THE PRESENT STATUS OF THE RESIDENTIAL HEAT PUMP

by

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TABLE OF CONTENTS

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HISTORY

Origin of the Heat Pump Principle

The heat pump idea has been traced back to an address by Professor William Thomson (Lord Kelvin) on December 1, 1852. The idea was not entirely new even then, as his paper of that date refers to a proposal by a professor Piazzi Smyth along similar lines.

Kelvin's paper, presented before the Glasgow Philosophical Society, concerned the economy of the heating or cooling of buildings by means of currents of air. The low pressure air would be heated up to approximate outside air temperature and then passed to a compression cylinder to be compressed back to atmospheric pressure. Its temperature would be raised well above the outdoor temperature and delivered to the room.

In the cooling cycle, the outdoor air would first be compressed and then passed through a coil subjected to outside air temperatures. The cooled, compressed air would pass to an expansion cylinder and the expanded air passing to the living quarters would be well below outdoor temperatures. The additional energy for making these transformations would be supplied by a steam engine. This type system became known as the open cycle air machine.

In 1877, J. J. Colman, who had been consulted by the Messrs. Bell as to the best means of mechanically refrigerating meat during overseas transit, discussed the problems with Lord Kelvin. As a result of the meeting, Mr. Coleman devised a form of refrigerating machine which afterwards became known as the Bell-Coleman refrigerating machine. This type of machine, used successfully in England, had its main features substantially the same as Lord Kelvin's original idea. It consisted of two work cylinders: a compression cylinder, and an expansion cylinder. The air was taken in by the compression cylinder from the room which was to be maintained at a low temperature; it was first compressed and thereby heated, then cooled by circulating water while in the compressed state. It was next made very cold by expansion to atmospheric pressure and was finally returned to the cold room from which it came.

There was no commercial development of the air machine for heating purposes, as the costs of existing heating equipment were far below the equipment and operating costs of a heat pump.

Early Heat Pump Applications

The first applications of the heat pump appeared in Europe shortly after World War I. These installations were industrial applications, where compressors were used to provide heat for drying or concentrating chemicals, sugar, and paper. As heat sources, some of the installations used waste liquids or air having higher temperatures than outside air or water.

The use of mechanical devices to heat or cool buildings did not become popular until electric energy became available at low cost. Summer air conditioning installations began to grow in the 1920's. However, most of these installations were limited to public meeting places and processing rooms and it was not until the late 1930's that any consideration was given to cooling homes. Most of the domestic applications were limited to unit air conditioners, cooling only one room.

The use of mechanical devices for cooling stimulated experiments on mechanical heating. In 1927, T. G. N. Haldane made an actual experimental application in his home in Scotland. The equipment included a 5 kw motor driven compressor, an outdoor evaporator and a condenser mounted in a duct supplying the living quarters. This installation was equipped with valves in the refrigerant lines, so that the flow of the refrigerant could be reversed for cooling, enabling the evaporator and the condenser to exchange functions.

In the early 1930's, engineers, in cooperation with utilities, started experimenting with heat pumps for heating and cooling both homes and offices. One of the first large commercial installations was made in the offices of the Southern California Edison Company in Los Angeles where the volume conditioned was 3,800-000 cubic feet. Outside air was used as a heat source. With a minimum temperature limit of 42 degrees F, the heat pump could supply full heating requirements. Electric resistors were used for supplemental heating whenever the outside temperature fell below 42 degrees.

During the ten-year period from 1930 to 1940, installations were made throughout the United States, with a few in foreign countries, most of them being sponsored by utilities and a few by manufacturers. Heat sources included outside air, well water, and process heat. In most cases, some sort of supplemental heating was provided for severe weather.

World War II retarded the experimental installations of the heat pump in this country, although engineers were busy working on development problems.

Just before the war and immediately following the war, attention was given by manufacturers to the construction of package-type heat pump units.

PRESENT STATUS

Heat Pump Principle

The heat pump, in popular usage, refers to a year-round air-conditioning system employing refrigeration equipment in a manner which enables a surface to deliver usable heat to a space during the winter period and to abstract heat from the same space during the summer period.

When the heat pump is used for heating, heat is picked up by the refrigerant in the evaporator. This refrigerant gas has its temperature and pressure increased as it passes through the compressor. The high-pressure, high-temperature refrigerant gas then goes to the condenser where the air to be heated extracts heat from the condenser as it passes over it. As this heat is extracted, the refrigerant is condensed to a liquid and returned to the receiver. In going through the expansion valve, the pressure is reduced and the refrigerant is put in a condition to absorb heat at low temperature from the source supplying the evaporator. The evaporator may use air, water, or the earth as a source of heat. The condenser may be an air or liquid condenser depending on whether it is used for house heating with hot air, a radiant heating installation, or in an industrial process.

To change from heating to cooling, either of two basic methods can be used. The first is to change the circuit of the heat source and the medium to be heated, leaving the refrigerant path unchanged. Figure 5 is an example of this method. The other method is to reverse the refrigerant path by suitable valves and not change the heat source and conditioning paths. This method is illustrated in Figure 6.

Sporn, Ambrose and Baumeister point out in their book, Heat Pumps, (1:1),

> There is no fundamental difference between a conventional refrigeration system and the so-called "heat-pump" system. Thermodynamically both systems are "heat pumps" employing a compressor, condenser, cooling coils, and expansion valve to absorb heat at a low-temperature level and reject it at a higher-temperature level. A system making use of the rejected heat cannot be properly termed a refrigeration system since the cooling is not the primary object during the cycle. Such a system has sometimes inaccurately been called the "reverse-refrigeration cycle".

As mentioned before, in popular usage the heat pump is thought of as a year-round air-conditioning system. Actually, it is the compressor of this system that "pumps" the heat. The idea of pumping heat is difficult to grasp as heat itself is not a material substance. The concept can perhaps best be understood by seeing what happens in the compressor of a heat-pump system.

When a vapor is compressed without the loss or addition of heat, the increase in pressure is accompanied by an increase in temperature. The thermal energy (popularly called "heat") stored in this vapor comes into the suction side of a compressor at a temperature of, say 30 degrees F. with an energy content of 81.6 Btu/lb. (taken from refrigerant tables of Freon-12). After being compressed to a pressure of, say 121 psi and 25 degrees F superheat, its energy content is 92.16 Btu/lb. and its temperature 119 degrees F. At 30 degrees F the energy in the vapor would not be of use in heating air in a home. However, at 119 degrees F, or the saturation temperature of 94 degrees F, the energy is useful. Therefore, by the addition of a small amount of electrical energy to drive the compressor, it is possible to make a larger amount of low-grade energy available for heating.

In order to follow what happens in the various elements of a heat pump, typical temperatures and pressures are shown in Figure 1. The air to be heated is returned from the conditioned space at a temperature of about 70 degrees F. The heat-exchanger surface is designed to increase this temperature to about 95 degrees F. The compressor delivers the refrigerant gas to the condenser

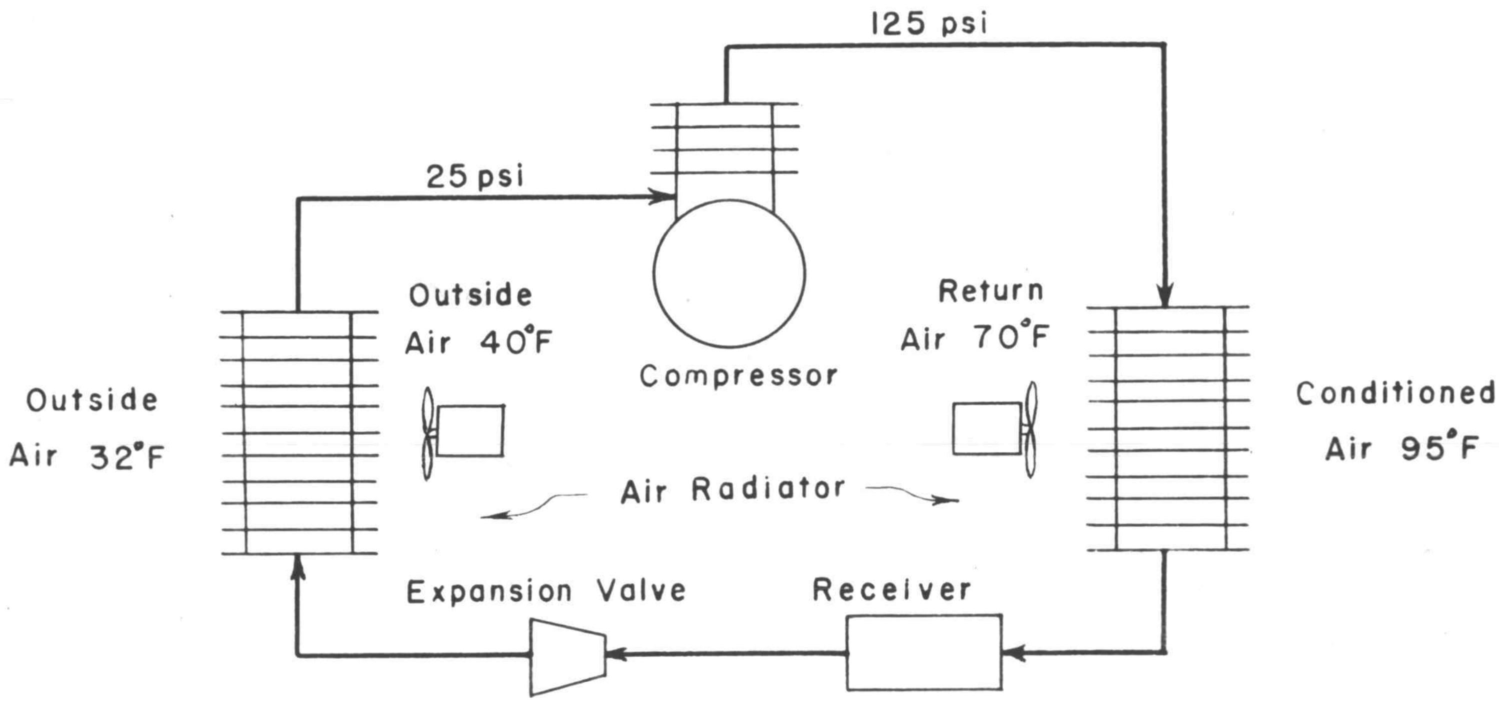

FIGURE 1

BASIC HEAT-PUMP SYSTEM

Air-to-Air Heating Cycle

in a superheated condition at about 125 psi. The refrigerant is condensed in the condenser and returned to the receiver at approximately the same pressure, but in a slightly subcooled condition. From the condenser it passes through the expansion valve where it is throttled to a lower pressure which is governed by the heat-source medium and temperature. When outside air is used as the heat source and operated on the heating cycle, it will have its temperature lowered in passing across the evaporator. In the example outside air at 40 degrees F is used and a drop in temperature of as much as 8 degrees may be expected. A suction pressure of 25 psi may be maintained in the evaporator. The refrigerant in passing through the evaporator will have little change in temperature and pressure, but it will change from a liquid to a gas. The heat to cause the refrigerant to vaporize is supplied by the outside air in this example. This low-pressure gas is drawn into the suction side of the compressor and completes the circuit. The temperatures and pressures in any heat-pump system vary depending upon the particular design, operating conditions and air volumes handled. Figure 2 indicates approximately the temperature situation that might exist when the basic air-to-air heat pump shown in Figure 1 is

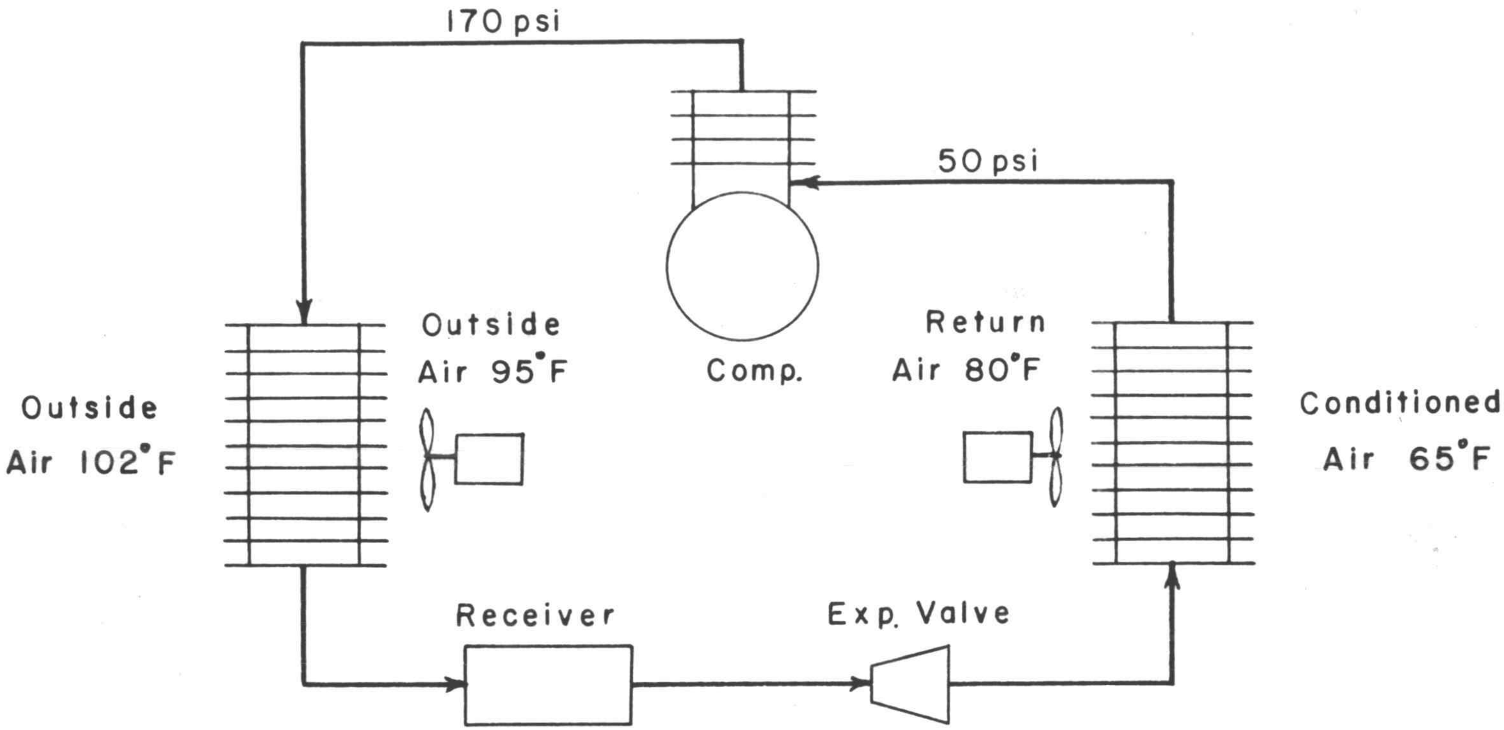

FIGURE 2

BASIC HEAT-PUMP SYSTEM

Air-to-Air Cooling Cycle

utilized for the cooling function. In this example, it will be noted that the air flow to the conditioned space passes over the evaporator instead of over the condenser as in the previous example.

<u>Thermodynamics of the Heat Pump</u>

The ideal heat-pump cycle, representing the highest possible performance between two temperatures, is the Carnot cycle as shown in Figure 3. Here the refrigerant fluid, entering the compressor at point 1; undergoes isentropic compression (constant entropy) to point 2; isothermal compression (constant temperature), or condensation, to point 3; isentropic expansion to point 4; and then isothermal expansion, or evaporation, back to point 1. The area Q_1 (area 1,4,5,6) represents the heat absorbed by the system (the refrigerating effect). The area Q_2 (area 1,2,3,4) represents the energy added to accomplish this effect. The sum of Q_1 and Q_2 (area 2,3,5,6) represents the heat rejected by the system. By definition, the coefficient of performance C.O.P. of a heat pump, during the heating cycle is the total heat output $Q_1 + Q_2$ divided by the heat equivalent of the net work required to produce the effect, and during the cooling cycle is the refrigerating effect Q_1

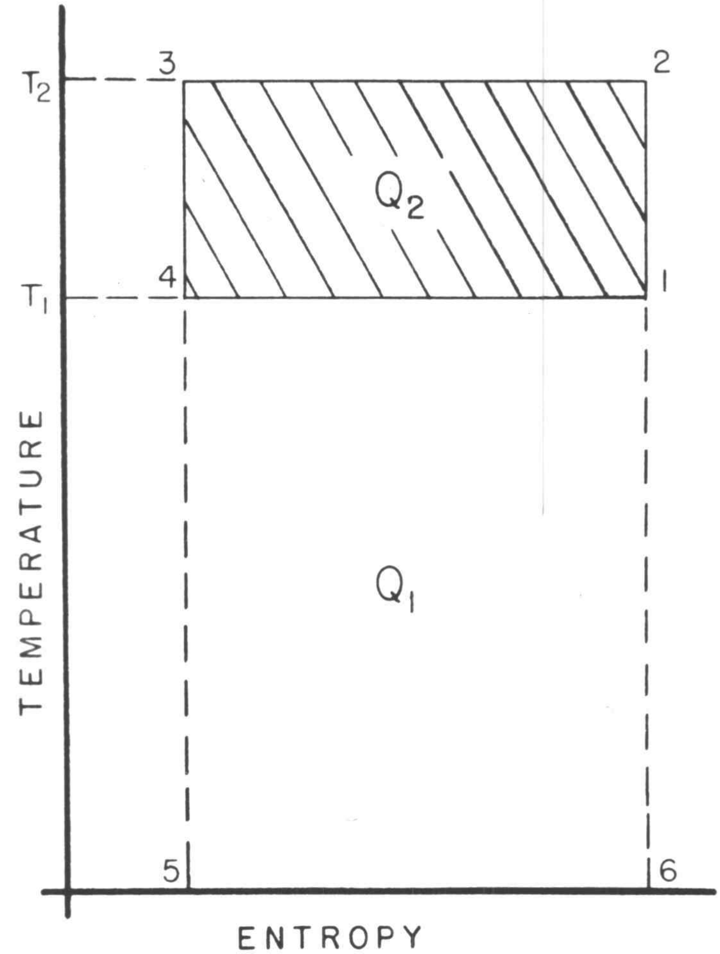

Figure 3

TEMPERATURE-ENTROPY DIAGRAM
FOR IDEAL HEAT PUMP (CARNOT) CYCLE

divided by the heat equivalent of the net work done in producing the effect, or

$$\text{C.O.P.} = \frac{\text{heat delivered, } Q_1+Q_2}{\text{work, } Q_2} \quad \text{(Heating cycle)}$$

$$\text{C.O.P.} = \frac{\text{refrigeration, } Q_1}{\text{work, } Q_2} \quad \text{(Cooling cycle)}$$

Since the change in entropy is the same for the three areas, the energy quantities represented by them are proportional to the absolute temperatures. The formulas for the theoretical coefficient of performance for the Carnot cycle are:

$$\text{C.O.P.} = \frac{T_2}{T_2 - T_1} \quad \text{(Heating cycle)}$$

$$\text{C.O.P.} = \frac{T_1}{T_2 - T_1} \quad \text{(Cooling cycle)}$$

These equations represent the highest performance coefficient between two limiting temperatures, as mentioned previously, and cannot be attained in practice. The Carnot cycle is used, therefore, to show ideal limits and as a general guide in predicting performance. One of the most important things to be remembered with reference to the C.O.P. is that it may be raised by lowering temperature T_2 and/or by raising temperature T_1.

The theoretical Rankine cycle closely approaches the practical refrigeration cycle and for that reason, is the one most commonly used today. The temperature-entropy diagram for the Rankine cycle is shown in Figure 4. The refrigerant is compressed isentropically in phase C to D; condensed at constant pressure (and therefore constant temperature) to liquid in phase D to K to A; expanded irreversibly at constant enthalpy through a throttle valve in phase A to B; and evaporated at constant pressure (and therefore at constant temperature) to wet vapor in phase B to C.

The heat absorbed in the evaporator, or the cooling effect, is the difference in enthalpy at C and B ($h_C - h_B$). This is equivalent to the area BCIH. The heating effect or heat rejected in the condenser will be the difference in enthalpy at D and A ($h_D - h_A$). This is equivalent to the area AGID. The amount of work supplied by the compressor is equal to the difference between the enthalpy at D and C ($h_D - h_C$). Knowing these quantities, the coefficient of performance of the cycle can be calculated when used either as a refrigerating machine or as a heating machine.

$$\text{C.O.P.} = \frac{h_D - h_A}{h_D - h_C} \qquad \text{(Heating cycle)}$$

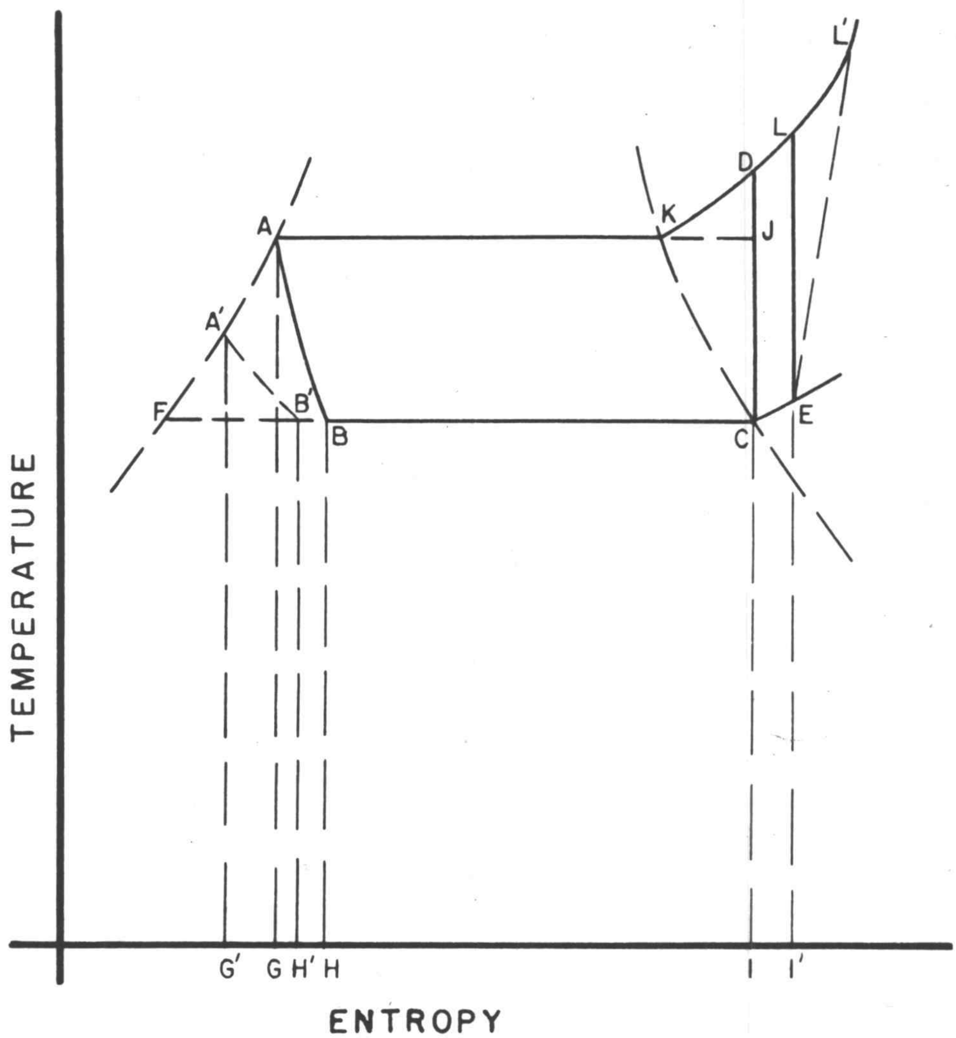

FIG. 4 TEMPERATURE-ENTROPY DIAGRAM

FOR ACTUAL HEAT PUMP (MODIFIED RANKINE) CYCLE

$$C.O.P. = \frac{h_C - h_B}{h_D - h_C} \quad \text{(Cooling cycle)}$$

This cycle differs from the Carnot cycle in that the compression of a dry gas to a superheated condition requires an extra amount of work equal to DKJ. The use of a throttle or expansion valve in effect results in a loss of cooling capacity equal to AGHB. The heating capacity will not be changed. The amount of work necessary to obtain these heating and smaller cooling capacities is greater than in the Carnot cycle. Thus the coefficient of performance is smaller.

The actual cycle will differ from the theoretical Rankine cycle shown in Figure 4 because of fluid friction in the system, mechanical friction and other losses during compression, subcooling of the liquid, and superheating of the vapor. The effect of fluid friction in the system is to raise line AKD and to lower line BC. This has the result of reducing the refrigeration effect and increasing the work required. The effect of subcooling the liquid refrigerant is to move point A to A'. Since the path from A to B takes place at constant enthalpy, the path for the subcooled liquid will be from A' to B'. This results in an increase in cooling capacity as is shown by area B'H'HB. If the subcooling of the liquid is from some external source, there will be an increase in refrigeration capacity without increase of work, since the work is still represented by area FCDKA. If, however, the liquid is subcooled from A to A' by refrigerant vapor from the evaporator as in a commonly used superheater in the suction line, additional work is necessary to accomplish this increase in cooling capacity. In this type of superheater the vapor at point C absorbs heat from the liquid being subcooled and point C moves to E. The work area now becomes AFCELKA. The cooling effect represented by ICEI' does not enter into the cooling capacity since it was obtained in subcooling the liquid from A to A'. In general the ratio of the increased heat absorbed by the subcooled liquid to the extra work required will be less than for the theoretical cycle. The effect of the compressor losses is to move point L to L', resulting in an increase in work required. This increases the work without increasing the refrigeration capacity. It will, however, increase the heat output by the heat equivalent of the irreversible work done. Since this is on a one to one basis, it is not desirable since it results in a lowering of the overall coefficient of performance.

Types of Systems

There are four basic types of heat pump systems. Figure 5 shows schematically an air to air design. Air is used as a source of heat, and air is used to remove heat from the condenser. The path of the refrigerant is reversed by means of eight two-way valves as shown.

During the cooling cycle, the gas refrigerant goes from the compressor through valve 1 to the outside coil where it is liquefied, giving up its heat to the outside air. From the outside coil the liquid refrigerant goes through valve 2 to the liquid receiver, through the expansion valve and valve 3 to the conditioner coil where it is gasified, absorbing heat from the air being delivered to the conditioned space. From the conditioner coil the gas returns to the compressor through valve 4.

During the heating cycle, the gas refrigerant goes from the compressor through valve 5 to the conditioner coil where it is liquefied, giving up heat to the air being delivered to the conditioned space. From the conditioner coil the liquid refrigerant goes through valve 6 to the liquid receiver, through the expansion valve and valve 7 to the outside coil where it is gasified, absorbing heat from the air outside of the conditioned space. From the outside coil the gas returns to the

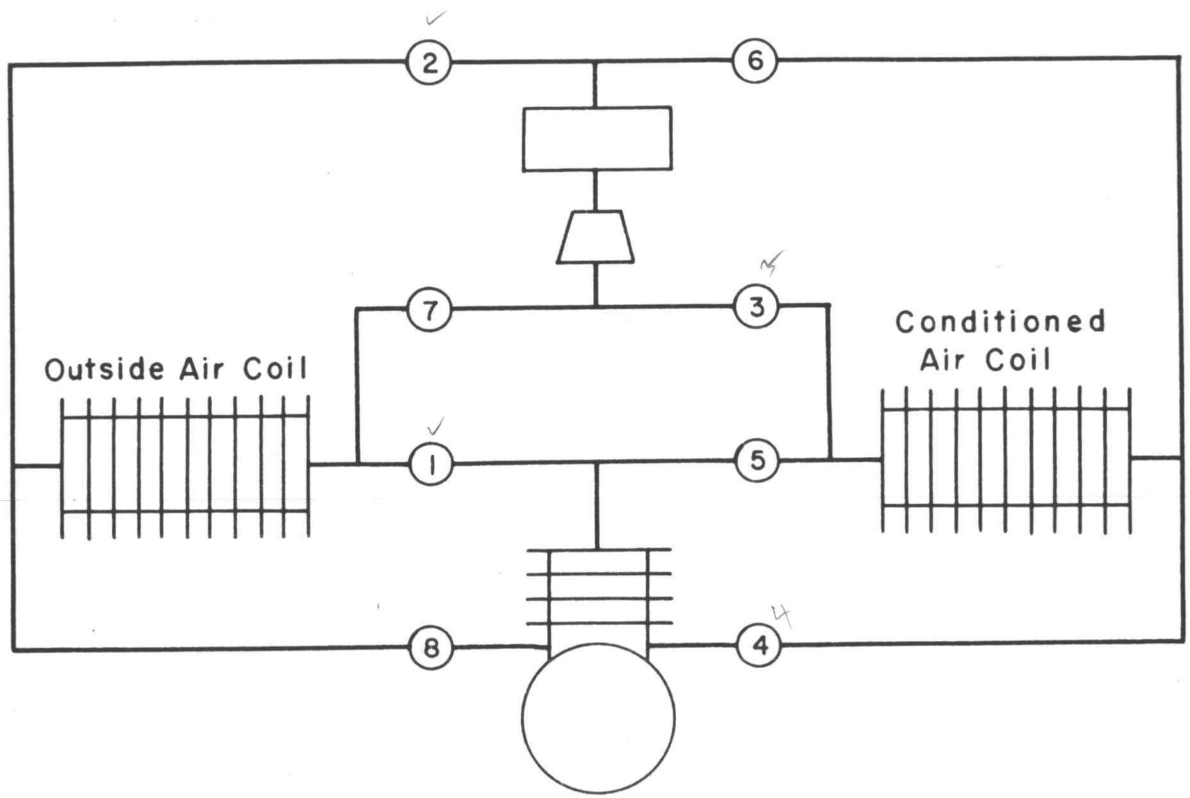

FIG. 5 AIR-TO-AIR SYSTEM, Fixed Air Circuit

Heating Cycle, Valves Open 1,2,3,4

Cooling Cycle, Valves Open 5,6,7,8

compressor through valve 8.

Instead of reversing the direction of the refrigerant as shown in Figure 5, an alternate design, Figure 6, maintains a fixed refrigerant circuit and reverses the flow. During the cooling cycle, air from the conditioned space passes through damper A over the cooling coil, through damper B back to the conditioned space. Outside air passes through damper C over the condenser through damper D to the outside.

During the heating cycle, air from the conditioned space passes through damper G, over the condenser, through damper H and back to the conditioned space. Outside air passes through damper E over the cooling coil through damper F, back to the outside air.

Air-to-air systems have the advantage of simplicity by being completely self-contained. In addition, there are no problems of water disposal, water availability, scale or sediment formations, all of which are prevalent in a system using water. Another advantage claimed for the air-to-air system is its ability to operate with a high performance coefficient when the temperature of the outside air varies only slightly from the temperature of the conditioned space. A unit of this type, however, is necessarily large because of the two

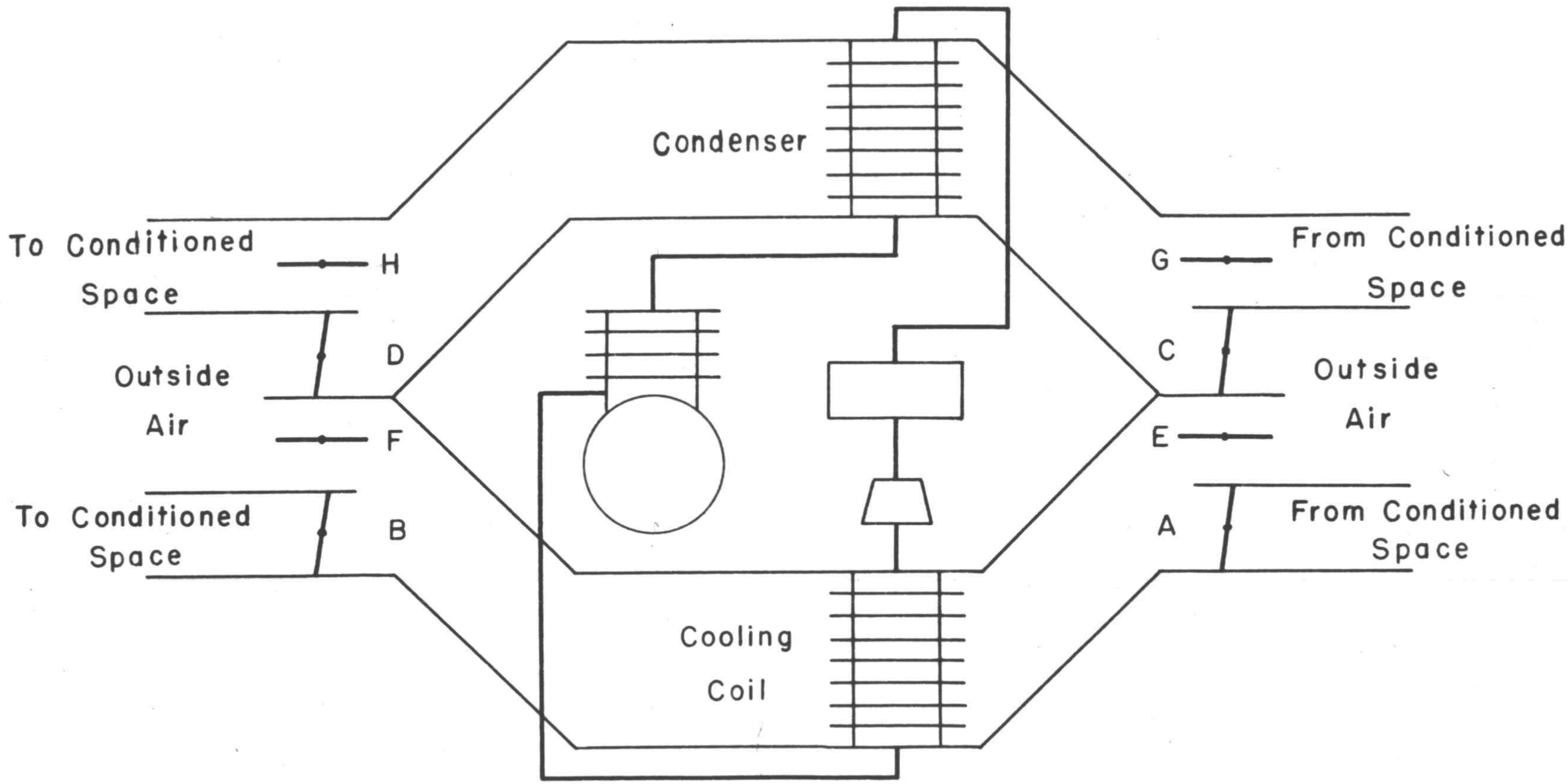

FIG. 6 AIR—TO—AIR SYSTEM, Fixed Refrigerant Circuit

Heating Cycle Dampers Open A,B,C,D

Cooling Cycle Dampers Open E,F,G,H

or more air heat-exchanger coils. These coils are considerably larger than corresponding water coils because of the lower heat-transfer coefficient of air. For the present, at least, air-to-air systems are limited to a mild climate since low outside-air temperatures reduce the coefficient of performance and less heat is thus available when it is needed most. Frost accumulations that occur on the outside-air coil also present a problem where air temperatures go below about 40 degrees F.

Figure 7 shows an air-to-liquid design. Air is used as a source of heat; liquid is used to transfer the heat from condenser and chiller. In this design, the refrigerant circuit is fixed, going from compressor to condenser, through the expansion valve and chiller, back to the compressor.

During the cooling cycle, pump A circulates the colder liquid through the chiller, valve 4, the inside-air heat exchanger then through valve 3 back to the pump. The circulating liquid in passing through the inside heat exchanger absorbs heat from the air being delivered to the conditioned space and in turn gives up this heat to the refrigerant in the chiller; pump B circulates the warmer liquid through the condenser, valve 1, the outside-air heat exchanger, then through valve 2

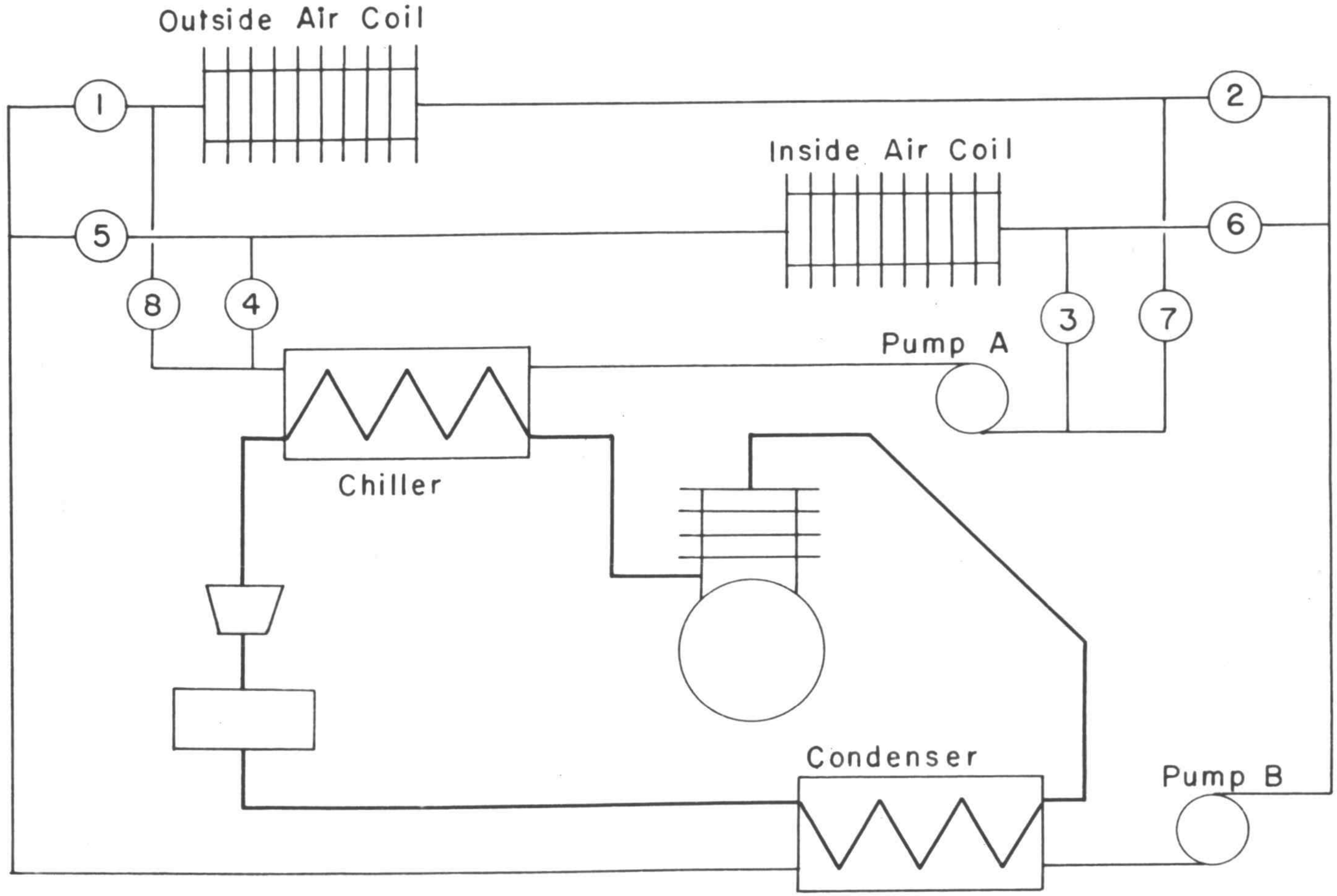

FIG. 7 AIR-TO-LIQUID SYSTEM

Heating Cycle Valves Open 1,2,3,4   Cooling Cycle Valves Open 5,6,7,8 back to the pump. The liquid in passing through the condenser absorbs heat from the refrigerant and gives it up to the outside air when passing through the outside heat exchanger.

During the heating cycle, pump A circulates the colder liquid through the chiller, valve 8, the outside heat exchanger, then through valve 7 back to pump A. The liquid in passing through the outside heat exchanger absorbs heat from the outside air which is transferred to the refrigerant in the chiller. Pump B circulates the warmer liquid through the condenser, valve 5, the inside heat exchanger, then through valve 6 back to pump B. In passing through the condenser, the liquid absorbs heat from the refrigerant which is transferred to the conditioned air passing over the inside-air heat exchanger.

The liquid used in this system can be water or any one of the common antifreeze solutions. Since outside air is used as the source of heat, the unit has the same disadvantage as an air-to-air type in that the coefficient of performance is greatly reduced at low outside-air temperatures. The system has, on the other hand, been used to advantage in storing hot water during mild weather for use when lower outdoor temperatures are experienced, and during the cooling cycle for storing cold water during mild weather for use when higher outdoor temperatures are experienced. It is also possible to store either hot or cold water, depending on the cycle of operation, during the night or off-peak periods for use during the day or when the demand is greatest.

A water-to-air system is shown in Figure 8. In this design water is used as the source of heat and air is used as the heat-transfer medium. During the cooling cycle, valves 3 and 4 are open, and valves 1 and 2 are closed. Water, taken from a well or some other source is circulated by a pump, through the water coil, where it liquefies the refrigerant, and is then discharged to the drain. The refrigerant path is from the compressor, through valve 3, the water coil, the check valve, the liquid receiver, through the expansion valve, the air heat exchanger, valve 4, back to the compressor to complete the cycle. The refrigerant gas is liquefied in the water coil by giving up its latent heat of condensation to the water and is changed back into a gas in the air heat exchanger by absorbing its heat of vaporization from the air going to the conditioned space.

During the heating cycle, valves 1 and 2 are open,

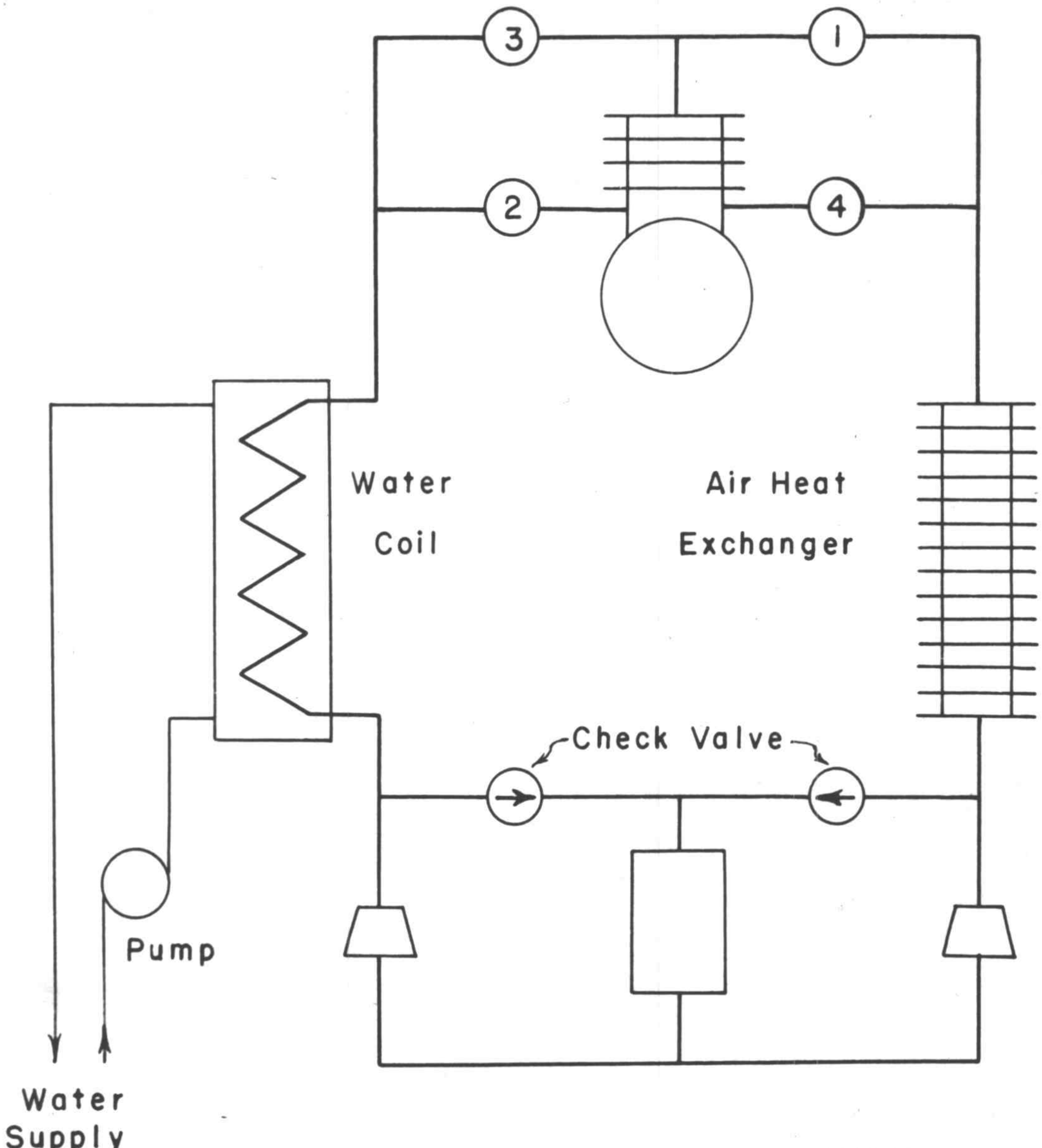

FIG. 8 · WATER-TO-AIR SYSTEM
Heating Cycle Valves Open 1 & 2
Cooling Cycle Valves Open 3 & 4

and valves 3 and 4 are closed. In this cycle the water taken from the well is circulated through the water coil to the drain in a manner similar to that for the cooling cycle, except that heat is removed from the water by the refrigerant. The refrigerant path is from the compressor, through valve 1, the air heat exchanger, the check valve, liquid receiver, the expansion valve, through the water coil, valve 2, back to the compressor. The hot compressed refrigerant gas from the compressor is liquefied in the air heat exchanger by giving up its heat of condensation to the air going to the conditioned space and is changed back into a gas in the water coil by absorbing the heat of vaporization from the well water.

This type of system operates with a relatively constant coefficient of performance regardless of outside air temperatures; hence it may be used in climates where extreme temperature variations are experienced. This is its greatest advantage over a system using outside air as the heat source. This unit is also smaller in size since it requires only one air heat exchanger. Its chief difficulties lie in obtaining an adequate water supply and in water disposal, the latter being more difficult, usually, than the former.

Figure 9 shows a water-to-water system. Water is used as a source of heat, and water is used to transfer heat from the condenser. For the heating cycle, valves 1 and 2 are open and valves 3 and 4 are closed. Water from the well is pumped through the water coil by pump A and then discharged through valve 1 to the drain or back to the well. Pump B circulates water from the condenser through valve 2 to the heat exchangers located in the conditioned space in a closed circuit.

During the cooling cycle, valves 1 and 2 are closed and valves 3 and 4 are open. Water from the well is pumped through the water coil where it is cooled further. It is then pumped by both water pumps through valve 3 to the heat exchangers in the conditioned space and returned through the condenser to the discharge through valve 4.

Since water is the heat source, it has the same advantages as the water-to-air type. It is frequently used where an adequate water supply is available for a heat source and a hot-water heating system is to be the final product. This system is, however, also adaptable to radiant heating systems.

The four basic heat-pump systems just described have all involved the use of a conventional vapor

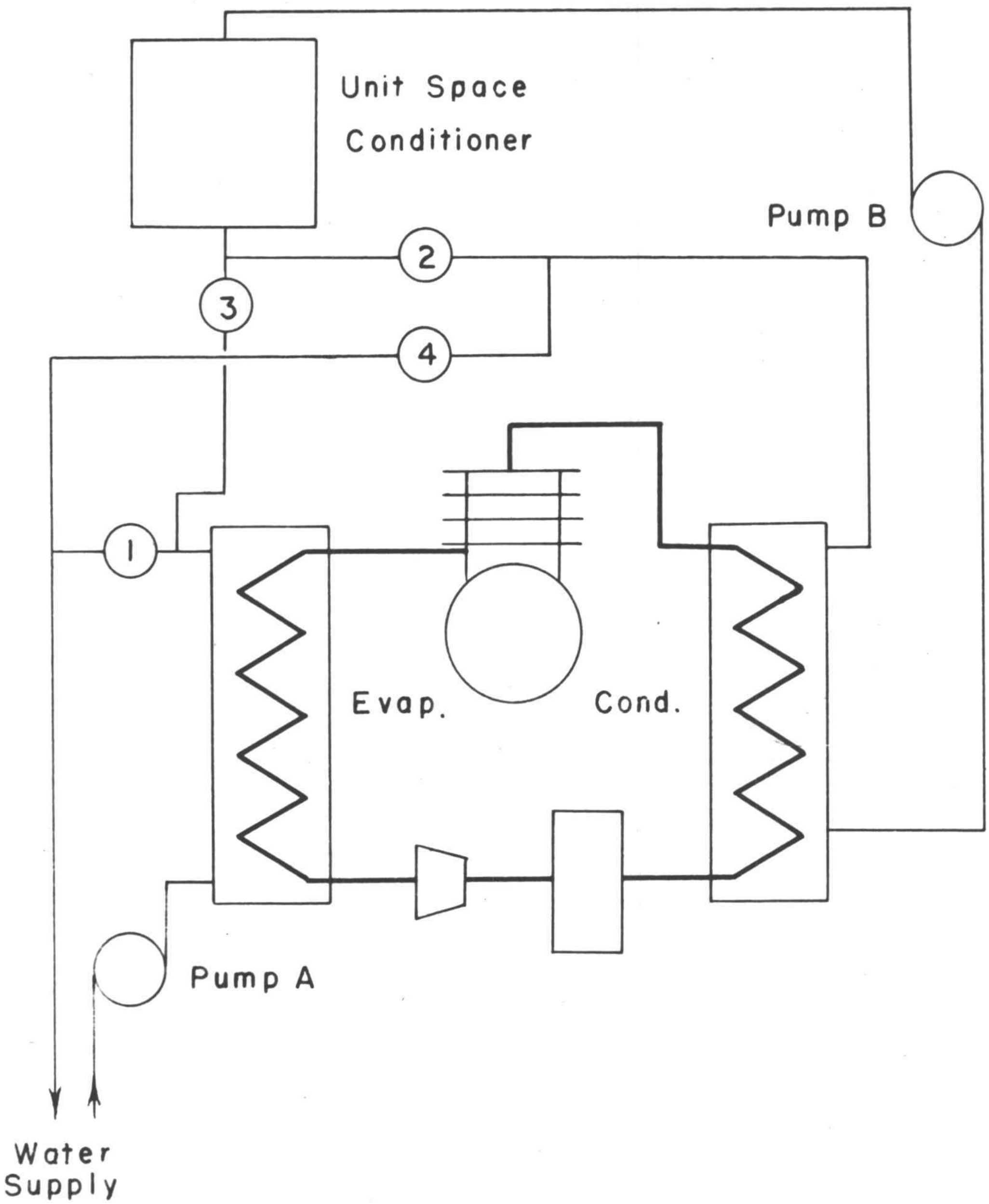

FIG. 9 WATER-TO-WATER SYSTEM

Heating Cycle Valves Open No.s 1&2

Cooling Cycle Valves Open No.s 3&4

compressor which serves as the device for actually pumping the heat. It is possible to use different means of pumping the heat through utilization of the absorption system. Basically the absorption-refrigerant system differs from the vapor-compression system only in the method of compressing the refrigerant. An absorption-heat-pump system would contain, in the place of the compressor, an absorption cycle. The condenser, evaporator, receiver, and expansion valve would be identical with the equipment in a vapor-compression system.

Kemler and Ambrose in their recent book, <u>Heat Pump Applications</u>, (2:122) state,

> The vapor-absorption system operates in principle as follows. The refrigerant vapor after leaving the evaporator is passed to an absorber which contains a solution at low temperature and pressure in which the refrigerant vapor can be absorbed. When the solution has absorbed a considerable quantity of refrigerant vapor, it is passed to a pump called "aqua pump" which raises the pressure of the liquid in which the refrigerant is in solution. This high-pressure liquid is then passed to a generator. Heat is applied to the generator and the refrigerant comes out of solution. Since the solution is at a high pressure, the vapor generated will also be at high pressure. This vapor is then passed to a condenser (as in a conventional vapor-compression heat pump) where it gives up heat and continues around the cycle.

Servel Incorporated, builds a practical absorption system composed of a refrigeration generator, condenser, evaporator, absorber, and liquid heat exchanger. This type of system has no compressor and operates with a coefficient of performance of the order of 1.5. Although this is less than may be obtained with a compressor-type system, the unit has the advantage of having no moving parts except a pump in some cases.

Many variations are possible in the basic systems to increase usefulness and efficiency and to satisfy special requirements. Several of these variations have been added, for purposes of illustration, to the basic air-to-liquid design shown in Figure 7. The operation of the system is the same as previously described but with the addition of four-way valves to simplify the reversing of the circuits; an auxiliary coil to provide heating and cooling simultaneously; and a heat exchanger in the refrigerant line to subcool the refrigerant entering the expansion valve. Reference to Figure 10 shows that the auxiliary coil furnishes cooling during the heating cycle and conversely, when the system is on the cooling cycle, the auxiliary coil will furnish heating. This feature is of considerable benefit in many special applications where both heating and cooling are needed at the same time. The subcooler, operating on refrigerant vapor from the evaporator, removes some of the heat from the hot liquid refrigerant as it comes from

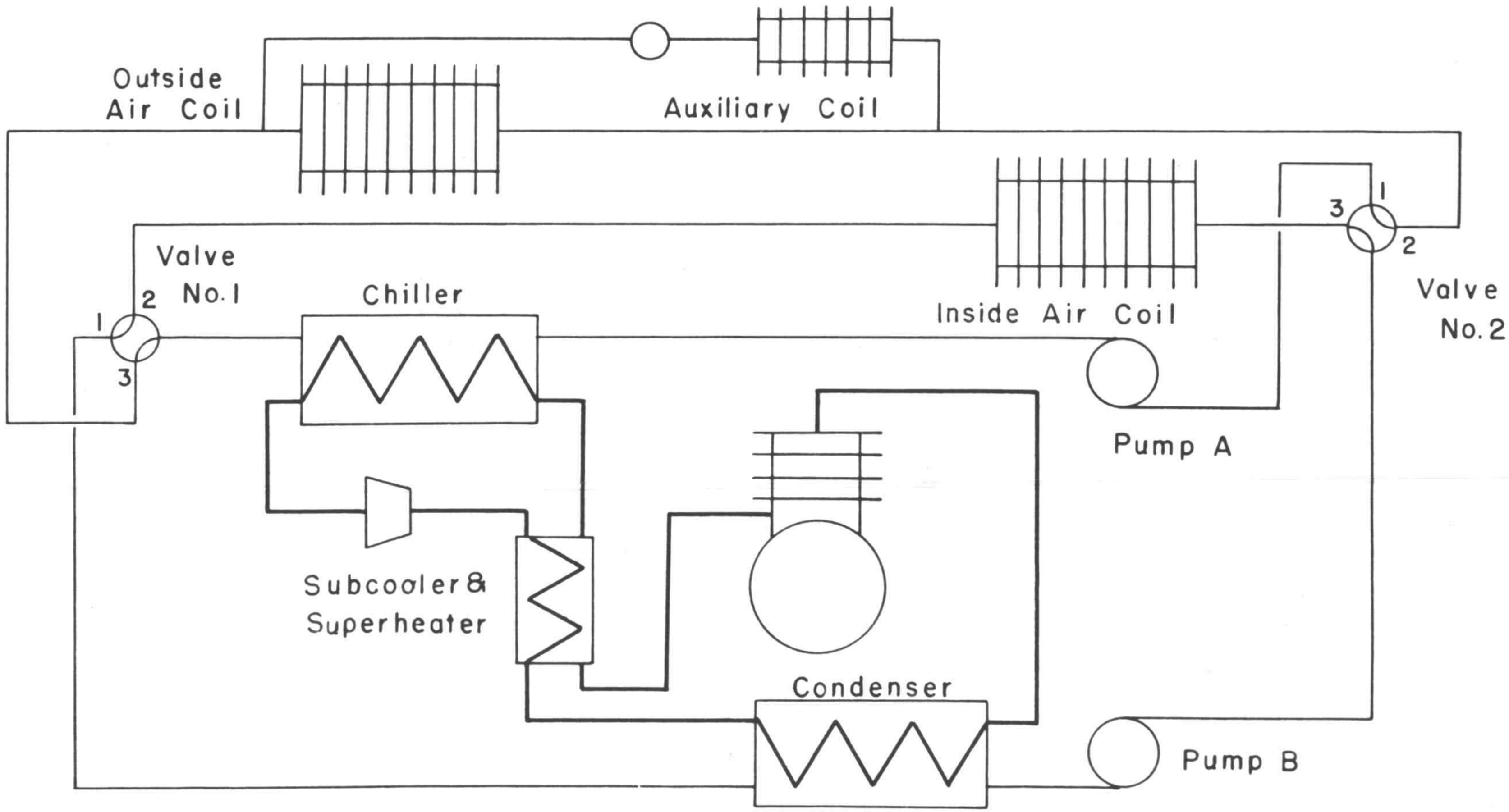

FIG. 10 AIR-TO-LIQUID SYSTEM SHOWING USE OF AN AUXILIARY COIL, SUBCOOLER & SUPERHEATER, & 4-WAY VALVES

Heating Cycle Valves 1 & 2, Position 1 to 2
Cooling Cycle Valves 1 & 2, Position 1 to 3

the condenser. The resulting subcooling effect increases the capacity of the evaporator and improves the coefficient of performance of the system at a slight cost in increased compressor input. The use of four-way valves in this illustration reduces the number of valves necessary to reverse the cycle from eight as shown in Figure 7 to two. This simplification, which can be applied to any of the basic systems, was achieved without a change in the circuit and should result in a saving in equipment and installation cost.

As heat-pump systems reach more advanced stages of development, more additions and variations appear as standard equipment. In addition to those mentioned above, pre-heating coils, precooling coils, humidifying equipment, and capacity modulation are appearing in standard designs.

Combined or auxiliary heat sources are incorporated in many designs, particularly those which use air as the primary heat source. The use of a second source of heat makes it possible to design units of much smaller size and therefore at less cost. The resulting unit operates at design capacity for longer periods of time at higher efficiency and depends upon the second heat source for additional heating when the temperature drops below design conditions.

Electric resistance heating is frequently used as an auxiliary heat source with air-to-air systems. The Southern California Edison Company building in Los Angeles, for instance, has been using this system with considerable success since its installation in 1931.

An excellent example of the design possibilities when an auxiliary heat source is used, is the Westinghouse building in Emeryville, California. In this unit city water is used in conjunction with an air-to-air system operating with a minimum design temperature (without auxiliary heating) of 35 degrees F. This system has been operating since 1939, with a coefficient of performance of five to one.

Another variation from the basic design which is receiving considerable attention in recent designs is the use of two evaporator and two condenser coils. The primary reason for this is that a heat exchanger designed primarily for use as a condenser does not necessarily function efficiently as an evaporator; conversely, a heat-exchange coil designed as an evaporator does not necessarily give good performance when functioning as a condenser.

To eliminate the dual functioning of a heat exchanger, several designs have been developed. One design, used on an air-to-air system similar to that shown in Figure 6, utilizes one evaporator and one condenser in each air duct. The heat exchangers are connected to the refrigerant circuit by suitable valves which control the flow through an evaporator and a condenser designed specifically for its function on each cycle. The drawbacks to this design are the higher cost of using four coils and the increased pressure drop in the air ducts due to air friction.

An alternate plan, also for use with an air-to-air system, is one in which the evaporator and the condenser coils used in each duct have a common set of fins. Such a design is less expensive than one using four separate coils, and the resistance to air flow is not so great. Extra heat transmission is also received by the pipes and extra fin surface of the inactive coil which is attached to the active coil.

Another advantage of the dual-coil system which helps to offset its higher cost is that the second coil in each duct may be placed in operation when design temperatures have been exceeded to take advantage of heating or cooling from a supplementary source.

Package-type Units

At the present time there are several package-type heat pumps being manufactured in sizes up to 10 horsepower for residential use. Development work on an increasing number of models is currently in progress.

The following descriptions of the most prominent commercially-produced units are taken from technical literature (3:77-82) and information supplied by the manufacturers.

Muncie Gear Works of Muncie, Indiana, are manufacturing a heat pump called "Marvair". This unit is an earth-or-water-to-air type. It employs the simplest type of refrigerant circuit consisting of an air and a water heat exchanger, compressor, expansion valve, receiver, and the valves necessary for interchanging the function of the two heat exchangers for summer and winter operation.

The production model of the Marvair unit is made in two housings. One housing contains the air filter and blower and the other unit contains the refrigeration equipment and controls. Ease of installation is given as the primary reason for the division of the unit into two housings.

The heating and cooling cycles are similar to the description previously given of the water-to-air cycle shown in Figure 8.

Control of the Marvair unit is maintained electrically. The general circuit includes a line disconnect and start-stop switch connected ahead of the main contactor. In order to protect the compressor motor, overcurrent trips are provided as well as overpressure and underpressure trips. To protect the water radiator and water pump motor, a water-temperature cutout switch is provided in case some failure of water supply would tend to result in freezing in the evaporator.

Marvair generally employs a closed circulating-water system using the earth as a heat source. This unit can be easiest applied where water from a well can be pumped and wasted. Since this basically utilizes earth heat, coils in a well or other means of picking up heat from the earth are possible. The principal advantage of the closed system as a source of heat is that it can be used in urban developments where water disposal would constitute a serious problem. Since no water is pumped from the ground, there is no effect on the water level and there is no water to be disposed of. The use of chemical inhibitors reduces scaling and corrosion and therefore, operating and maintenance costs.

Marvair is being manufactured in 3, 5, and 7½ horsepower models. The physical characteristics and capacities for the five horsepower unit are as follows: length-40", height-34", width-28", weight-1175#, heating capacity (with 50 degree water) 100,000 btu, cooling capacity (with 75 degree water) 54,000 btu.

Installation costs for the Marvair unit are slightly above the cost of an automatic heating system and an air-conditioning system of conventional design but the company maintains that operating costs are "definitely comparative with other standard types of fuel". A formula recommended by the company for estimating the probable operating cost per year is as follows:

$$\text{Annual Cost} = \frac{(S)\ (D)\ (E)\ (K)}{1000}$$

Where: S = Space to be heated (cubic feet)
D = No. of degree days in ave. heating season
E = Electricity cost ($/KWH)
K = .25 (KWH/degree day/thousand cu. ft.)

Drayer Hanson, Incorporated, of Los Angeles, California, manufactures a heat pump called "Airtopia". This unit is an air-to-air type and is especially adaptable to commercial installations although it may be used in residences, provided sufficient space is available.

Conditioned air is drawn to the unit through a typical return-air system, is filtered, and taken through coils which may be either cold or hot, depending on the cycle called for by the thermostat. The blower above the coils distributes air to the various spaces through a duct system. At the same time, outside air is drawn in and over the outside air coils, which may be either hot or cold (always the opposite of the conditioned-air coils). The outside air blower discharges into a duct leading outdoors at some point away from the intake.

The Airtopia operates on an air-to-air cycle with a fixed air circuit similar in most respects to the circuit diagram shown in Figure 5. The main differences are that switching circuits have been simplified by the use of three-way valves and four coils are used instead of two. The refrigerant flow can therefore be directed to different coils instead of being reversed. This arrangement simplifies the refrigerant switching and allows better design for both the condenser and the evaporator coils. In order to make the unit practical at outside air temperatures down to 10 degrees F., a fresh air preheater has been located immediately behind the fresh air filters. This is a fin coil through which is circulated warm liquid from the receiver. In a typical example, the liquid temperature is reduced 43 degrees F while the fresh air temperature is increased 11 degrees F. The reduction of liquid temperature increases the refrigerating effect of the Freon-12 about 19% per lb., while at the same time, if a 20% fresh air addition is being used, there is an increase of temperature of the mixture of fresh air and return air under the conditioned air coil of 2.2 degrees F. Both of these factors improve the capacity and performance of the unit on the heating cycle. Since the fresh air being brought in during the cooling cycle is likely to be about the same temperature as the warm liquid refrigerant from the receiver, this coil is not used in the cooling cycle.

Dehumidification on the cooling cycle is accomplished by the impingement of the mixture of conditioned air return and fresh air against cold coils. The balance between air mass velocity and evaporator area is such that at high speed the typical relative humidity in the conditioned space is about 50%; slightly higher at half speed (on models having two-speed motor). In most installations the condensed moisture is conducted by a horizontal pipe to a point immediately under the outside air, or condenser coils and the moisture atomized by being picked up by a spinner disc running at motor speed.

When the small particles of water strike the hot condenser surface, they are evaporated and carried away by the updraft of outside air. At the same time, the evaporation tends to cool the coils and reduce condenser temperature and power input to the compressor. On the heating cycle, moisture condensed on the outside air (evaporator) coils is conducted to a point under the conditioned air coils and an identical spinner breaks it up so it can be evaporated into the conditioned air stream, thus raising the relative humidity in the conditioned space, without need of an auxiliary water supply.

This unit is equipped with an automatic defrosting system consisting of a draft gauge connected across the outside-air coil. This gauge closes a contact which shuts down the outside-air fan and changes the system from a heating to a cooling cycle when the frost formation on the outside-air coil increases the pressure drop across it to a predetermined value. The hot refrigerant gas passes through the outside-air coil for a predetermined time and completes the defrosting cycle. This is accomplished automatically, and the unit returns to normal operation after the system is defrosted.

Airtopia units are being manufactured in four sizes, 3, 5, 7½, and 10 horsepower. The dimensions and capacities for the five horsepower unit are as follows: length-82", height-74", width-47", heating capacity (outside air temperature, 30 degrees F) 58,000 Btu/hr., cooling capacity (outside air temperature, 80 degrees F) 63,100 Btu/hr.

The cost of operation of the Airtopia varies considerably and is dependent upon several factors difficult to determine accurately. However, the company has made these general statements regarding costs: In weather requiring nothing but cooling, the cost of operation is substantially that of any other air conditioning system, if proper weight is given to the absence of any cost for condenser water, and the somewhat lower coefficient of performance of an air-cooled machine. In weather requiring nothing but heating, the cost will vary with the difference between 65 degrees F and the actual outside temperature. This agrees with the usual degree-day calculations, and assumes that the night temperatures in the conditioned space will be somewhat lower than those in the daytime.

As a further aid in estimating probable operating costs with an Airtopia unit, the company states that estimates in the Los Angeles area are about 2000 kwh per year per hp; in localities like Bakersfield, California or Phoenix, Arizona, where both summers and winters are more severe, about 3500 kwh per year per hp may be expected. These figures include substantial allowances for both conditioned air blower and outside air blower, and are based on the assumption that the unit is properly sized to the load.

The "Miracula" is a water-to-air heat pump manufactured by General Engineering and Manufacturing Company, St. Louis, Missouri. The cabinet is in baked "Hammerloid" enamel insulated with Fiberglas covered with glass cloth.

One unique feature of the unit is the two-stage compressor which with the motor housing is constructed of aluminum alloy to give lighter weight. The entire unit weighs less than 900 pounds.

The two-stage compressor gives a means of controlling capacity. During periods of high suction temperatures, the unit is operated normally. As the suction temperature decreases, the system is changed to single-stage compression, which results in greater output during periods when additional heat is required. The ground coil recommended by the manufacturers on the basis of their studies and tests consists of about 750 to 1000 feet of 1-1/8 in. O.D. copper tubing for a 5 hp heat pump. The manufacturers recommend that the ground coil installation be made in a trench 6 inches wide, preferably cut by a trench digger. The minimum depth recommended is one foot below the frost line. The trench is filled first with sand to a depth of 6 inches. This maintains good contact with the pipe and then with soil.

Miracula units are available with either manual or automatic change-over from heating to cooling and with thermostats located either in the return-air circuit or in the room. Also available are units using an indirect air-to-air circuit with a ground coil as a supplement.

The units just described represent the commercially produced package-type heat pumps in widest use today. There are, however, a considerable number of companies engaged in development and field-test work and it is highly probable that the majority of these companies will produce units for public consumption in the near future.

Following is a listing, reported recently by Edison Electric Institute, of companies manufacturing packaged heat pump units for commercial or residential use.

COMPANY	LOCATION	TRADENAME
Drayer-Hanson Inc.	Los Angeles, Calif.	Airtopia
Muncie Gear Works	Muncie, Ind.	Marvair
General Engineering & Manufacturing Co.	St. Louis, Mo.	Miracula
York Corp.	York, Pa.	--
Chrysler-Airtemp	Dayton, Ohio	--
General Electric Co.	Bloomfield, N. J.	--
Simpli-Refrigeration Co.	Brawley, Calif.	--
Heat Pump Inc.	Seattle, Wash.	Tempump
Webber Engineering Corp.	Indianapolis, Ind.	Terra Therm
Northwest Heating Co.	Portland, Ore.	Solair
Zimmerman Electric Co.	Paynesville, Minn.	Zim's Fire-less Furnace

Present Installations

The number of installations of residential and commercial heat pump units in this country now numbers in the thousands. Muncie Gear Works announced in November, 1949 that at that time about 1500 Marvair installations were in operation. Add to this the production from the assembly lines at Drayer-Hanson and General Engineering and Manufacturing Company, who have been producing heat pump units for several years, and the total would come to a pretty impressive figure. There is no definite way of knowing how many other units are undergoing field tests and for which little or no information has been released publicly. The total number of heat pump units operating in this country is therefore a matter for conjecture.

It is known definitely, however, that active development and testing of heat pump installations has been going on for the past twenty years and that much valuable data has been gathered with regard to performance and operating costs. Most of this development work has been sponsored by the electric utilities, whose principal interest, quite naturally, is in the increased electric consumption in the homes of the nation with the acceptance and widespread usage of the heat pump.

Hundreds of installations in the offices and buildings of electric utility companies have been in operation for periods in excess of ten years. A study of some of these installations is of interest in that it gives a background for an analysis of current developments. The performance of the installations described can not be used as an index as to the performance to be expected of the newest equipment, since the refrigeration industry has made rapid advances during the past decade. For this reason, a heat pump installation of 1935 would compare with one made today in about the same way that a 1935 model automobile would compare with today's new models.

The heat pump installation of the San Bernardino Commercial Office of the Southern California Edison Company (4:20-36) is of particular interest since it offers comparison between direct electric resistance heating and heating with a heat pump. The office was built in 1927 and heated with direct electric wall heaters. The office was remodeled in May, 1937 but without changing the building's total heat requirements. A 10 hp air-to-air heat pump was installed with a 2 hp fan on both the evaporator and condenser coils. The unit was completely automatic and contained both time and temperature control. In winter, on heating operation, it has satisfactorily replaced the electric heating, reducing maximum demands from 72 kw to 13.85 kw. A comparison of the power requirements during the period of direct electric heating shows an average per month of 35,312 kwh for the 10-year test period. The figures for the heat pump during a similar period showed that 7,088 kwh were used as an average per month during the heating cycle, also measured of a period of about 10 years and under weather conditions very nearly the same. It is the opinion of company engineers, who have made extensive studies of this unit since it's installation, that the system operates with a coefficient of performance in excess of 4 to 1. Another point of interest with respect to this installation is that the standard method of calculating the heating and cooling loads indicated that a 22.5 ton refrigeration plant would be needed. Actually, the 10-ton unit installed has given complete satisfaction to date.

Well water is used as the source of heat in the Salem, New Jersey office building of the Atlantic City Electric Company. Well water at 57 degrees F is pumped through four heat exchangers in series which serve as evaporators during the heating season and as condensers during the cooling season.

The heat pump installation consists of four General Electric single-action refrigeration compressors, condenser, evaporators, well pump, circulating fan, and controls.

During the heating season, heat is picked up from the well water through the evaporator and transferred through separate refrigerant circuits to the condensers where heat is given up to the air stream. All four compressors are in operation during the heating cycle and are staged by separate outside thermostats to improve the overall performance of the system. Two units which together have sufficient capacity for summer cooling, are arranged to operate as a single unit with a reversible refrigerant path. Reversing is accomplished by manually operated valves which change the refrigerant flow making the air coil the evaporator and the water heat exchanger the condenser of the heat pump, and by transferring control of the units from heating to cooling thermostats.

Air is distributed to the conditioned space through a conventional high-speed duct system. Air enters the rooms through high wall registers and returns through baseboard grilles.

The system has an average COP of approximately 3.25 and increases as the outdoor air temperature decreases. This increase is due to the fact that the power required for the water pump motor remains constant over the entire range so the ratio of power required for the well pump to the power required for the compressors decreases with lower outside temperatures.

The system has been in operation for fifteen years and has given excellent results. Maintenance costs have been low and only very minor difficulties were experienced with the refrigerating equipment.

The Whittier, California District Office of the Southern California Edison Company, Ltd., (5:37-40) was constructed in 1936. It is a wood frame structure with 2 inches of mineral wool bat insulation on side walls and ceiling. The conditioned space is 75,300 cubic feet and is handled with a 10 hp, 10-ton Westinghouse compressor. Reversing from cooling to heating is by automatic motor-driven dampers. Control is 100% automatic by means of temperature and the use of a time clock. The observed maximum demand on record is 11.5 kw giving an annual load factor of 24% for year-round air conditioning. It was noted that 2/3 more energy is required to cool the building than to heat it during the months of maximum requirements.

The only performance figures made public concerning this installation were made by students at California Institute of Technology with the cooperation of the company. These test figures, indicating a coefficient of performance of 7.35 were made during very moderate weather when the machine was operating for only a short time. Consequently, it is felt that the results are not entirely accurate and that more tests are needed. Nevertheless, it has been shown that of the company's four district offices (all of which have heat pumps installed) the Whittier installation has the best performance record with reference to operating costs for cooling and for heating.

An unusual installation (5:899-903) was made at the Tidd Plant Control Building of the Ohio Power Company in Brilliant, Ohio. The principal feature of this heat pump installation is the addition of water storage facilities to meet peak demands. Although the use of storage to reduce the size and give improved load factors has been used extensively in commercial refrigeration, it has been used only to a limited extent in connection with year-round air conditioning. For the storage water, a 384 cubic foot tank was installed with a capacity of

1,920,000 Btu based on an 80 degree F temperature drop. The controls are so adjusted that the heat pump will raise the water to 120 degrees F, and a 15 kw electric resistance heater will raise the temperature from 120 to 160 or 180 degrees F as required.

The conditioned air is distributed to the several zones of the building by means of galvanized-iron ducts. The air is returned through grilles, located in the outside walls near the floor (usually underneath the windows), which connect to a horizontal duct below the floor by means of wall chases.

A blow-through type conditioner unit is employed. In this design, the conditioner fan delivers the outside-recirculated air mixture through the filters, then over the conditioner coil, or through the by-pass into one of two plenums. The zone thermostats, by controlling the operation of the two dampers located in the plenums, regulate the temperature of the supply air.

The unit used to absorb the heat from the outside air consists of a coil, fan, and housing. During the heating cycle, the air is taken in from the outside, over the coil where heat is given up to the refrigerant, then discharged by the fan back to the outside. During the cooling cycle, or during the defrosting cycle, the outside coil is used as an air-cooled condenser. The installation operates as an air-to-liquid system with the liquid in this case being water.

The minimum design temperature for the system is 22.3 degrees F. Below this temperature, the heat pump equipment has insufficient capacity to meet the heating requirements, and above this point the heat pump is capable of supplying considerable excess capacity. The purpose of the storage tank, during the heating cycle, is to furnish the heat requirements during those days when the capacity of the heat pump is insufficient. The storage tank is charged with warm water by the heat pump equipment during the periods when excess capacity exists over and above that required for heating the structure.

The load factor on the heat pump system has been improved considerably because of the ability to use equipment of smaller capacity operating for longer periods of time in order to satisfy a given load.

The average coefficient of performance for this unit is 3.5 and it is felt that a material improvement can be made in this figure by some slight modifications and additional testing.

Current Problems

As development work on the heat pump principle progresses, many problems develop which require investigation and research. Following is a list by Kemler and Kulik (6:107-112) of the principal heat pump problems for general study:

1. Heat Source
    a. General advantages and disadvantages of air as heat source
    b. General advantages and disadvantages of earth as heat source
    c. Collection of general information on heat sources
    d. Methods of tapping the earth for heat
    e. Methods of maintaining high thermal conductivity with earth
    f. Analytical studies of heat flow
    g. Design information on heat source equipment
    h. Cost information on heat pickup systems
    i. Study of special heat sources
    j. Performance of earth pickup devices
2. Application Problems
    a. Study of comfort requirements in terms of heat pump operation
    b. Analysis of air distribution systems
    c. Determination of noise and vibration requirements

d. Collection of installation design information

e. Working out of design procedure

f. Collection of performance data

g. Collection of cost data

h. Study of service problems

i. Collection of experience with heat pump installations

j. Study possibilities of applying heat pumps to existing homes

k. General studies on temperatures, velocities, etc., in a home

3. Technical Details

a. Improvement of motor characteristics

b. Development of multiple-way valves for switching

c. Improvement of solenoid valves

d. Development of improved defrosting methods

e. Development of refrigerants

f. Study of electrostatic dust precipitators

g. Study of germicidal lamps

4. Miscellaneous General Problems

a. Study of extreme possibilities of space heating units

b. Analyze in more detail hot water heating

c. Study methods of determining heating requirements

d. Study radiant heating possibilities using heat pump

e. Study humidity-control problems

f. Home designs to take advantage of heat pump

g. Study possible industrial applications

h. Study possibilities of combination units

i. Analyze effect of storage on performance

5. Correlation of Work in Heat Pump Field

Perhaps the most important problem in the heat-pump field is the selection of a universal heat source. Theoretically any source of low-grade heat can be exploited by using the heat-pump principle, since the C.O.P. of the heat-pump cycle is dependent on the temperature of the medium and is not affected by the type or kind of heat source employed.

An ideal heat source is one which is abundant and inexpensive with an average temperature of 40 to 80 degrees F the year round. Outdoor air, earth and water from wells, lakes and rivers may meet the requirement.

Outside air offers a universal heat source in locations where the minimum temperatures are not too low or of too long duration, and where means can be found to offset the resulting loss of capacity caused by extremely low and wide fluctuations in daily temperatures. The main disadvantages of using air as the heat source are: (1) As the air temperature drops the heating demand increases, and (2) as the temperature falls below 32 degrees F, frosting of the heat-absorbing coils is threatened. These disadvantages may be offset by incorporating an auxiliary heat source or a storage tank in the design and by providing a method of defrosting.

Well water temperature is fairly constant year round and would be an ideal universal heat source if it were chemically satisfactory and if it could be obtained at a low cost. Unfortunately there is always the uncertainty of finding water at any given location and the cost of drilling and the maintenance involved in the use of water further detract from its use in many places. Also, the disposal of the water after its use may constitute a serious practical problem. In many locations it may be found that due to the cost of drilling a well or the cost of obtaining suitable water, one of the other heat sources will be more practical.

The earth offers excellent possibilities as a heat source but considerably more data are necessary before this heat source can be evaluated properly. Several universities, manufacturers, and national engineering societies (7:313-317) are investigating the ground as a heat source. Actual installations have been in operation for several years to determine the transfer coefficients for different types of soil and at the same time obtain some knowledge on the cost and performance of the systems. Information published to date indicates that the conductivity of heat directly to and from the soil is quite variable because of the wide range of climatic conditions and geological formations found throughout the country. The heat loss conductivity coefficients in Btu per hour per degree F per sq ft per ft of depth which have been compiled for buried pipe lines indicate a range from 0.14 for dry white sand to 2.62 for a very wet soil.

In spite of its limitations and the lack of adequate knowledge of heat transfer characteristics of various soils, it is the opinion of C. H. Coogan, Jr. of University of Connecticut (8:49), who has worked on various aspects of the heat-pump problem for the past several years, that "The ground coil appears feasible and most favorable for use as a heat source for residential heating in New England."

The use of the earth as a heat source has met with favor in the Midwest where it is used extensively in package-type residential installations and in larger commercial and industrial applications. In the West-coastal area, however, experience with earth as a heat source has not been so favorable. W. E. Gordon of the Portland General Electric Company reported to the members of the AIEE at the Pacific general meeting in August, 1949 (9:881), that as a result of two years of experience with the heat pump in the Pacific Northwest, ground coils should not be used if there is another heat source available. U. G. Smith, a heating and ventilating contractor of Portland, who has had considerable experience with the installation of heat pumps, maintains (10:70) that the greatest application problems occur in heat pump installations where the ground coil is used as the only heat source.

In most areas of the Far West, Southwest, and South, air is used as a source of heat almost exclusively. Mild weather with few extremes in temperature makes this universal heat source practical in these areas.

Second only to that of heat sources is the problem of high initial cost. A survey of heat pump manufacturers and companies or organizations which have worked on heat pump problems shows that the equipment and installation costs on present-day heat pump installations are a major factor in holding back acceptance of the heat pump by the general public.

The equipment and installation cost of a heat pump is often compared directly with the cost of a conventional heating system. This does not give an accurate indication since the heat pump provides both heating and cooling in an automatic year-round air conditioning system, whereas the conventional system supplies winter heating only. The heat pump, even now, compares quite favorably in cost with a conventional heating system plus a cooling system.

The application of mass-production methods, particularly in the manufacture of package-type units will materially reduce the initial cost of equipment. Developments in the research organizations, refinements in design, and the benefits of actual experience have already had an appreciable effect in lowering installation costs.

A good indication of the present costs of equipment and installation may be gained from the report of the American Gas and Electric Service Corporation of New York. Their report in February, 1950 was a result of an investigation of 15 residential heat pump installations. The average manufacturer's price of equipment for the 3 hp system is $1500 and for the 5 hp system, $1700. This price does not include any installation cost or the cost of the transfer surface for the heat source. The equipment installation cost is quite variable and should average about $200 per installation. The cost for the heat source would probably add another $300 for the 3 hp system and $500 for the 5 hp system, giving a total (without overhead or profit) of $2000 for the 3 hp system and $2400 for the 5 hp system. Adding a 20% mark-up for overhead and profit, the customer's price would probably be about $2400 for the 3 hp system and $2880 for the 5 hp system.

In a paper presented by W. W. McMillan before the Southern Electric Exchange in October, 1949, it was stated that the Marvair 3 hp unit is being sold in the Jacksonville, Florida area, completely installed for $1400 to $1700. This price includes a well, pump, ductwork, necessary wiring and plumbing. The 5 hp unit in that area is being sold for $2500 completely installed, plus $500 for ductwork, making a total for the complete installation of $3000.

The cost of operating and maintaining a heat pump installation is in most cases competitive with other types of fuel. Service life, dependability, and maintenance compare, roughly, with an oversized home refrigerator. Operation costs in comparison with other common fuels are shown in the following table.

ENERGY COSTS OF VARIOUS HEATING METHODS

(Fuel burning efficiencies taken as 0.60)

Method of Heating	Cost $/Unit	Cost, $ per Million Btu
Electrical resistance	.02 per kwh	5.87
Electrical resistance	.01 per kwh	2.94
Artificial gas, 550 Btu/cu ft	.70/1000 cu ft	2.12
Heat pump, COP of 3	.02 per kwh	1.96
Artificial gas, 550 Btu/cu ft	.60/1000 cu ft	1.82
Heat pump, COP of 4	.02 per kwh	1.47
Oil, 140,000 Btu/gal	.12 per gal	1.43
Oil, 140,000 Btu/gal	.10 per gal	1.19
Heat pump, COP of 5	.02 per kwh	1.17
Coal, 12,000 Btu/lb	15.00 per ton	1.04
Heat pump, COP of 3	.01 per kwh	.98
Heat pump, COP of 6	.02 per kwh	.98
Oil, 140,000 Btu/gal	.08 per gal	.95
Natural gas, 900 Btu/cu ft	.50/1000 cu ft	.93
Natural gas, 900 Btu/cu ft	.40/1000 cu ft	.74
Heat pump, COP of 4	.01 per kwh	.74
Coal, 12,000 Btu/lb	10.00 per ton	.69
Heat pump, COP of 5	.01 per kwh	.59
Heat pump, COP of 6	.01 per kwh	.49

FUTURE

Mechanical Improvements

During the last few years there have been many developments which have changed the outlook for the heat pump. From the mechanical side are improved refrigeration compressors. The trend has been toward centrifugal and rotary compressors, rather than just improving on the reciprocating type. Higher operating speeds make it possible to build machines which are much smaller than previous units. There have been developed hermetically sealed compressor units of a capacity readily adaptable to the size of heat pump which will fit the average five and six room house, and for which there will be the largest sale.

Heat transfer surfaces have undergone considerable development and designs are being produced at present, which will materially reduce the weight and size of the heat exchangers which form so important a part of the heat pump.

Improvements can most certainly be expected in the field of heat pump accessories and controls. A trend is already evident toward the use of such efficiency-improving devices as: pre-cooling coils, pre-heating coils, and dual heat exchangers. Further improvements in the system include: auxiliary coils, supplementary heating, three and four-way automatic valves, capacity modulation, improved filtering, humidifying and dehumidifying devices, and highly sensitive electric and pneumatic controls.

<u>Research in Progress</u>

Research work in the heat pump field received its first large-scale backing from the electric utilities. These companies are responsible for most of the early progress and are still very active in the field.

The Southeastern Electric Exchange, composed of a group of electric utilities in the southeastern part of the United States, have employed the Southern Research Institute for the past several years to conduct basic research in the heat pump field. This organization did much of the early work in gathering and disseminating information. The American Gas and Electric Service Corporation, in cooperation with other utilities, has contacted interested manufacturers and has prepared tentative specifications to be used by the manufacturers for the design and development of equipment. Recommendations were made to the industry by an informal group representing interested utilities to create a coordinating committee which would encourage research and development. The result was the formation of the Joint AEIC-EEI Heat Pump Committee composed of members of the Association of Edison Illuminating Companies and The Edison Electric Institute.

In addition to the activities of the electric utilities, there is a rapidly expanding interest in heat pump development on the part of universities, private research organizations, and manufacturers.

Research under way at the present time covers a wide range of subjects related to the heat pump principle. For instance, with respect to heat sources, investigations are being made of the feasibility of combining solar heating, radiant heating, and the heat pump (11:86). The use of heat storage either in water or special chemicals is being tested in order to take advantage of cheaper electrical rates during off-peak load periods. Experimentation is also under way with ground coils coated with water absorbing compounds which may make it possible to make use of the heat of fusion of water, thereby making available vast quantities of low-temperature heat.

The subject of heat pump cycles has not remained centered around the vapor compression cycle used almost exclusively today. Attempts are being made to bring within practical limits, the air cycle and the water cycle. The principal advantage of these cycles is the fact that they are the only really safe refrigerants discovered to date.

The rapid growth of the air conditioning field has brought new efforts toward developing the steam-jet refrigeration principle which is very economical where a cheap source of steam is available. Servel Inc. has developed a heat pump using the absorption refrigeration principle which shows definite promise.

Another promising heat pump application, now in the experimental stage, is the invention of a young Chicago engineer, Norman C. Powers. His device (12:108-111) is an unusual type of warm air furnace which includes a heat pump activated by a revolutionary type of refrigerator compressor. The compressor, called a thermo-syphon jet unit, enables the furnace to deliver more heat in the form of warm air or warm water than is put into the furnace by the conventional fuel burning boiler, which can be designed to burn any fuel. The additional heat is removed by the heat pump from outside air or water.

Potentialities

The heat pump offers to the homeowner for the first time an electrically powered, automatic, year-round comfort producing machine. This type of electrical, automatic comfort is not practical in any other way. It can only be approximated by a heating system plus a cooling system. The heat pump offers a type of heating which is not otherwise generally available, that is, combustionless heat. The complete elimination of combustion with all its unsatisfactory characteristics such as dust, dirt, smoke, explosion and fire hazards, makes the heat pump an unusually attractive type of heating for the home, as well as for commercial establishments. The heat pump also gives cooling with the same equipment. This means that the heat pump has a decided economic advantage from an investment point of view. The cooling function as performed by the heat pump again offers to the homeowner something which has not been obtainable up to the present time. One of the important developments which manufacturers of heat pumps have made is that of making the operation of the system completely automatic. The equipment heats or cools as dictated by the thermostat without attention by the homeowner with no valves to turn, no switches to remember to turn on or off, or ashes or clinkers to carry, etc.

There is every indication through precustomer acceptance and in the intense general interest that the heat pump will offer to the manufacturing industry an extensive market. The package-type unit offers itself to assembly-line production on a mass production scale. Being package-type equipment, it offers many advantages to the dealer from the standpoint of both installation and servicing. The package-type heat pump has a place in the general air-conditioning field and appears to offer many advantages over the two-plant system for year-round installations. All these factors add up to making the heat pump appear to be a very desirable product from manufacturing, distribution, and selling points.

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