leak from the water jacket to the water tank. If the caps blow off the refrigerant line, there is a leak from the refrigerant tube to the water jacket. Either of these occurrences is an indication that the assembly must be repaired or replaced.

### 4.4.3 Tank Pressure Test

The water tanks used are pressure-tested by the manufacturer prior to shipment to EUS. The additional pressure test performed during heat pump assembly is necessary to check the seal around the condenser-assembly flange.

After the condenser is mounted in the tank, a positive displacement pump is used to pump the tank full of water at a pressure of approximately 150 psi ($1.03 \times 10^6$ Pa). A visual inspection for leaks around the flange and bolts is made. If leaks are evident, the joint must be adjusted and retested.

### 4.4.4 Refrigerant Leak Test

Following completion of the unit assembly, all soldered joints in the refrigerant tubing are checked for leaks. The detector used for these tests is very sensitive and can detect very small leakage rates. Any joint which fails the test can be resoldered and tested again.

### 4.4.5 High-Potential Dielectric Strength Test

This test is run after the unit is fully wired to insure that there are no shorts, improper grounds, or other electrical defects in the wiring or electrical components. The test is performed using the instrument described previously to apply a deliberate overvoltage to the heat pump circuits for a preset time interval. The instrument measures current flow through the unit components to ground. If this current flow exceeds a maximum allowable value, the voltage is automatically turned off and a breakdown indicator lights up to signal a fault in the unit.

### 4.4.6 Operational Test

The operational or run test is the final test performed on the units (except for those units going to the laboratory) prior to crating and shipping. The tank is filled with water and the unit is connected to an electrical supply and monitoring equipment so that its operational performance can be determined. Water temperature is measured during the test, as are energy usage of the heat pump and resistance elements. A preliminary coefficient of performance calculation can be made using the results of the run test and this is used as an indication of whether or not the unit is operating properly.

### 4.4.7 Laboratory Tests

Three test units and several production units were tested in the laboratory following completion of the other tests. The tests performed were intended to measure the heat pump water heater performance under test conditions similar to those established during the development phase of this project. Results of these tests are provided in Section 6.

# 5. PILOT RUN MANUFACTURING EXPERIENCE

## 5.1 GENERAL DISCUSSION

The pilot run project was designed to produce a sufficient number of heat pump water heaters for field testing and also to evaluate any production difficulties which might arise. A number of problems were encountered during the pilot run. These problems fall into two general categories: component/system design inadequacies and post-manufacturing difficulties related to shipping, testing, etc. Various minor modification have been made to the field demonstration units to correct some of the difficulties identified in Section 5.2.

## 5.2 PILOT RUN UNIT DESIGN PROBLEMS

Problems were encountered with various components due to design inadequacies and assembly difficulties. The major problems are:

- condenser mounting flange and gasket design
- tubing leakage and blockage
- condensate drip pan design
- unit wrapper and screen guard assembly

These problems are addressed in this section.

### 5.2.1 Condenser Mounting Flange and Gasket Design

Several difficulties with the flange design were encountered. These design problems caused leakage, stripping of bolts during unit assembly and various assembly difficulties.

The inside diameter of the weld or ring flange on the tank was designed with too much tolerance with respect to the outside diameter of the condenser coil. This caused difficulty in inserting the condenser into the tank. The tolerance will be decreased slightly on future units to allow ease of assembly.

The amount of thread engagement on the flange was often found to be inadequate. This resulted in stripping of the flange bolt threads during production. The stripped bolts had to be removed and the bolt holes redrilled and retapped. This problem can be corrected by proper quality control to insure adequate thread engagement on future units.

The flange gasket also caused problems. This gasket crushed when the flange bolts were tightened. Retorquing of the bolts was required and it was difficult to obtain a good seal. The gasket may be replaced with an "O" ring which would solve the problem of crushing and sealing on future units.

### 5.2.2 Tubing Leakage and Blockage

A number of refrigerant leaks at solder joints and blockages in the tubing at these joints occurred due to assembly procedures, material problems and rough handling during shipment. This problem was solved shortly after the start of the pilot run by improving personnel training.

Another problem involved breakage of the soldered joints during shipping. The rough handling that the units received in shipment caused some of the joints to break even though they had passed the pressure tests and run test during assembly.

Some tubing was not sufficiently inserted into the sleeves at the joints, causing a weak connection. However, another important cause of the breakage was the use of soft silver bearing solder which does not hold up well under impact, as compared with a silver brazing alloy such as Sil-Foss #5.

Shipping procedure changes will also help solve the problem. The floating mount of the compressor absorbs vibration during operation but also allows vibration during shipping. Use of a shipping bolt would prevent vibration during shipment; the bolt could be removed during installation. Flexing loops in the refrigerant tubing at the compressor joints can also be used to absorb shocks.

A refrigerant leak problem developed at the flair fittings on the expansion valves. The original heat pump design specified a sweat fitting rather than the flair fitting. However, because delivery of expansion valves with the proper fittings would have delayed the project by approximately three months, the flair fittings were used. The leaks were eliminated by resoldering as necessary. Sweat fittings will be used in the future.

The access fittings used for pressure testing and charging of the refrigerant during maintenance frequently leaked. The leaks were barely detectable and often went unnoticed. Those leaking valves which were detected were replaced. The problem was solved by insuring that when a unit left the production area, the fittings were tightly capped. No access fittings will be used in the production units. Instead, the system will be completely sealed after charging.

5.2.3 Condensate Drip Pan Design

The condensate drip pan is made of styrene, vacuum-formed into the shape of a tray. The material used, however, is difficult to bond, so that there was a problem in attaching the drain tube to the tray. This problem was overcome by using hot glue.

Another problem was that the front lip of the tray was made too low, allowing condensate to drip down onto the edge and partially miss the tray. Consequently, condensate sometimes soaked the tank insulation. The problem was solved temporarily by sealing the space between the base pan and the tray with a silicone-based sealant. Because the amount of condensate collected in a humid environment can be as much as 11 gallons (41.6 liters) per week, a more permanent solution to this problem will be developed. A new design currently being considered employs a heat pump base with a tray stamped into it in order to eliminate the problem associated with the separate condensate tray.

### 5.2.4 Unit Wrapper and Screen Guard Assembly

The unit wrapper (outer shell) is made of a steel sheet and a piece of 1/4-inch (0.64 cm) mesh wire cloth. The 26-gauge steel sheet is prepainted with enamel.

This prepainted sheet was easily scratched during heat pump assembly and testing. This problem was temporarily solved by imposing administrative controls to require more careful handling. However, the handling procedure must be changed in the future to insure that this is not a continuing problem. Also, an attempt will be made to find material with more durable paint.

The wrapper and screen guard assembly was difficult to fabricate as designed. Redesign is underway to allow easier assembly.

## 5.3 POST-MANUFACTURING PROBLEMS

Several difficulties not directly related to the manufacturing operation were also encountered. Three major problems are:

- o packaging and shipping
- o retrofit unit testing
- o local plumbing and building codes

These have been classified as post-manufacturing problems.

### 5.3.1 Packaging and Shipping

A number of heat pump water heaters were damaged during shipment to the participating utilities due to rough handling by the carriers. This problem was addressed early in the pilot run by engaging a packaging consultant to design a shipping crate that would adequately protect the units. After implementing the consultant's recommendations, only one unit was damaged of 60 shipped. The package is expensive, however, costing approximately $60 per unit.

When in full production, the units will be shipped by truckload only. This will eliminate the need for the costly packaging necessary when sending small shipments via common carrier.

### 5.3.2 Retrofit Unit Testing

Testing of the retrofit units was very time consuming and costly and was one of the major problems encountered during the pilot run. Difficulties arose because the retrofit units must be connected to a test tank for run- and leak-testing, then disassembled from the test tank, reassembled, pumped down and charged with refrigerant for shipment. A revised testing procedure is needed to reduce testing time and cost.

### 5.3.3 Plumbing and Building Codes

A local building code problem was encountered in North Carolina. The units were found to be in violation of safety criteria specified in one section of the state building code. The code provision requires that all parts internal to the water heater tank or in contact with the water under pressure must be capable of withstanding temperatures up to 400°F (204°C). A small piece of plastic tubing, used as a cushioning device to protect the anode inside the TEMCOR tank during shipment, did not meet this criterion and had to be removed from the North Carolina units in the field.

This problem can be solved in the future by elimination of the plastic part. However, it indicates that there may be other potential problems in the field due to local code requirements. Plumbing and building codes for potential market areas should therefore be reviewed.

# 6. LABORATORY TEST RESULTS

Successful demonstration of the electric heat pump water heater concept requires more than one method of testing. A laboratory test program was developed to prove the design and to assure that final design performance would meet expectations prior to running the field tests. A field test program was also developed to test 85 new type units and 15 retrofit units over a period of one year. This section provides a discussion of the results of the laboratory test program. The results of the field test program will be discussed in a final report at the conclusion of the testing period.

## 6.1 LABORATORY PERFORMANCE TESTS

### 6.1.1 Laboratory Test Procedure

The test procedure used in this program was designed to determine the overall coefficient of performance of the unit as a function of ambient air, delivery water and source water temperatures. Each test was conducted over a twelve-hour period following a withdrawal schedule similar to that used during the development phase (see task 3 of reference 2). The withdrawal procedure requires that 64.3 gallons (0.24 $m^3$) of water be withdrawn from the tank at a rate of 3 gallons per minute (0.011 $m^3$ per minute) according to the schedule shown in Table 6-1. The fast-recovery (upper) resistance element was not used during these tests. Data was recorded prior to the first withdrawal and then at 30-minute intervals during the course of the test. A final reading was taken at the end of the test when the unit had fully recovered from the last withdrawal.

The efficiency ratio (E) represents the useful energy factor and was calculated in the following manner:

$$E = \frac{Q}{3.413\ Q_E}$$

Table 6-1

PRESCRIBED WITHDRAWAL SCHEDULE

| Hour | Withdrawal Gallons $(M^3)$ | | Simulated Usage |
|---|---|---|---|
| 0 | 15 | (0.057) | shower or bath |
| 1 | 3 | (0.011) | miscellaneous |
| 2 | 0 | (0.00) | |
| 3 | 25 | (0.95) | clothes washer |
| 4 | 0 | (0.00) | |
| 5 | 3 | (0.011) | miscellaneous |
| 6 | 0 | (0.00) | |
| 7 | 0 | (0.00) | |
| 8 | 3.3 | (0.012) | miscellaneous |
| 9 | 0 | (0.00) | |
| 10 | 15 | (0.057) | dishwasher |
| 11 | 0 | (0.00) | |
| 12 | 0 | (0.00) | |

where

$Q_E$ is the total electrical energy input to the heat pump system during the test period in watthours

and

Q is the total amount of useful heat added to the water, defined as follows:

$$Q = WC_p\ (T_{out} - T_{in}) + V\ C_p\ (T_f - T_i)$$

where

W = number of gallons ($m^3$) withdrawn during test period,

$C_p$ = average specific heat of water at constant pressure in range of test, (Btu/gal - °F) or ($J/m^3$ - °C),

$T_{out}$ = average delivery water temperature during test, (°F) or (°C),

$T_{in}$ = average source water temperature during test, (°F) or (°C),

$T_f$ = average tank water temperature at end of test, (°F) or (°C),

$T_i$ = average tank water temperature at beginning of test, (°F) or (°C), and

V = tank water capacity (gallons) or ($m_3$)

The unit coefficient of performance (COP) is then calculated as:

$$COP = \frac{Q + Q_L}{3.413\ Q_E}$$

where

$Q$ and $Q_E$ are as previously defined,

and

$Q_L$ is defined as the tank losses over the test period as follows:

$$Q_L = UA\ t\ (T_{avg} - T_{amb})$$

where

$T_{avg}$ = average tank water temperature during test, (°F) or (°C),

$T_{amb}$ = average ambient temperature during test, (°F) or (°C),

$t$ = duration of test in hours, and

$UA$ = empirically determined representative heat loss coefficient for the tank and fittings, (Btu/hr - °F) or (J/hr - °C).

6.1.2 Instrumentation

The electrical input to the compressor is measured using a Duncan model EM-10 watthour meter. This meter has a guaranteed accuracy of ± 1.0% and has a 0.1 watthour resolution. Also attached to the circuit are a volt meter and a watt meter which are used to monitor instantaneous power consumption and to allow good control of the supply voltage. Supply voltage is controlled by a variac to 220 volts.

The unit is tested in an environmentally-controlled laboratory where the air temperature can be maintained within ± 1°F (± 0.6 °C) of a given value. Ambient temperature during the test is monitored by a Trerice series 86000 temperature recorder.

Water withdrawal rate is measured with a Dwyer model RMC-146-SSV differential flowmeter. The overall rated accuracy of this flowmeter is ± 5%. As a check on water flow, the total amount of water withdrawn is monitored by a Rockwell model SR5/8 residential-type water meter, accurate to ± 1%.

Water temperature is measured using iron versus copper-nickel (constantan) thermocouples and Omega model 2166A digital thermometers. The calibration accuracy of these digital thermometers is ± 0.9°F (± 0.5°C) with a resolution and repeatability of ± 1°F (± 0.6°C). During the test, these thermocouples monitor inlet and outlet water temperatures as well as average tank water temperature. The tank water temperature is measured by seven thermocouples located inside the tank approximately six inches (15.2 centimeters) from the vertical centerline of the tank. The first thermocouple is placed four inches (10.2 cm) below the highest point in the tank and the remaining six thermocouples divide the tank into volumetrically-equal segments.

The temperature of the refrigerant is monitored using iron-constantan thermocouples at the following locations in the cycle:

- Compressor suction
- Compressor discharge (condenser inlet)
- Condenser outlet
- Expansion valve outlet (evaporator inlet)
- Evaporator outlet

High-side and low-side gauge pressures are measured using Robinair model 11692 pressure gauges.

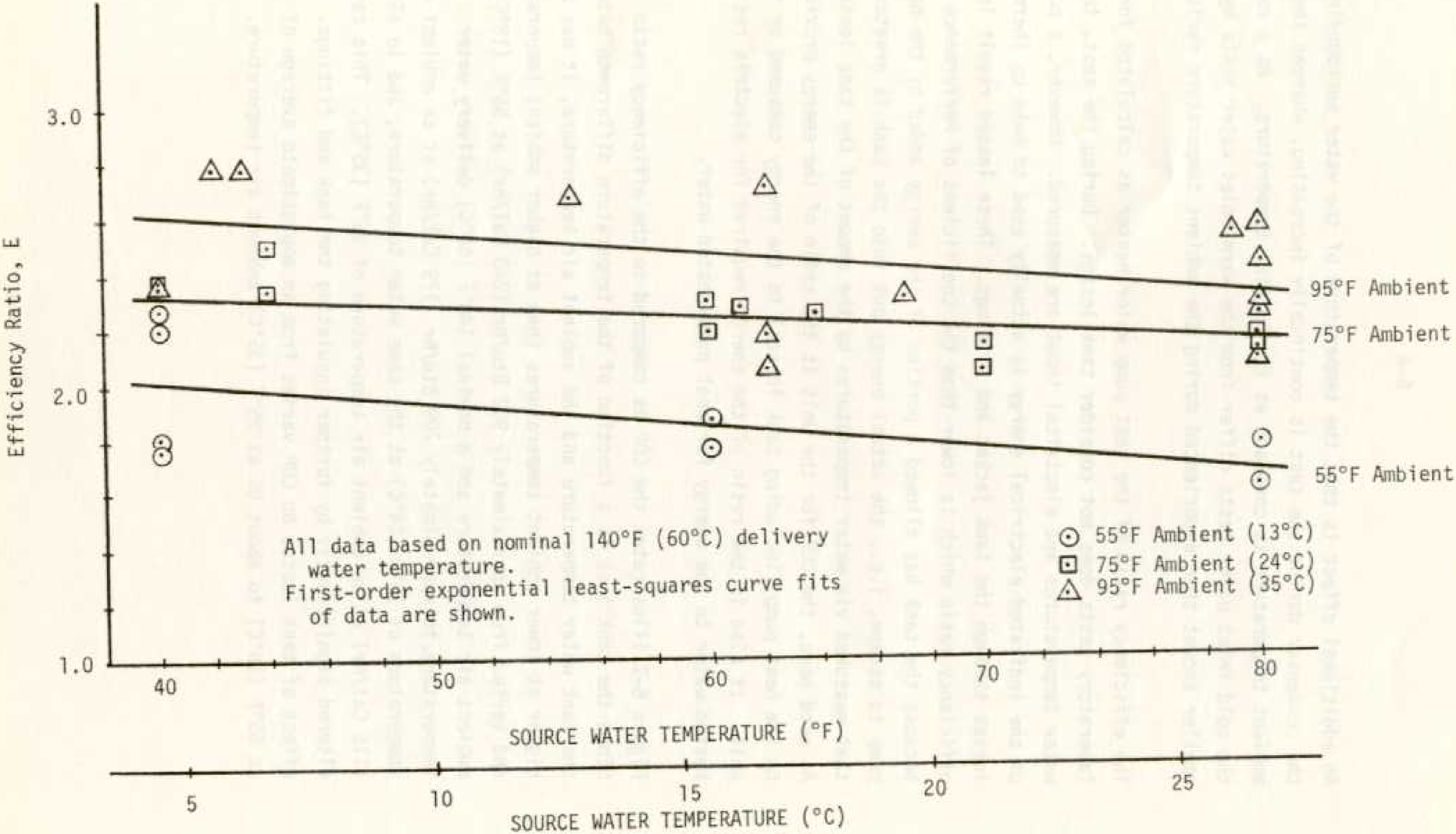
### 6.1.3 Performance Test Results

A summary of the ambient temperature and source-water temperature test results is presented in Figure 6-1. The data were taken from two identical units undergoing testing in the laboratory at the same time. Every effort was made to insure that the units were identically charged, but some variation probably occurred and would be the major source of experimental error. All data points are presented on the figure.

The set of curves of Figure 6-1 shows the relationship of the unit efficiency ratio to variations in source water and ambient air temperatures. The curves shown represent first order exponential ($y = e^{(a+bx)}$) least-squares curve fits of the available data. It is evident from the results that the effect on performance of changes in ambient air temperature is greater than the effect of changes in source water temperature. The reason for this apparent change in system performance is as follows. The heat pump high-side (condensing) pressure is controlled by the condenser working temperature, that is, the temperature of the water to which the heat is transferred. Likewise, the low-side (evaporating) pressure is controlled by its supply medium, the ambient air. If the low-side pressure is held contant but the high-side pressure is increased, i.e. constant ambient air temperature and increased water temperature, the compressor must work harder to compress a given mass of gas to the higher pressure but the amount of mass, and consequently, the amount of energy moved, is slightly reduced. The reason it is slightly less is that the compressor volumetric efficiency is inversely proportional to compression ratio, which has been increased due to the increase in high-side pressure.

However, if the high-side pressure is held constant and the low-side pressure is decreased, not only does the compressor have to work harder to compress the gas due to the increased pressure difference, but the reduction in low-side pressure causes a much lower density intake gas to be supplied to the compressor, thereby reducing the amount of mass being moved from the low-side to the high-side. This consequently degrades the efficiency ratio because more compressor work is required to deliver a unit of energy.

Figure 6-1. Heat Pump Water Heater Laboratory Performance Test Data

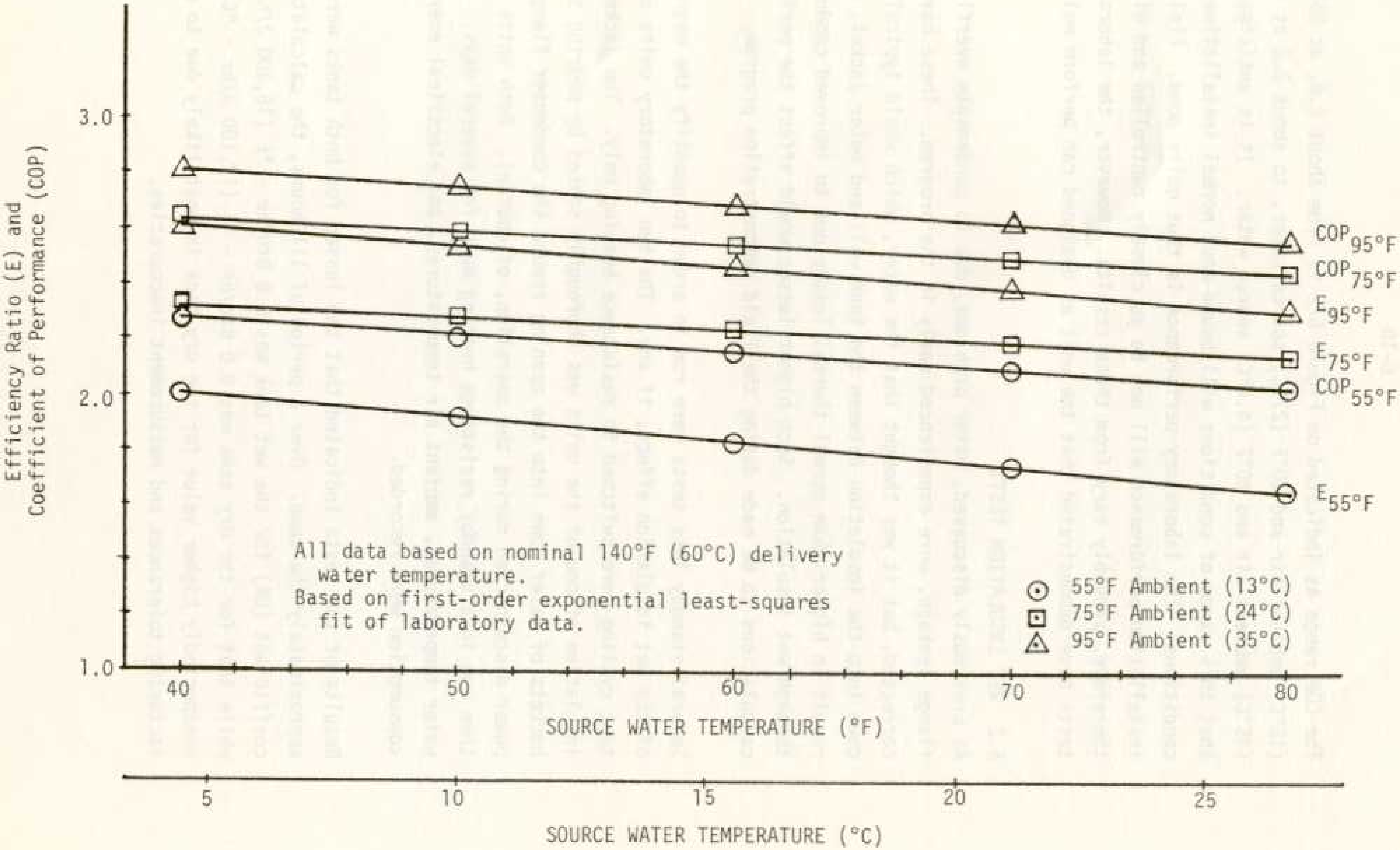


An additional effect is that the temperature of the water surrounding the condenser during the test is continually increasing, whereas the ambient temperature is constant at the initial temperature. As a result, the cold inlet water tests differ from the warm inlet water tests by a smaller amount than experienced during the ambient temperature variations.

The efficiency ratio of the heat pump water heater as calculated for the laboratory tests does not consider tank losses. During the test, tank water temperatures and electrical input are measured. However, a portion of the indicated electrical energy is actually used to make up thermal losses through the tank jacket and fittings. These losses result in an efficiency ratio which is lower than the Coefficient of Performance (COP) because the tank has allowed a portion of the energy added by the heat pump to escape, i.e., the actual energy put into the tank is greater than that measured via water temperatures by the amount of the tank losses. As used here, the COP for the unit is the ratio of the energy provided by the heat pump (including tank losses) to the energy consumed by the unit. It also is the ratio of the energy required for electric resistance-heated water to the energy for heat pump-heated water.

Figure 6-2 illustrates the COP as compared to the efficiency ratio. Since the tank loss is a function of the temperature difference between the tank water temperature and the ambient air temperature, it was much higher at lower ambient temperatures than at higher ambient temperatures, and varied from approximately 952 Btu/hr (240 Cal/hr) at 55°F (18°C) ambient air temperature and a nominal 140°F (60°C) delivery water temperature, to approximately 709 Btu/hr (179 Cal/hr) at an ambient air temperature of 75°F (24°C) at the same water temperature, and to 459 Btu/hr (116 Cal/hr) at an ambient air temperature of 95°F (35°C). This can be altered significantly by further insulating the tank and fittings. The effect of tank losses on COP varies from an approximate average of 17% at 55°F (18°C) to about 9% at 95°F (35°C) ambient air temperature.

Figure 6-2. Heat Pump Water Heater
Efficiency Ratio and Coefficient of Performance Curves



The COP range as indicated on Figure 6-2 is from about 2.0, at 55°F (18°C) ambient air and 80°F (27°C) source water, to about 2.8 at 95°F (35°C) ambient air and 40°F (4.4°C) source water. It is anticipated that this range of conditions will bound most normal installation conditions. The laboratory performance is thus quite good. Field installation performance will not be as closely controlled and will, therefore, probably vary from these results. However, the laboratory tests have demonstrated that the unit as designed can perform well.

## 6.2 WET INSULATION TESTS

As previously discussed, water problems, due to condensate overflow and flange leakage, were experienced early in the program. These have been corrected, but it was thought that the water, which would typically run down into the insulation between the tank wall and outer jacket, would result in higher than normal thermal losses due to improved conduction through wet insulation. Such higher losses would affect the performance calculations to be made during the field demonstration program.

Several standby loss tests were run in order to quantify the magnitude of the wet insulation effect, if any. The two laboratory units on life test cycling were switched to resistance heating only. The jacket insulation of one of the units was thoroughly soaked by pouring several buckets of water down into the opening around the condenser flange (with power disconnected during the operation, of course). Both units were then run in a standby resistance heating mode for several days. Tank water temperatures, ambient air temperatures, and electrical energy consumption were recorded.

Results of the tests indicated that the losses for both tanks were approximately the same. Over a period of 111 hours, the calculated loss coefficient (UA) for the wet tank was 8.6 Btu/hr - °F (16,300 J/hr - °C) while that for the dry tank was 9.0 Btu/hr - °F (17,100 J/hr - °C). The unexpectedly higher value for the dry tank is most likely due to manufacturing tolerances and measurement inaccuracies.

The results indicate that wetting the insulation had little or no effect on system losses. This at first did not seem reasonable, so the wet tank insulation was inspected by removing the resistance element covers and feeling the insulation by hand. It was found that the insulation felt dry except at the very bottom, where water had collected in the bottom cover. Apparently, the tank heat is sufficient to drive off most moisture in the insulation; water vapor can escape through several places on the unit, including the top opening and around the side panels. Water can collect in the bottom up to about the level of the bottom cover (it will normally leak out around the cover joint or resistance element panel) and will remain there for a long time, although it is expected that some wicking action occurs, via the fiberglass insulation, which will eventually dry out the system.

A slow, continuous small leak (such as dripping condensate) might not significantly affect the unit's performance. A very large, continuous leak (such as a bolt or flange leak) would have some effect if it were severe enough to keep the insulation soaked constantly. However, in such a case, there would more than likely be water spilling out onto the floor of the installation and some action would be taken to correct the problem.

# 7. PILOT RUN PRODUCTION COSTS

The total cost for items covered under Tasks 1 through 4 of Phase II, including final specifications and design of the units and production facility, manufacturing facility preparation, prototype construction and testing, and pilot run manufacturing and shipping, was approximately $378,000.

Table 7-1 is a cost breakdown which indicates the various cost factors but should not be viewed as a complete accounting. These costs provide a reasonable indication of current expenditures during Tasks 1 through 4 of Phase II. The remainder of this section elaborates on these costs.

## 7.1 DESIGN MODIFICATIONS AND MANUFACTURING FACILITY LAYOUT

As described in Section 2, some redesign of the unit evolved during the research and development phase and implementation of the resulting modifications was required prior to manufacture. Additional pre-production effort included drafting, final manufacturing process design, manufacturing facility design and tooling design, described in Section 4. The cost of this portion of the work, approximately $92,000, was essentially all for labor.

## 7.2 MANUFACTURING FACILITY PREPARATION

It was necessary to establish the pilot run manufacturing facility by installing work stations and special equipment prior to building units. The work performed and equipment are described in Section 4. The total cost of the facility preparation effort, $32,800, was split about evenly between labor and installed equipment expenses.

Table 7-1

PILOT RUN COST SUMMARY

| Item | Cost |
|---|---|
| Design Modifications and Manufacturing Facility Layout | $ 92,000 |
| Manufacturing Facility Preparation | 32,800 |
| Pilot Run Production Costs | |
| Manufacturing | 78,300 |
| Spare and Replacement Components | 7,300 |
| Technician Training | 900 |
| Field Test Instrumentation | 84,800 |
| Laboratory and Special Testing | 11,200 |
| Management and Professional Labor | 58,000 |
| Shipping and Special Materials | 10,200 |
| Special Consultants | 1,700 |
| Travel | 900 |
| | $378,100 |

## 7.3 PILOT RUN PRODUCTION COSTS

Labor and material costs on a per-unit basis for the new and retrofit heat pump units are given in Tables 7-2 through 7-5. The total manufacturing cost was approximately $78,300. This amount is based on 94 new-type units and 25 retrofit-type units as listed in Table 7-6 and does not include spare or replacement components.

The replacement component inventory and repair cost is estimated as 15 percent of the total material cost of the 85 new and 20 retrofit units manufactured for utilities. This cost was then 15 percent of $44,095, or $6,614, plus G&A charges of $675, for a total spare parts cost of approximately $7,300.

Because temporary labor was used, an additional cost was incurred for training replacement personnel. This is estimated at $900, based on eight hours for each of 20 technicians and including G&A costs.

## 7.4 FIELD TEST INSTRUMENTATION

Labor and material costs on a per-unit basis for the new and retrofit field instrumentation packages are given in Tables 7-7 through 7-10. The total manufacturing cost was approximately $84,800. This amount is based on the number of units listed in Table 7-11.

## 7.5 LABORATORY AND SPECIAL TESTING COSTS

Special laboratory testing was performed for quality control purposes, for determination of unit performance, and for Underwriters' Laboratory (UL) approval. The estimated labor costs and estimated fees and testing costs for the UL unit are listed separately in Table 7-12. The total cost for the work is approximately $11,200.

## 7.6 MANAGEMENT AND PROFESSIONAL LABOR

A large effort was required to insure that facility preparation, testing, production and shipping problems were resolved, and that the project progressed as scheduled. In addition, an expanded effort was required to deal with participating utilities prior to shipping the units, as well as for general project management.

The cost for this overall effort was approximately $58,000 with overhead and G&A charges. These costs are estimated to be distributed as follows: 20 percent for facility preparation; 50 percent for production, testing and shipping; and 30 percent for general project management, report writing and utility contacts.

7.7 SHIPPING AND SPECIAL MATERIAL COSTS

The cost of shipping the new and retrofit units to the participating utilities was $5,626. With G&A, the total shipping cost was $6,200.

Special material costs include freight charges on material, instruction and training manual materials, printing and photography costs, etc. The total for these items, including G&A, was $4,000.

7.8 SPECIAL CONSULTANTS AND TRAVEL

During the course of the project, it was necessary to employ special consultants for packaging and for arranging for utility participation in the project. The total outside consultant labor cost was approximately $1,700, including G&A.

Travel costs, incurred during trips to Oak Ridge and Washington, D.C. in order to hold discussions with ORNL and DOE personnel during the pilot run portion of the project, amounted to about $900.

Table 7-2

NEW TYPE HEAT PUMP WATER HEATER
PILOT RUN LABOR COST PER UNIT

| Task | Approx. Hours to Complete | Approx. Cost |
|---|---|---|
| Rewire existing tank | 0.5 | $ 2 |
| Prepare Condenser, including coiling, brazing, tin-plating and pressure testing | 2.0 | 9 |
| Assemble Top Cap, including drilling, mounting fan, installing on unit | 0.7 | 3 |
| Assemble Unit Base, including drilling and mounting compressor | 0.3 | 2 |
| Prepare Side Panel, including drilling and installation | 0.2 | 1 |
| Prepare Evaporator and Tubing, including drilling and bending | 1.3 | 6 |
| Assemble Heat Pump Cabinet, including screen, evaporator and tubing; solder components | 3.0 | 17 |
| Complete Unit Assembly, including mounting heat pump on tank, installing condenser, wiring | 1.3 | 8 |
| Perform leak test and charge unit | 1.1 | 6 |
| Perform Hi-Pot, Pressure and Run-Tests | 2.4 | 15 |
| Perform Final Inspection, Cleanup and Rework as necessary, including repair of bolts, flanges, alignment and replacement of elements as necessary | 7.0 | 42 |
| Assembly Supervision | 2.0 | 25 |
| Packaging | 4.0 | 21 |
| Subtotals | 25.8 | $157 |
| Allow for Labor Efficiency (20%) | 5.2 | 31 |
| Total Assembly Cost Per Unit | 31.0 | $188 |

Table 7-3

NEW TYPE HEAT PUMP WATER HEATER PILOT RUN

MATERIAL COST PER UNIT

| Item | Approx. Cost |
| --- | --- |
| Water Tank | $153 |
| Condenser | 87 |
| Compressor Assembly | 72 |
| Weld Flange and Bolt Plate | 30 |
| Fan Assembly | 21 |
| Evaporator | 16 |
| Expansion Valve | 13 |
| Instrumentation/Power Cable Assembly | 11 |
| Copper Tubing and Fittings | 10 |
| Evaporator Drip Tray Assembly | 7 |
| Heat Pump Base | 6 |
| Heat Pump Top Cap | 6 |
| Evaporator Screen | 5 |
| R-12 Refrigerant | 3 |
| Filter-Dryer | 3 |
| Cold Water Inlet Tube | 3 |
| Toggle Switch | 1 |
| Heat Pump Side Panel | 1 |
| Schraeder Valves | 1 |
| Tubing Insulation | 1 |
| Tank Gasket | 1 |
| Fiberglass Insulation (HP Housing) | 1 |
| Miscellaneous Hardware, Fitting, etc. | 5 |
| Shipping Carton and Packaging Material | 10 |
| Total Material Cost Per Unit | $467 |

Table 7-4

RETROFIT UNIT PILOT RUN LABOR COST PER UNIT

| Task | Approx. Hours to Complete | Approx. Cost |
|---|---|---|
| Prepare Condenser, including coiling, brazing, tin-plating, pressure testing | 3.6 | $26 |
| Top Cap Assembly, including drilling, mounting fan, installing on unit | 0.7 | 3 |
| Unit Base, including drilling and mounting compressor | 0.3 | 2 |
| Side Panel, drilling and installation | 0.2 | 1 |
| Prepare Evaporator and tubing, including bending and drilling | 1.3 | 6 |
| Assemble Heat Pump Cabinet, including screen, evaporator and tubing; solder components | 3.0 | 17 |
| Complete Assembly, including mounting on test tank, wire, pump down and charge | 2.0 | 12 |
| Perform tests, including Hi-Pot and run-tests; recharge unit | 2.0 | 13 |
| Perform Final Inspection and cleanup | 1.0 | 5 |
| Rework as necessary (repair stripped bolts, leaking flanges, alignment problems; replace wrappers and failed elements) | 6.0 | 36 |
| Assembly Supervision | 2.0 | 25 |
| Packaging | 4.0 | 21 |
| Subtotals | 26.1 | $167 |
| Allow for Labor Efficiency (20%) | 5.2 | 33 |
| Totals | 31.3 | $200 |

Table 7-5

RETROFIT HEAT PUMP PILOT RUN

MATERIAL COST PER UNIT

| Item | Approx. Cost |
| --- | --- |
| Compressor Assembly | $72 |
| Condenser | 32 |
| Fan Assembly | 21 |
| Evaporator | 16 |
| Expansion Valve | 13 |
| Instrumentation/Power Cable Assembly | 11 |
| Evaporator Drip Tray Assembly | 7 |
| Heat Pump Base | 6 |
| Heat Pump Top Cap | 6 |
| Copper Tubing and Fittings | 5 |
| Evaporator Screen | 5 |
| R-12 Refrigerant | 3 |
| Cold Water Inlet Tube | 3 |
| Filter-Dryer | 3 |
| Heat Pump Side Panel | 1 |
| Schraeder Valves | 1 |
| Fiberglass Insulation (housing) | 1 |
| Miscellaneous Hardware, Fittings, etc. | 5 |
| Shipping Carton and Packaging Material | 9 |
| Total Material Cost Per Unit | $220 |

Table 7-6

TOTAL MANUFACTURING COST BASED ON PER-UNIT CHARGES

| | Quantity | Cost Per Unit | Total Cost Per Item |
|---|---|---|---|
| New Units for Utilities (Labor) | 85 | $188 | $15,980 |
| New Units for Utilities (Material) | 85 | 467 | 39,695 |
| Spare New Units (Labor) | 4 | 188 | 752 |
| Spare New Units (Material) | 4 | 467 | 1,868 |
| New Units for Testing (Labor | 3 | 188 | 564 |
| New Units for Testing (Material) | 3 | 467 | 1,401 |
| New Units to ORNL (Labor) | 2 | 188 | 376 |
| New Units to ORNL (Material) | 2 | 467 | 934 |
| Subtotal | | | 61,570 |
| Retrofit Units for Utilities (Labor) | 20 | 200 | 4,000 |
| Retrofit Units for Utilities (Material) | 20 | 220 | 4,400 |
| Spare Retrofit Units (Labor) | 5 | 200 | 1,000 |
| Spare Retrofit Units (Material) | 5 | 220 | 1,100 |
| Subtotal | | | 10,500 |
| Total | | | $71,070 |
| G & A | | | 7,250 |
| | | | $78,320 |

Table 7-7

NEW UNIT INSTRUMENTATION PACKAGE LABOR COSTS PER UNIT

| Task | Approx. Hours to Complete | Cost Per Unit |
|---|---|---|
| Assemble Components to Board | 4 | $25 |
| Wire Unit | 8 | 50 |
| Calibrate Instruments | 1.5 | 9 |
| Test Unit | 0.5 | 3 |
| Packaging | 3 | 16 |
| Subtotals | 17 | $103 |
| Allow for Labor Efficiency (20%) | 3 | 21 |
| Total Assembly Cost Per Unit | 20 | $124 |

Table 7-8

RETROFIT INSTRUMENTATION PACKAGE LABOR COSTS PER UNIT

| Task | Approx. Hours to Complete | Cost Per Unit |
|---|---|---|
| Assemble Components to Board | 1.5 | $ 9 |
| Wire Unit | 4.0 | 25 |
| Calibrate Instruments | 1.5 | 9 |
| Test Unit | 0.3 | 2 |
| Packaging | 1.5 | 8 |
| Subtotals | 8.8 | $53 |
| Allow for Labor Efficiency (20%) | 2.0 | 11 |
| Total Assembly Cost Per Unit | 10.8 | $64 |

Table 7-9

NEW UNIT INSTRUMENTATION PACKAGE
MATERIAL COST PER UNIT

| Item | Approx. Cost | |
|---|---|---|
| Dual-Temperature Recorder | $235 | |
| Single-Temperature Recorder | 171 | (one per utility) |
| Kilowatthour Meters (3) | 68 | |
| Current Transformer Kilowatthour Meters (2) | 62 | |
| Water Meter and Fittings | 43 | |
| DPST Relay | 28 | |
| Meter Sockets (3) | 26 | |
| Current Transformer | 25 | |
| Timer | 24 | |
| Current Transformer Meter Sockets (2) | 23 | |
| DPDT Relays (2) | 21 | |
| Conduit and Connectors | 18 | |
| Wire and Terminals | 16 | |
| Junction Box and Panel | 13 | |
| Hardware | 3 | |
| Thermocouples | 2 | |
| Packaging Material | 33 | |
| Total Material Cost Per Unit | $811 | |
| Total Material Cost Per Unit Without Single-Temperature Recorder | $640 | |

Table 7-10
RETROFIT UNIT INSTRUMENTATION PACKAGE
MATERIAL COST PER UNIT

| Item | Approx. Cost |
|---|---|
| Dual-Temperature Recorder | $235 |
| Kilowatthour Meters (2) | 45 |
| Water Meter and Fittings | 43 |
| Meter Sockets (2) | 20 |
| Conduit and Connectors | 15 |
| Wire and Terminals | 12 |
| Junction Box and Panel | 12 |
| Hardware | 3 |
| Thermocouples | 2 |
| Packaging Material | 20 |
| Total Material Cost Per Unit | $407 |

Table 7-11

TOTAL COST FOR FIELD TEST INSTRUMENTATION

| Item | Quantity | Cost Per Unit | Total Cost Per Item |
|---|---|---|---|
| New Unit Instrumentation for Utilities (Labor) | 85 | 124 | $10,540 |
| New Unit Instrumentation for Utilities (Material) | 85 | 640 | 54,400 |
| Spare Instrumentation Units (Labor) | 2 | 124 | 248 |
| Spare Instrumentation Units (Material) | 2 | 640 | 1,280 |
| Retrofit Unit Instrumentation for Utilities (Labor) | 15 | 64 | 960 |
| Retrofit Unit Instrumentation for Utilities (Material) | 15 | 407 | 6,105 |
| Single-Channel Temperature Recorders | 20 | 171 | 3,420 |
| | | Subtotal | $76,953 |
| | | G&A | 7,850 |
| | | Total Manufacturing Cost | $84,803 |

Table 7-12

LABORATORY PERSONNEL AND MATERIAL COSTS (TESTING)

| Item | Hours | Cost |
|---|---|---|
| Manufacturing Unit Quality Control Audit | 240 | $ 1,440 |
| Performance Tests | 480 | 2,880 |
| UL Fee | | 4,000 |
| EUS Lab Personnel Effort (Pre-testing, design modifications, shipping preparation) | | 845 |
| Material and Shipping | | 980 |
| | Subtotal | $10,145 |
| | G&A | 1,035 |
| | Total | $11,180 |

REFERENCES

1. Research and Development of a Heat Pump Water Heater, prepared for ORNL by Energy Utilization Systems, Inc., vol. 1, ORNL/Sub-7321/1 (August 1978).

2. Research and Development of a Heat Pump Water Heater, prepared for ORNL by Energy Utilization Systems, Inc., vol. 2, ORNL/Sub-7321/2 (August 1978).

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Appendix A

# SUMMARY OF PHASE II WORK BY TASK

## TASK 1

Develop final specifications and engineering design of the optimized heat pump water heater and of the pilot run manufacturing facility. Major work items include completion of final design, preparation of heat pump water heater specifications and drawings, design of pilot run tools and fixtures, completion of final design of instrumentation package, selection of suppliers, preparation of detailed pilot run cost estimates, preparation of pilot run facility layout, and submission of Task 1 report covering these items.

## TASK 2

Prepare facility for pilot run. Major work items include purchasing of tools and equipment, ordering of material and components for 88 new units and 25 retrofit units, pre-pilot run checkout of assembly procedure, and purchasing of pilot run supplies.

## TASK 3

Construct and test three pilot run prototypes. Major work items include assembly of three prototype units, laboratory testing of one prototype, submission of test results to ORNL and sending prototypes to Underwriters' Laboratory (UL) for testing and approval.

## TASK 4

Manufacture and test heat pump water heaters, instrumentation packages and service parts. Major work items include assembly and testing of 88 new units and 25 retrofit units, assembly and testing of instrumentation panels, packaging and shipping of equipment, and submission of report summarizing Task 3 experience to ORNL.

## TASK 5

Train utility service personnel for method of installation, servicing and data monitoring and collection. Work items include utility selection and contractual agreements and conducting training sessions for utility personnel at the pilot plant.

TASK 6

Install heat pump water heaters and instrumentation packages in preselected locations and monitor operation. Major work items include installation, monitoring assistance, data reduction and analysis, service installations as necessary, and summarize data and submit report to ORNL.

TASK 7

Analyze and evaluate results of a 12-month field demonstration and prepare a final report for ORNL. Revise market analysis based on field experience and make recommendations for further work which could accelerate commercialization of the heat pump water heater.

TASK 8

Make special presentations as requested by ORNL. Submit 24 monthly reports.