TENRAC/EDF--075

DE83 900870

NON-RESIDENTIAL GROUNDWATER-HEAT-PUMP RETROFIT DEMONSTRATION

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FINAL REPORT

August 31, 1981

TEXAS ENERGY AND NATURAL RESOURCES ADVISORY COUNCIL

ENERGY DEVELOPMENT FUND

Project #80-C-3-1

TENRAC/
Report # EDF-075

EXECUTIVE SUMMARY

Although groundwater heat pumps save energy over conventional air-to-air heat pumps, questions have risen as to whether this saving is sufficient to pay for the site specific cost of drilling a well. The goal of this project is to address the question through direct experimental comparison of the performances of heat pumps of each type, by alternately comfort-conditioning the same building space. Data gathered in this manner leads to energy and economic analyses of the differences.

Precise measurements were made on a system at the Energy Laboratory which was retrofitted with a groundwater 3-ton heat pump-air conditioner and a 5-ton air-to-air heat pump-air conditioner that has been modified to operate also in a water-to-air mode. Measurements spanning a period of months show that the air conditioning COP of the 3-ton water-to-air unit was 3.7. Measurements in the heating mode still need to be completed. These type of units provide for excellent retrofit operations where adequate well water or surface water is available, as in lake areas. The well water is not actually consumed but reinjected into the ground in a second well.

This technology is available in off-the-shelf items. The heat pump-air conditioning units are commercially available in a variety of sizes. Excellent well water drillers and suppliers are also available in every locale in Texas.

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I. INTRODUCTION

Air-to-air heat pumps have been available in this locale since the thirties; however, they were not popular until the last two decades or so. The chief reasons for lack of popularity were low fuel costs that permitted householders to use electric furnaces or strip heaters, poor equipment reliability, especially when switching from heating to air conditioning, and units freezing when outside temperatures approached freezing or fell below zero. Ice forming on heat exchangers significantly lowers the coefficient of performance (COP) in present designs. Intermittent defrosting of the outside coils is possible, but the efficiency drops to small values just when home heating is needed most.

Within the last two decades, heat pumps and combined air conditioners have become reliable and their popularity has increased. The most common units are still air-to-air, but the advantages of water-to-air units are now being recognized. Water units operate with a higher coefficient of performance and do not freeze in the winter where ground or well water is used. The improved COP is largely due to the favorable groundwater temperature and the excellent heat transfer capability of water.

To explain the efficiency of groundwater heat pumps, we need to consider the thermodynamic performance and interrelations of heat pumps and air conditioners, in general. Put simply, any house air conditioner with compressor and heat exchanger could be operated as a heat pump. The heat pump mode could be accomplished by moving the outside heat exchanger inside the dwelling and the cooling coils to the outside, but, in practice, a valve is used to reverse the direction of freon flow. In effect, by trying to cool the outside world, we can heat the inside space. By adding water coils to the cooling exchanger coils, now on the outside, we could convert to a water-to-air heat pump.

Let us now consider the fundamental aspects of heat pump and air conditioning performance. Fig. 1 is a schematic form of a heat pump to transfer heat from reservoir at T_L to room at T_H. Fig. 2 shows an ideal thermodynamic cycle of either a heat pump or a heat engine operating between a hot reservoir T_H and a colder reservoir T_L. By following steps in the cycle clockwise power can be produced and by following processes counter clockwise heat can be pumped from the lower reservoir to the upper reservoir at T_H. Such a unit can be used as either a heat pump with T_H being the room temperature or as an air conditioner with T_L being the room temperature.

The coefficient of performance (COP) of an air conditioner is defined as

$$COP_R = \frac{\text{Heat per second extracted from room}}{\text{Electric power required to accomplish this}} \qquad (1)$$

The theoretical maximum or theoretical COP as given by the second law is

$$COP_{RT} = \frac{T_{room}}{T_{outside} - T_{room}} \qquad (2)$$

where the temperatures are in ^oK or ^oR. ($^oK = 273.1 + ^oC$)

For a heat pump the coefficient of performance is

$$COP_H = \frac{\text{Heat per second into room}}{\text{Electric power required}} \qquad (3)$$

The theoretical COP is

$$COP_{HT} = \frac{T_{room}}{T_{room} - T_{outside}} \qquad (4)$$

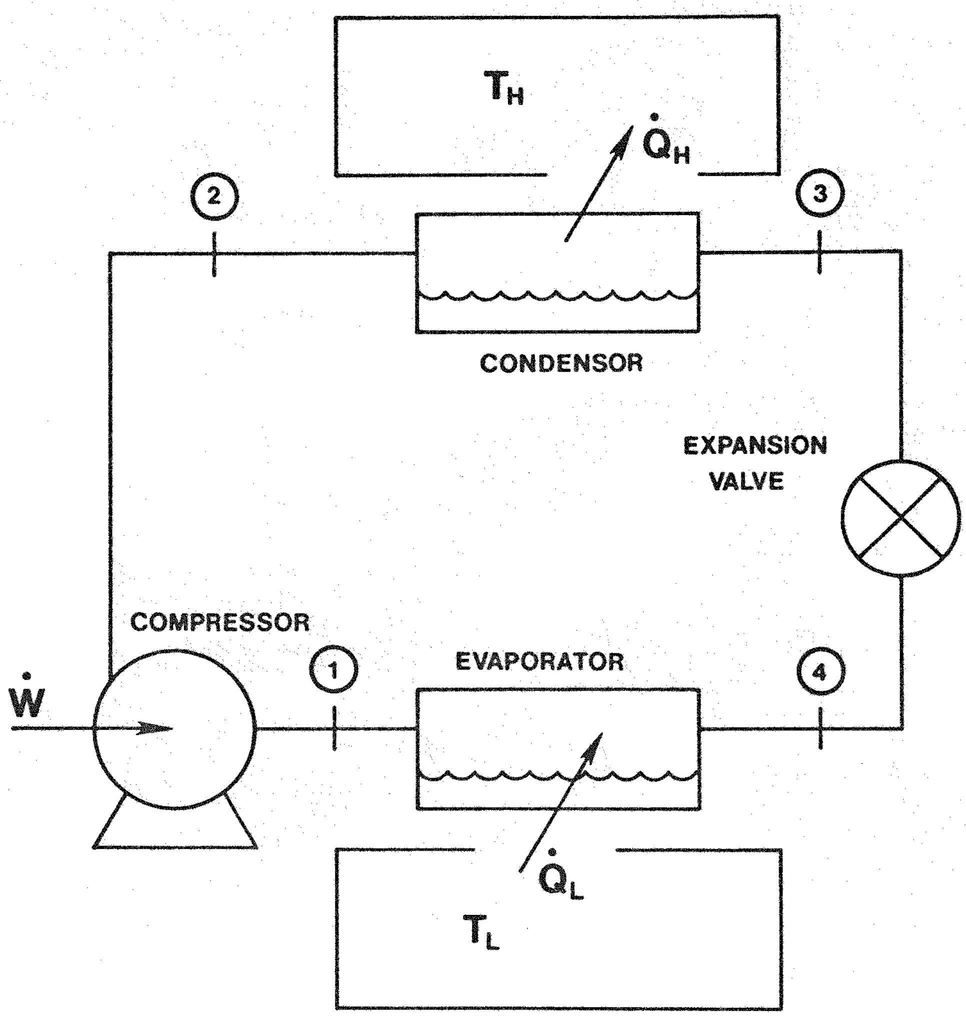

FIG. 1 — SCHEMATIC FORM OF HEAT PUMP OPERATING BETWEEN RESERVOIR AT T_L AND ROOM AT T_H.

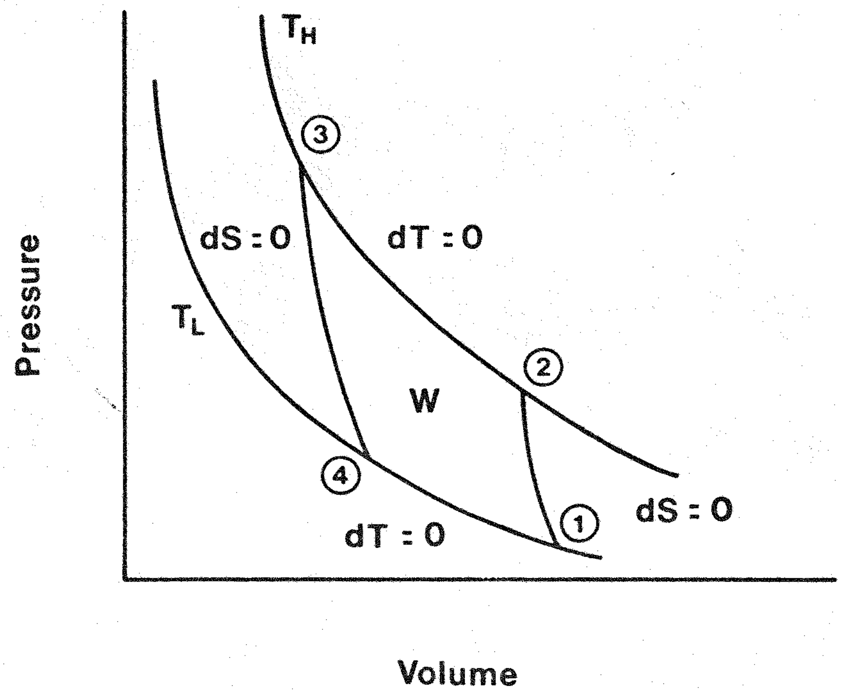

FIG. 2 — HEAT ENGINE -- HEAT PUMP CYCLE

The coefficient of performance of a resistance heater inside a room is one from equation (3). From (2) and (4) it follows that COP's of 5 and higher are theoretically possible for room temperature of 25°C and temperature differences between inside and outside of 30-60°C.

Much smaller coefficients are realized in operation because of a variety of technical variants. The largest single factor is the large deviation from the theoretical maximum owing to excessive temperature drops across heat exchangers. Parasitic losses in small systems also explain coefficients no better than half the theoretical maximum. A large power generating turbine, which is the reverse of a heat pump, can achieve an efficiency of 0.7 of the theoretical value.

For the practical measurements of water-to-air modes, (1) becomes

$$COP_R = \frac{\text{Heat per second into water minus electrical power}}{\text{Electrical power}} \qquad (5)$$

The numerator describes the heat per second removed from the room. In order to establish the coefficient of performance of the system, water well pump power can be added to the denominator.

For the case of a water to air heat pump, (4) becomes

$$COP_H = \frac{\text{Heat per second removed from the water plus electric power}}{\text{Electrical power}} \qquad (6)$$

Again, the water well pump power can be added to the denominator, but since well power varies widely and we wish to determine the COP of the heat pump, we will discuss it separately.

Measurements for air-to-air pumps are considerably more complicated. Here one has to measure the air quality entering the cooling region and air quality coming out the blower. The temperature is easily measured, but it is more difficult to measure total air flow rate for various duct shapes. Measurement of humidity change or water vapor change is also difficult.

II. PROJECT PLAN

Previous work at the University of Houston[1] has established that groundwater heat pumps are energetically and economically more attractive than natural gas or electrical resistance heaters. Work at the University of Texas[2] recognizes that groundwater heat pumps save energy over air-to-air heat pumps but points out that the cost of drilling a well makes groundwater heat pump systems not necessarily more economical than air-to-air heat pumps. The present work involves experimental comparisons of the two types of systems.

Specific tasks are to:

1) design and install the retrofit groundwater heat pump system and instrumentation;
2) operate existing and retrofit systems to collect data comparing air-to-air and water-to-air heat pump systems for the same non-residential building;
3) monitor the water well system for information on changes in the groundwater; and
4) perform energy analyses.

The retrofit demonstration is installed in the South Park Annex of the University of Houston, as shown in Fig. 3. The unit on the right is a Singer model E-S 34, 5-ton air-to-air conditioning unit that has been modified with the addition of a freon-to-water heat exchanger. The unit in the middle and to the left of the air to air unit is a 3-ton water-to-air heat pump-air

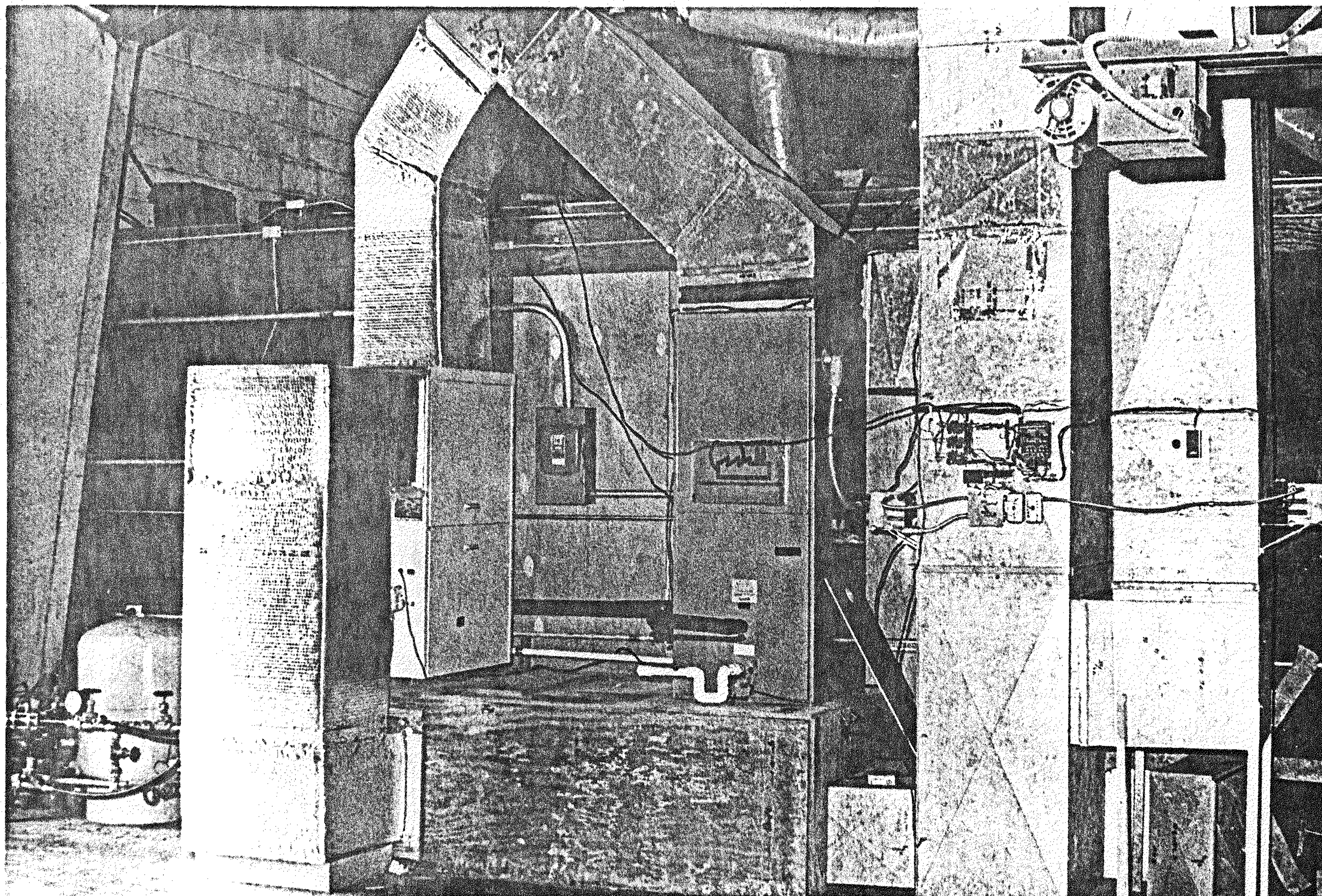

FIG. 3 - RETROFIT DEMONSTRATION INSTALLATION
Unit on left is a 3-ton water-to-air unit and unit on right is a 5-ton air-to-air unit

conditioner Vanguard model HPAV-36AA111. A view of this unit with panels removed is shown in Fig. 4. The apparatus to the left of the units is the water handling equipment and plumbing with a small pressure tank.

Measurements were taken of compressor power, air handler power, water pump power, water flow, water temperature in, water temperature out, outside temperature and humidity and, inside the room, air temperature and humidity in, and air temperature and humidity out. Data were recorded with a thirteen-channel Model 9300 Data Logger (Fig. 5), using time averages, where appropriate.

The air conditioned space consisted of approximately 2000 square feet of office/laboratory space containing computer facilities.

Switching the operation from one unit to the other is accomplished via a toggle switch. Also each unit can be switched to either air conditioning or heating as well as changing the air-to-air unit to water-to-air operation. The temperature sensor and control comprise a single common unit where operation can be switched to either unit. Both units ultimately supply output to a common duct, but when a particular unit is not in operation a louvre is closed immediately following the unit.

III. RESULTS

The 3-ton water-to-air cooling mode has been studied in some detail, but the heating mode needs additional studies. Studies of the air-to-air unit are not yet complete. This paucity of information is due largely to instrumentation, installation, and well problems which only permitted us to gather data during part of an air conditioning season. Various graphs show interrelations. In Fig. 6, we show the power consumed by the 3-ton unit over a 24-hour period for July 15-16 in a cooling mode (top curve) and the water

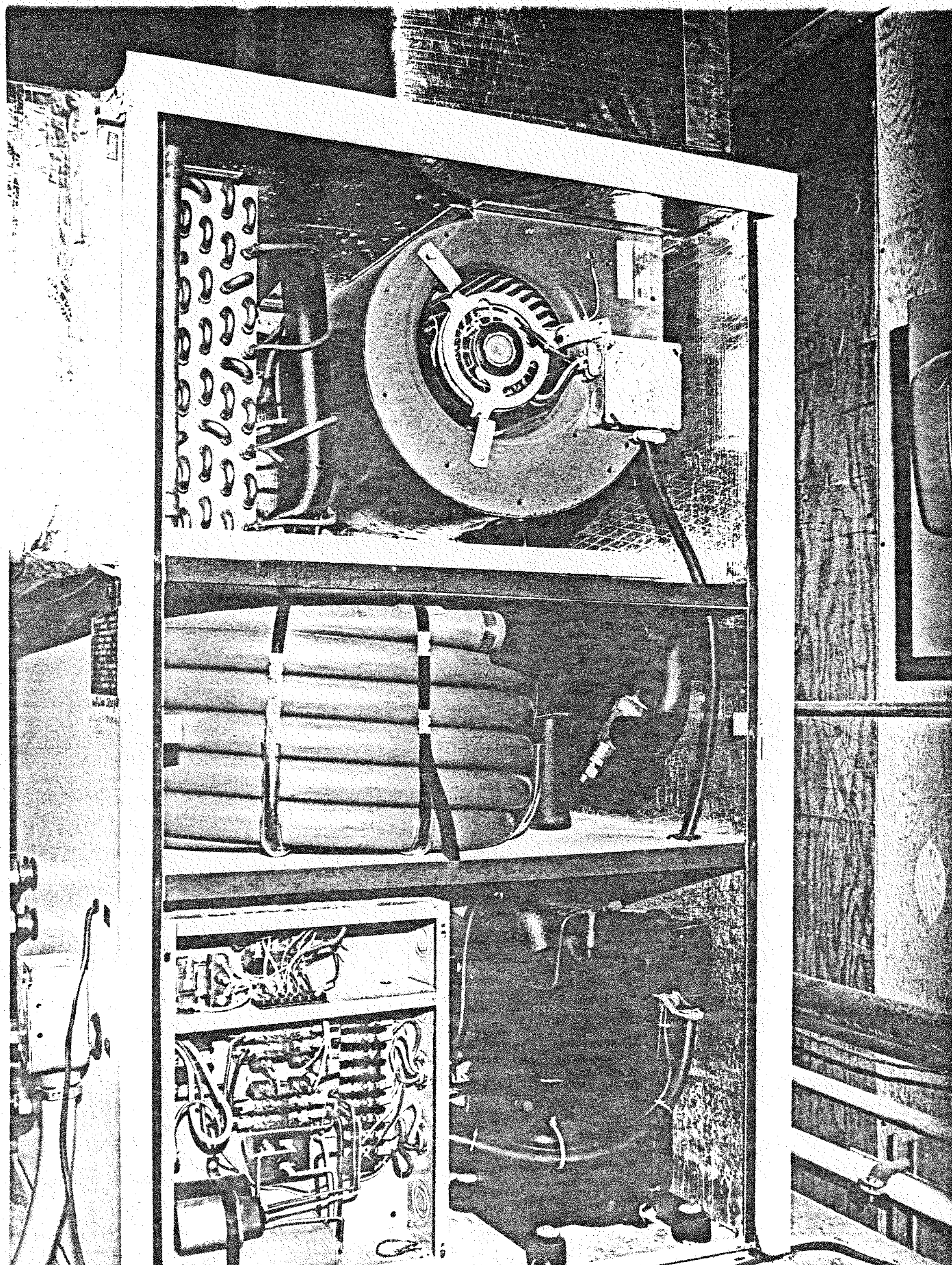

FIG. 4 - 3-TON WATER-TO-AIR UNIT WITH PANELS REMOVED

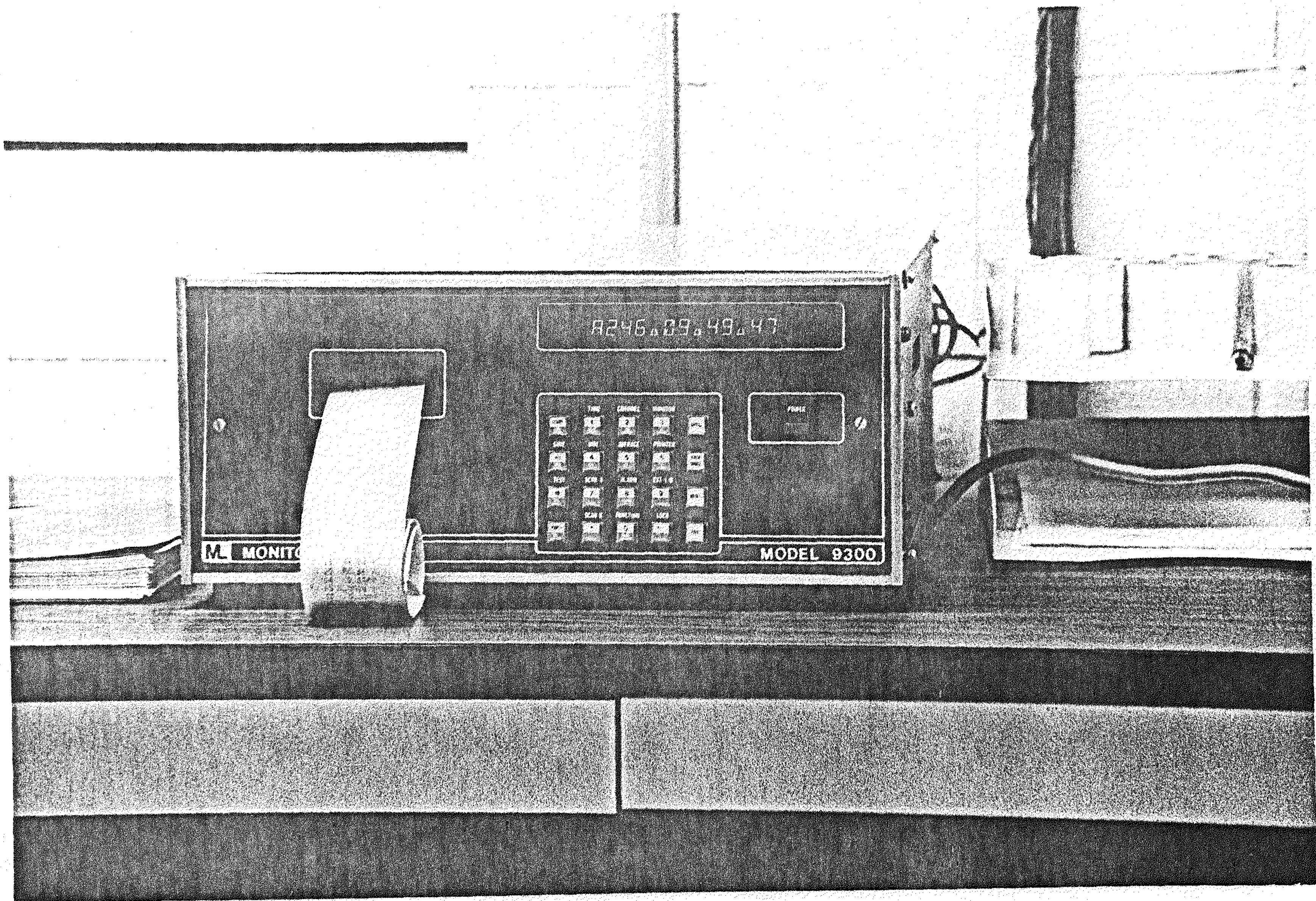

FIG. 5 - MONITOR LABS INC. DATA LOGGER

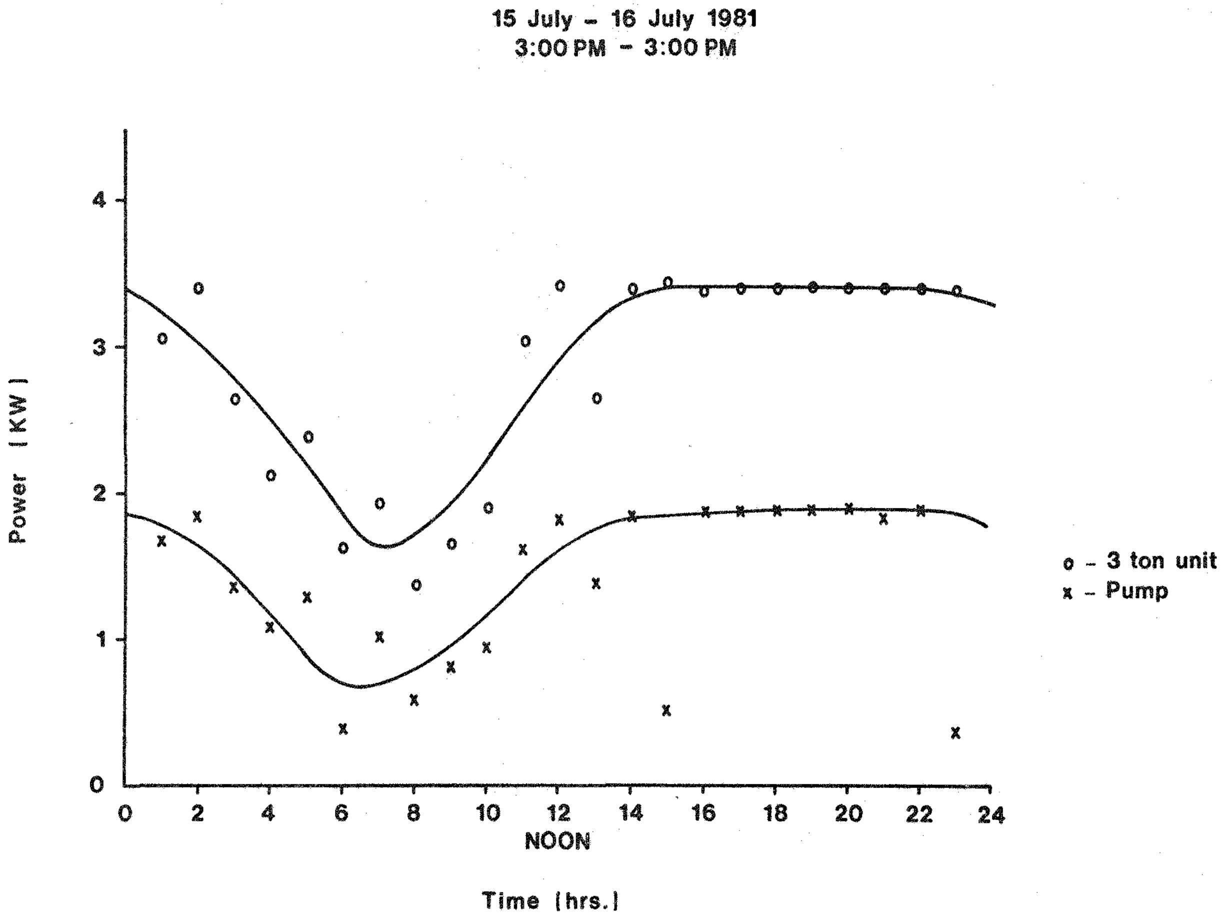

FIG. 6 — UNIT AND WELL PUMP POWER CONSUMPTION

pump power (lower curve). Fig. 7 includes the flowrate of water in gallons per minute for the same 24-hour period. Fig. 8 is a record of the essentially constant groundwater temperature for this same period in ^{o}F($^{o}F = 32 + 9/5^{o}C$). Small variations in temperature are probably caused by convective heat absorption by the surge tank.

Figures 9a and 9b trace the 3-ton heat pump power consumption along with water pump power cycles in one-hour periods. One can notice the phase correlations of the heat pump power variation and the water pump power. This variation is caused by the pump cycling between 30-50 psi causing the flowrate to vary, which, in turn, causes a fluctuation of the power consumption. When the water pressure is high, the increased water flow lowers the compressor temperature and lowers the power slightly.

The results for the 3-ton water-to-air unit operating as an air conditioner are shown in Fig. 10. The lower curve shows the water heat exchange temperature drop; the second curve shows the water flowrate in gallons per minute. The second curve from the top shows the kilowatt power level of the heat pump which includes the air handler motor. The curve on top is the resultant coefficient of performance. The compressor is running continuously for this period. Averages are taken over ten minute intervals. The average COP for the hour is 3.7, using equation (5). This figure does not include the well water pump power. By calculation the water pump was operating at an efficiency of only 9 percent in lifting and reinjecting the water, whereas efficiencies of better than 50 percent are reported (this well system will be replaced). But even with the poor efficiency here, a COP of 2.4 is obtained including the water pump power.

Similar data were taken for the heat pump mode of the 3-ton air-to-water unit. The preliminary value obtained here was 2.5 without including water

15 July – 16 July 1981
3:00 PM – 3:00 PM

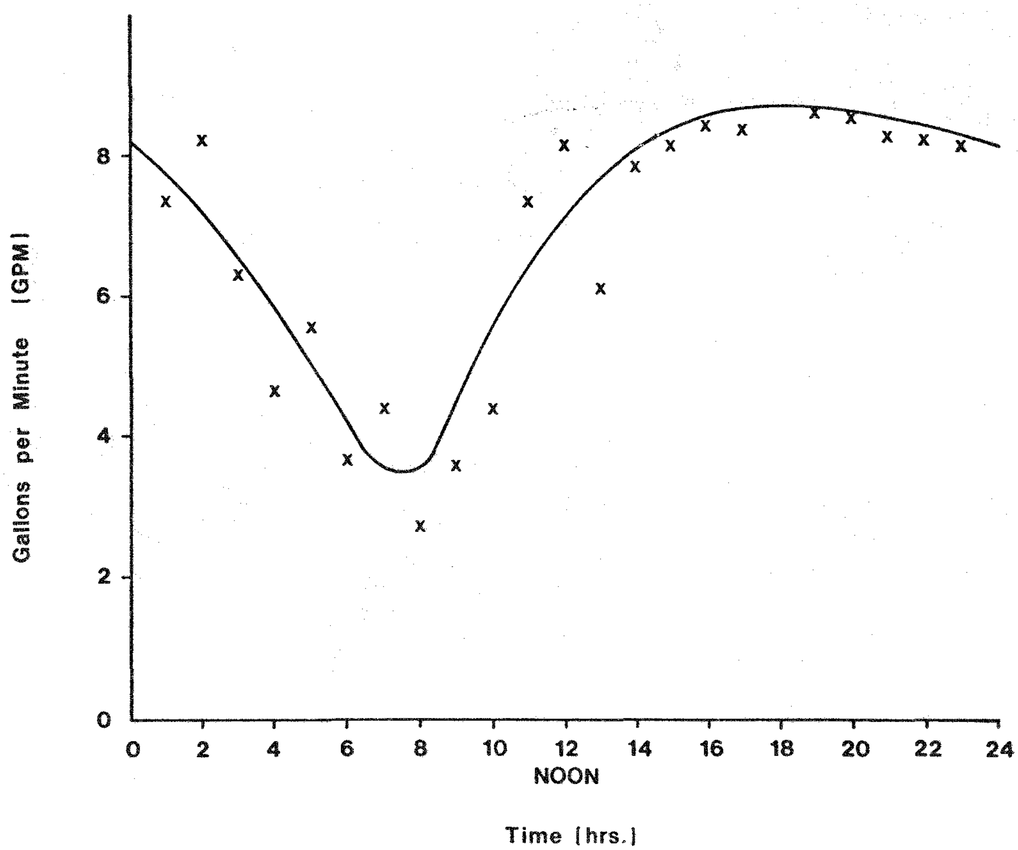

FIG. 7 — WATER FLOWRATE THROUGH 3 TON UNIT

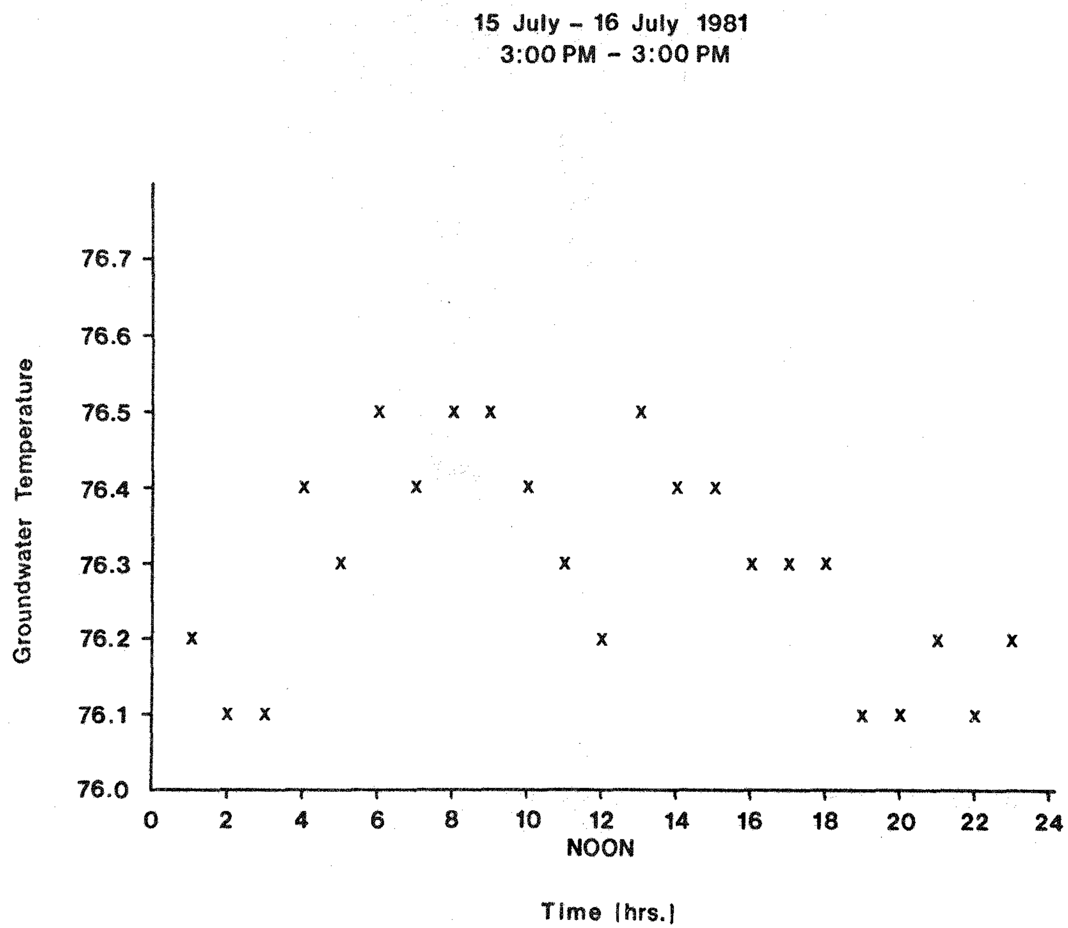

FIG. 8 — GROUNDWATER TEMPERATURE °F

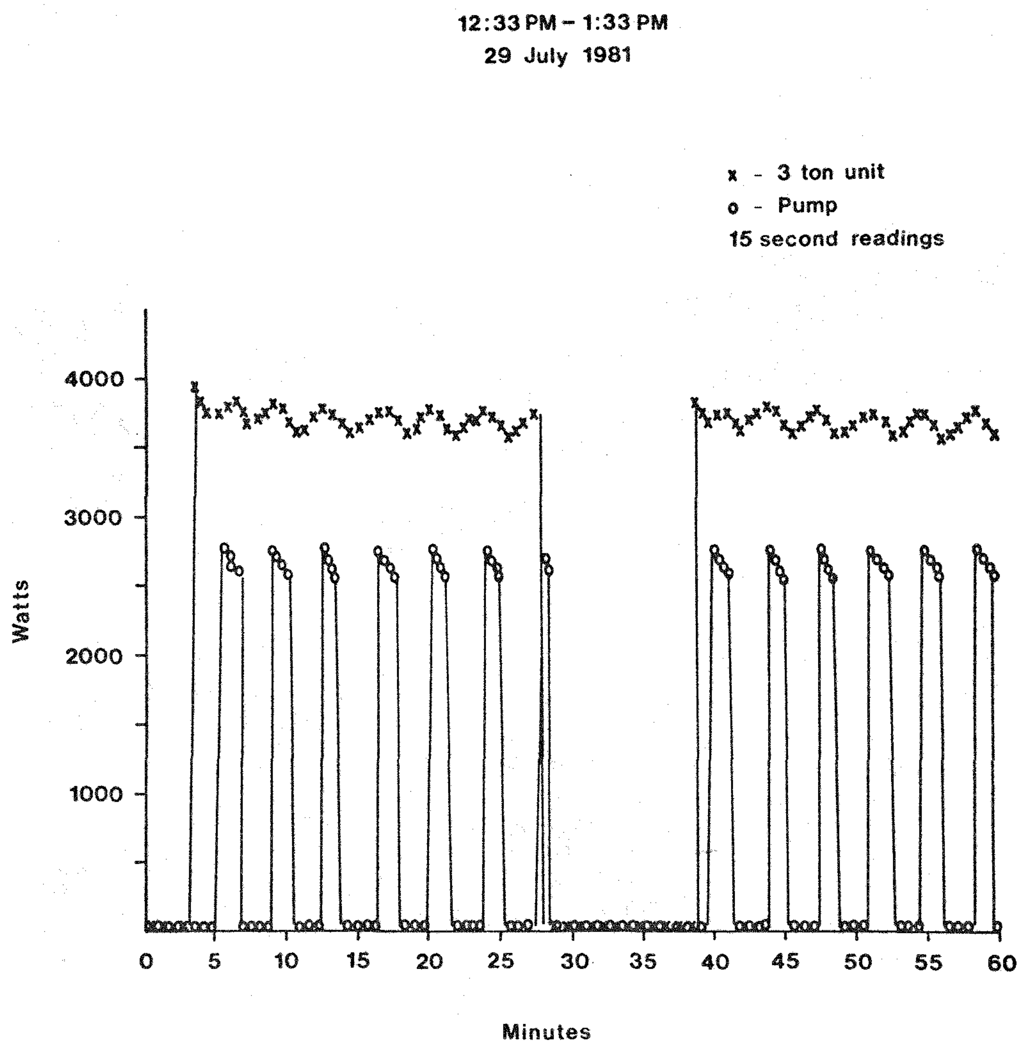

FIG. 9a — 3 TON UNIT AND WELL PUMP POWER CYCLES, JULY AFTERNOON

8:45 AM – 9:45 AM
13 August 1981

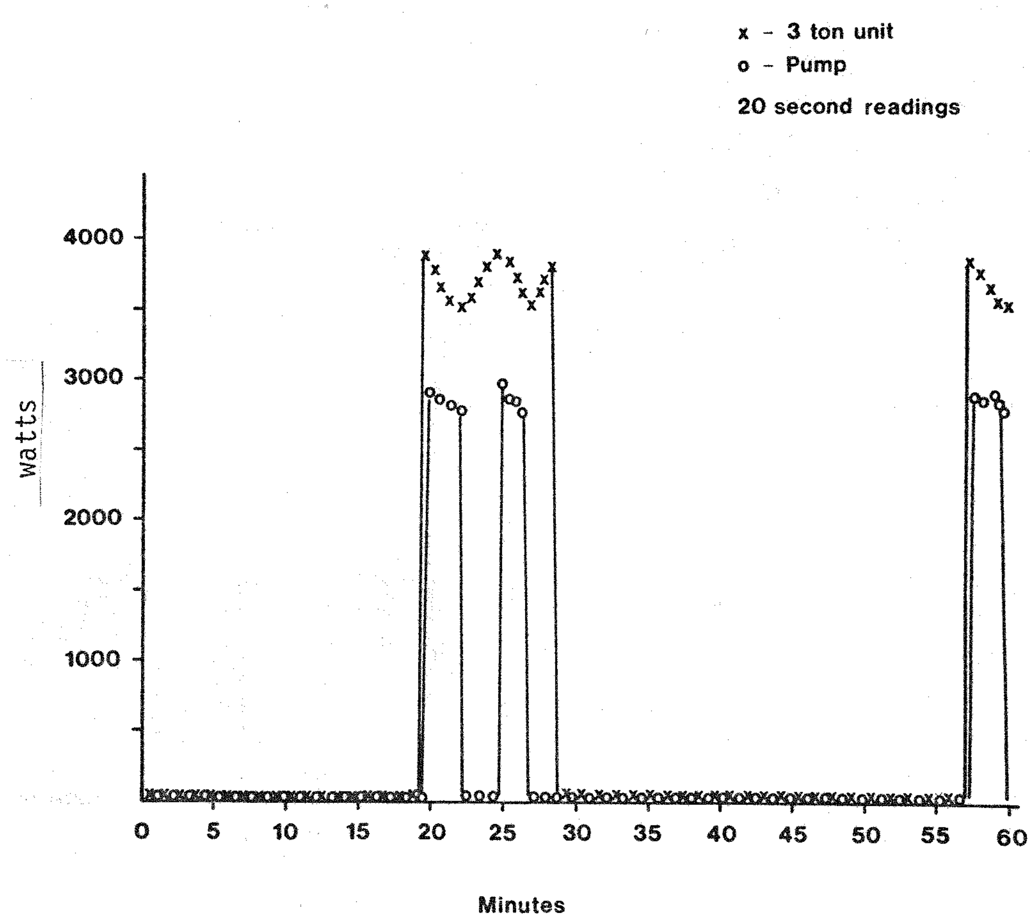

FIG. 9b – 3 TON UNIT AND WELL PUMP POWER CYCLES, AUGUST MORNING

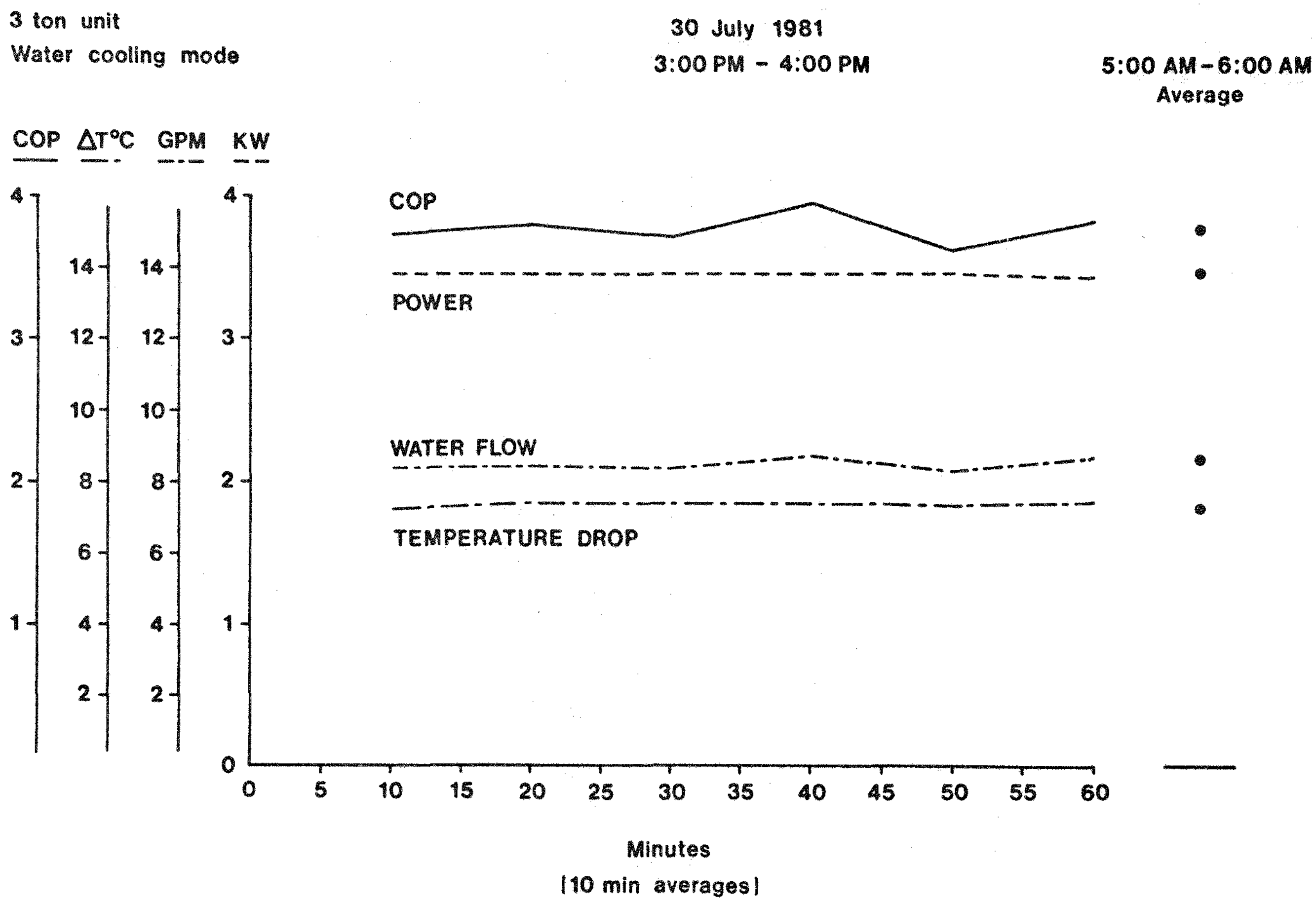

FIG. 10 — STEADY-STATE OPERATION OF 3 TON UNIT (COOLING MODE)

pump power. This was obtained for a single continuous one hour run during a weekend. Obviously more data is required during full winter operation.

A preliminary measurement on the 5-ton unit in a water-to-air cooling mode gave a COP_R of 1.9. These results need to be extended to coverage of the air-to-air and water-to-air heating mode for the 5-ton unit, as well as air-to-air cooling mode.

IV. CONCLUSIONS AND RECOMMENDATIONS

This project has developed a very effective way of measuring water heat pump and air conditioning COP's, through measurement of all required quantities in terms of electrical power and accurate calorimetry with standard water flow and temperature measurements. We need not measure the precise air heat load of a room because the heat taken out of the room is measured through water calorimetry and power supplied to conditioner. Humidity measurements can be made but are not essential to determining COP's, because the humidity is only part of the heat load.

This particular technique of measurement could be used to measure air-to-air units by directly coupling a water air conditioner to an air-to-air heat pump. The two units would have to have approximately the same rating but standardization measurements could be made without having to measure accurately either duct air flow profiles or humidity.

A high COP value (3.7) for a 3-ton water-to-air unit operating in an air conditioning mode was found when the water pump power was not included. This performance would be appropriate for shallow wells and surface water or from lakes. Unusually high pump power was attributed to poor pump operation, with only about 9 percent efficiency in drawing water from a depth of 150 feet and discharging it into a second well of 150-foot depth. Typical efficiencies for commercial pumps are in the range of 50 percent and greater. When the excessive pump power is included, the COP lowered to 2.4. The well depth of 150 feet was dictated by the nearness to a deep bayou whereas a depth of 50-75 feet would be preferred.

The modified 5-ton unit in the water-to-air cooling mode yielded a COP_R of 1.9.

The original goal of the program was to obtain seasonal measurement to fully compare in complete detail air-to-air and water-to-air units. Because of equipment and instrumental difficulties this was not possible and limited point measurements had to be made. Although long term economic comparisons can not be developed at this time, electrical bills would vary inversely with the COP. For example a COP of 3 would reduce the electrical bill by a factor 3 and a unit with a COP of 1.5 would reduce an electrical strip heater bill by 1.5.

Water-to-air heat pumps and air conditioners are a valuable addition for retrofit applications when either shallow well water or ground water, such as water from lakes, is available. Lakes or ponds should be sizable since a fully rated 3-ton air conditioner with a COP of 3 operating continuously for 24 hours would heat a pool of water 20 ft. x 20 ft. x 10 ft. deep a total of approximately 2.5^{o}C or 4.5^{o}F. This assumes no other effects on the pool in the 24-hour period such as evaporation or the addition of convective energy from the environment.

These heat pump units should be operated in the future to obtain additional data, especially for the heating modes. We expect to investigate pump power behavior further. The water well system has been redesigned and will be replaced. Also, humidity measurements and air duct profile measurements will be made.

V. REFERENCES

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2. Jones, Jerold W., Philip S. Schmidt, and Charles W. Kreitler. Groundwater Source Heat Pump Design Development for Texas: Vol. 3. "Economics and Summary," EDF 038-3, TENRAC (1981).