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# HEAT PUMPS: SUBSTITUTES FOR OUTMODED FOSSIL-FUELED SYSTEMS

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# HEAT PUMPS: SUBSTITUTES FOR OUTMODED FOSSIL-FUELED SYSTEMS

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## SECTION I

## INTRODUCTION

Clean burning premium fuels such as natural gas and distillate oil No. 2 are marketed primarily as combustion fuels in the commercial and residential sector in the United States. This extensive use of premium fuels is at the expense of the most abundant energy sources in the United States, bituminous coal, oil shale and some lignite. Modern combustion technology has now progressed to the point where these "dirtier" fuels can be used efficiently as boiler fuels with the use of modern fuel processing and stack-gas cleaning technologies (i.e., wet scrubbers, dry scrubbers and catalytic oxidation) to reduce the pollutant emissions to such a level as to be competitive with the "premium" fuels.

In order to reduce significantly the demand for clean premium fuels by the major consumers, the more abundant fuels can be used for generating electrical energy to be supplied as a clean energy source in the commerical and residential sector. Consideration of this means of reducing the demand for clean premium fuels should be included in all future discussions of an Energy Program by the U. S. Government. The potential benefits that might result from the primary use of electrical energy by the commercial and residential sector are that the premium fuels can then be used in energy demand areas which are not amenable to fuel substitution and in the manufacture of chemicals and fertilizer where feed stock shortages already exist. Also, the conversion of outmoded "premium" fossil fuel heating systems to heat pumps in the residential and commercial sector where the electricity is generated by steam coal or nuclear power plants may significantly reduce our national consumption of scarce natural gas and fuel oil.

An independent assessment has been made of the state of the art relative to the development, capacity, adequacy and application of the heat pump as a potential replacement for fossil-fueled equipment designed to serve in the space heating and cooling mode. A projection has been made of the rate at which heat pumps could be manufactured, supplied, and installed in the commercial and residential sector as replacements for for outmoded fossil fueled equipment whose service life has been exhausted and is scheduled for replacement.

SECTION II

## BASIC HEAT PUMP CONCEPTS AND COMPONENTS

The key components of a heat pump system are shown in Figure 2-1. The main function of the compressor is to pump a refrigerant vapor from a relatively low suction pressure to a higher head pressure. The suction and head pressures that a compressor experiences are a function of the design, the ambient temperatures, and possible abnormal fault situations which develop during the life of a heat pump system.

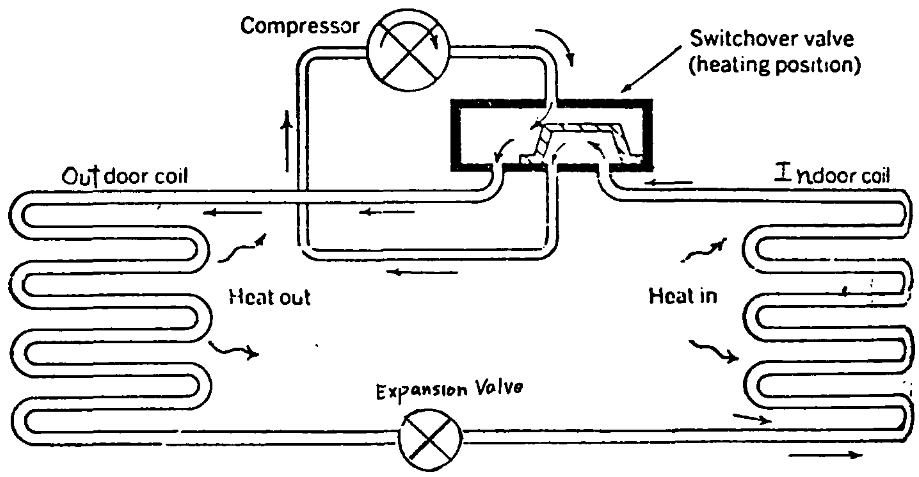



Figure 2-1 - Simplified Heat Pump Flow Diagram in Cooling Mode Showing Use of Switchover Valve to Reverse Flow of Refrigerant

Under cooling conditions, the refrigerant is pumped from the compressor through the condenser or outdoor coil. Upon leaving the outdoor coil in liquid form, the refrigerant travels through the evaporator or indoor coil, and here, as it changes from a liquid into a gas, it removes heat from the interior, thereby cooling the indoor coil. The gas is then drawn back into the compressor where it is compressed again into a very-high-pressure hot gas, which is liquefied or condensed in the outdoor coil.

The first heat pumps were more or less simplified versions of this cooling unit, and were obtained by merely reversing the flow of refrigerant as shown in Figure 2-1. With the aid of a switchover valve, the outdoor condensing unit became, in essence, the evaporator, and the indoor evaporator became in essence, the condensing unit. The hot gas, therefore, was pumped indoors, where it gave off heat as it was condensed into a liquid in the indoor section. The liquid was then pumped into the outdoor section now the evaporator where the refrigerant changed back into a gas, absorbing heat during this process from outdoor air.

The four basic heat pump designs for space heating and cooling employ: (1) air as the heat source-sink and air as the heating and cooling medium; (2) air as the heat source-sink and water as the heating and cooling medium; (3) water as heat source-sink and air as the heating and cooling medium; or (4) water as heat source-sink and water as the heating and cooling medium.

Each of these basic designs can supply the required heating and cooling effect by changing the direction of the refrigerant flow, or by maintaining a fixed refrigerant circuit and changing the direction of the heat source-sink media. A third alternative is to incorporate an intermediate transfer fluid in the design. In this case the direction of the fluid is changed to obtain heating or cooling and both the refrigerant and heat source-sink circuits are fixed. The fixed refrigerant circuit designs, generally referred to as the indirect type of application, are becoming increasingly popular, particularly in the larger capacities.

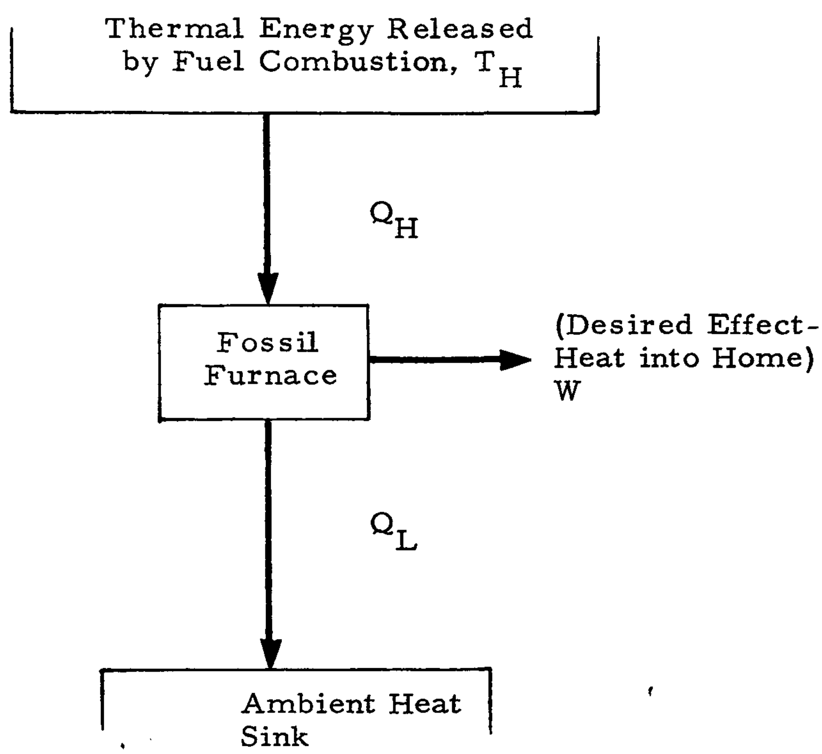
The basic designs are quite flexible and are readily adaptable to a number of different types of applications. Flow diagrams, together with a brief description, are given for some of the more typical arrangements in Appendix A (Ref. 1).

It is easy to confuse the heat pump coefficient of performance (COP) with efficiency (Eff) since they both represent an index of performance of a cycle. Efficiency is defined as the desired effect divided by the energy required to produce the desired effect. For a fossil furnace as shown in Figure 2-2, the efficiency is

$$\text{Eff} = \frac{W}{Q_H} \times 100\% < 100\%$$

Classically, the efficiency is less than 100%. However for a heat pump operating on the Brayton cycle, the index of performance is the COP which can be greater than 100%. In the heating cycle the $COP_h$ of the heat pump is, by definition, the desired effect (heat into the home, $Q_H$) divided by the energy required to produce the desired effect (electrical input — W) as shown in Figure 2-3 or

$$COP_h = \frac{Q_H}{W} \times 100\% > 100\%.$$



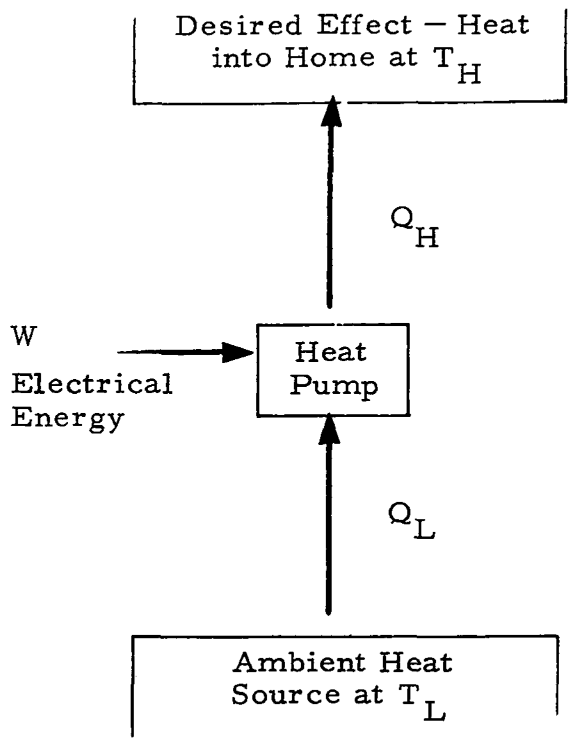

$$\text{Efficiency} = \frac{W}{Q_H} \times 100\% < 100$$

$$\text{Since } W = Q_H - Q_L$$

Figure 2-2 - Efficiency

For the cooling cycle, the heat pump $COP_c$ is defined as the desired effect (heat removal from the home, $Q_L$) divided by the energy required to produce the desired effect (electrical input — W) as shown in Figure 2-4 or

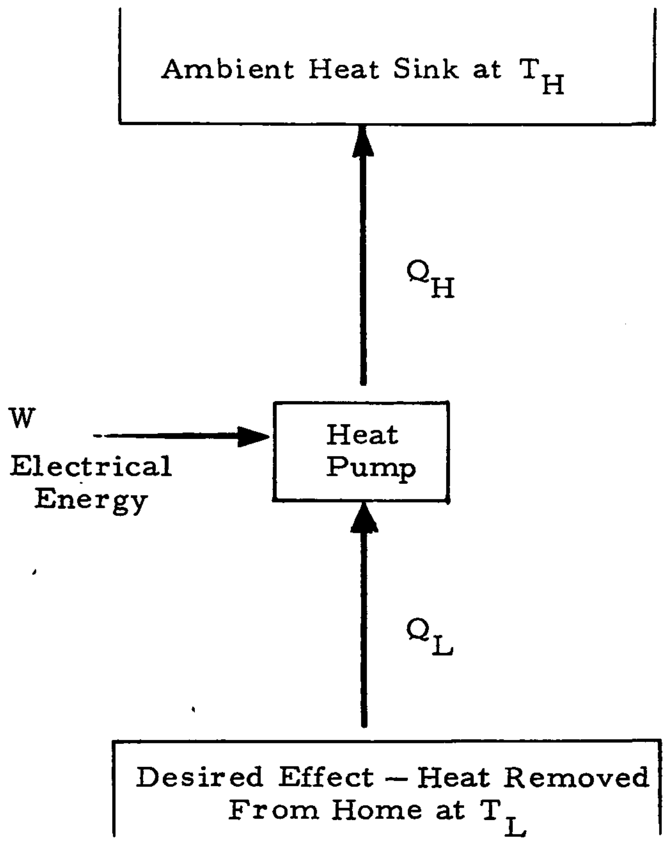
$$COP_c = \frac{Q_L}{W} \times 100\%$$




$$COP_h = \frac{Q_H}{W} \times 100\% > 100\%$$

Since $Q_H = W + Q_L$

Figure 2-3 - Coefficient of Performance ($COP_h$), Heating Mode




$$COP_c = \frac{Q_L}{W} \times 100\%$$

where

$$Q_L = Q_H - W$$

Figure 2-4 - Coefficient of Performance ($COP_c$), Cooling Mode

Efficiency normally refers to the transfer of energy from a high temperature ($T_H$) source (fuel) to a low temperature ($T_L$) receiver whereas COP refers to the transfer of energy from a low temperature ($T_L$) source to a high temperature ($T_H$) receiver to produce a desired effect.

SECTION III

# CURRENT SYSTEMS

## 3.1 CAPACITY

There are many companies which produce quality heat pumps for both residential and commercial applications. The Air-Conditioning and Refrigeration Institute lists 32 participants in their Directory of Certification, January 1 through June 30, 1976 (Ref. 2). The heat pump manufacturers offer a complete range of heat pump sizes from small residential units (i. e., less than 5 tons = 60,000 Btuh cooling) to large commercial systems (i.e., greater than 500,000 Btuh cooling). Larger systems may be designed by utilizing multiple units. A few of the largest manufacturers of heat pumps are the Trane Company, General Electric, Lennox Industries and Carrier. There are many other small companies which manufacture heat pumps only for the residential market (i.e., less than 5 tons).

## 3.2 ADEQUACY AND APPLICATION IN THE COMMERCIAL AND RESIDENTIAL SECTOR

When sized properly for the particular application, heat pump systems have performed adequately in both the residential and commercial sectors since the middle 1960s. Heat pumps have been available for residential application since the early 1950s. Based on its concept and efficiency, the heat pump was an immediate success in 1950. History can be simplified by stating that the heat pump was marketed before it was sufficiently developed. It failed from the reliability standpoint during the 1950s. The compressor, the key component of the heat pump, was not designed to withstand the high head and suction pressure which can result during conditions of switchover, high ambient temperatures and possible abnormal fault conditions. These conditions require high electrical input resulting in high mechanical stresses in bearings, crankshafts, and valves producing early compressor failure. By the early 1960s, recognition of these problems resulted in compressor redesign, high and low pressure cutoff switches and other protective devices for heat pump systems. With many more improvements, today's heat pump systems are as reliable as the fossil fuel heat systems with electric air conditioning as shown in Figure 3-1 (Ref. 3).

The future acceptance of heat pumps for both industrial and residential applications depends on the total annual cost to own and operate a heat pump system relative to other systems as discussed in Section V. Current residential heat pump systems are competitive only when used as a total space comfort conditioning system.

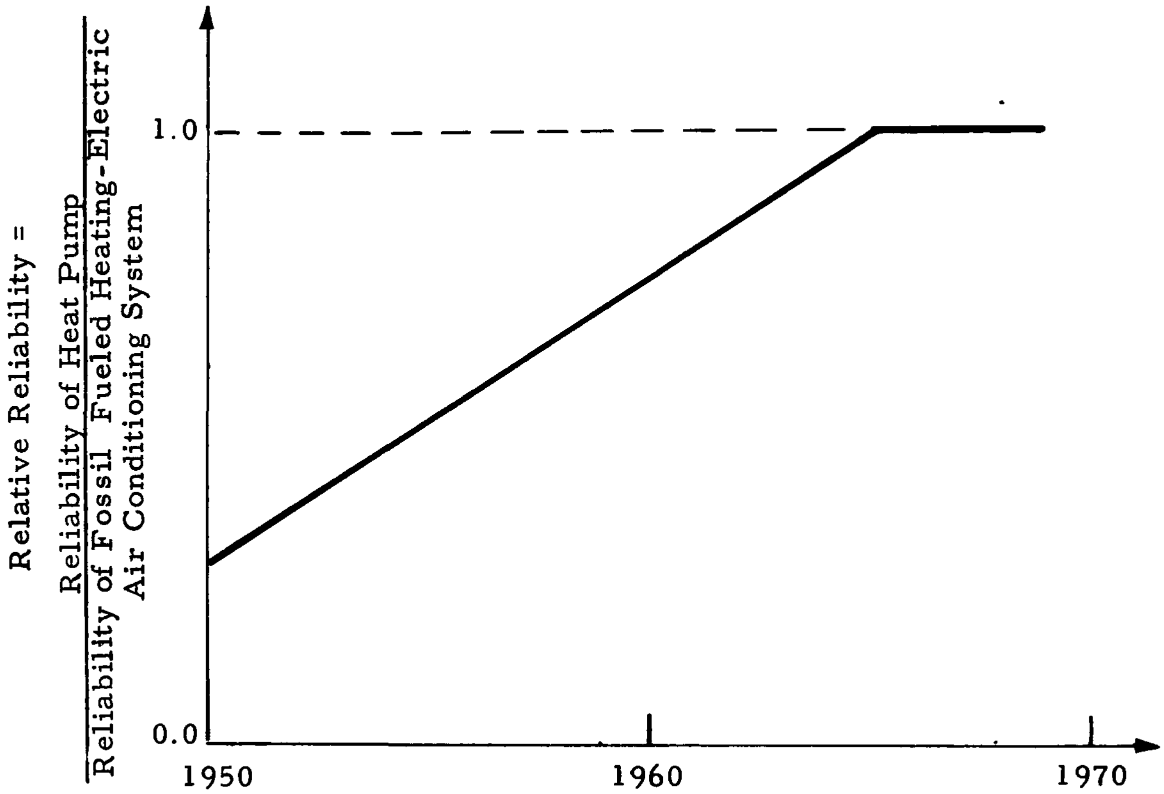



Figure 3-1 - Relative Reliability of Today's Heat Pump Systems

All residential heat pump systems utilize the atmosphere as a heat source/sink. However in large industrial applications, improved efficiencies may be obtained by combining the heat pump with a chilled water system or other secondary heat transfer mediums (Refs. 3 and 4). In these applications the heat pump may have a significant economic advantage over fossil fueled/electric air conditioning systems. The orientation and relative amounts of perimeter and internal areas now being used in the modern office buildings, department stores, and commercial structures, together with accompanying internal heat gains from lights, people, and heat producing equipment are major influencing factors in the proper selection of air conditioning systems. To provide indoor comfort, the air conditioning system may be called upon simultaneously to furnish heating to the exterior zones and cooling to the interior, even on the coldest winter day.

The heat pump, because of its many inherent design features, is readily adaptable to such applications. In many instances the cooling effect supplied to the internal areas by the heat pump can be made to serve as the heat source for the heat delivered to the exterior areas. Also, reheat can be furnished at the same time to maintain a closer control of relative humidity. In contrast, it is often necessary with other types of air conditioning systems to reject the condenser heat to the outside when cooling is required in the internal areas, and to provide heat from another source for the reheat cycle and for the perimeter areas. This latter method of heating and cooling can add considerably to the operating cost.

Water can be used as the heat source-sink and as the medium to provide simultaneous heating and cooling to the conditioned space. In this arrangement the refrigerant flow is always in the same direction, going from the compressor to the condenser, then to the cooler. The major refrigerant components together with all refrigerant piping and accessories can be purchased as a compact package with a hermetically sealed refrigerant circuit. The hot and cold water piping, the indirect and cooling surfaces, and other needed accessories for a particular installation can, in turn, be installed by the contractor

During a considerable portion of the year the heating and cooling requirements of the structure may be in balance, so that an external heat source or sink is not required. Thus, the heat removed from the zones requiring cooling is automatically transferred to the condenser circuit and made available to the zones requiring heat. In this way the coefficient of performance is materially improved to give a considerable saving in operating cost.

Figure 3-2 (Ref. 1) illustrates how simultaneous heating and cooling are readily available at all times. For the basic heating cycle, valves are positioned to path 1-3 to provide two water circuits. Pump 1 circulates the warm water through the condenser-liquid receiver, valves A, the conditioner coils, and valves B in a closed loop. Pump 2 circulates the cold water through the cooler, valve D, the exchanger (where heat is taken from the well water), and valve E back to pump 2 to repeat the cycle.

For the basic cooling cycle, valves are positioned to path 1-2. Pump 1 circulates the warm water through the condenser, valve E, the exchanger (where heat is rejected to the well water), and valve D back to pump 1. Pump 2 circulates the cold water through the cooler (where heat is taken from the water by the refrigerant), valves A, the conditioner coil, and valves B back to pump 2 in a closed loop.

During the intermediate cycle, simultaneous heating and cooling are provided by modulating valves D and E to maintain the desired temperatures in the two circuits. Usually, during this cycle the water is maintained at 100 to 120 F in the condenser circuit and 45 to 50 F in the chiller circuit. The excess heating and cooling are rejected from the exchanger to the well water. The well water can be supplied directly to the condenser and chiller circuits instead of through the heat exchanger, as indicated. The direct use of the well water is most attractive, provided it is chemically acceptable and does not unduly contaminate the heat transfer surfaces.

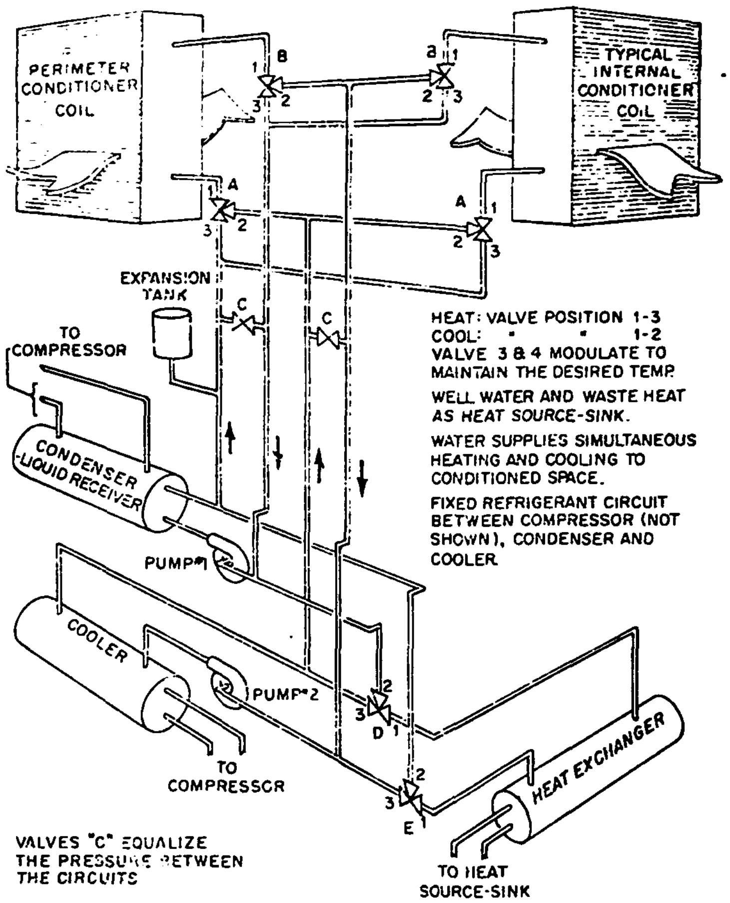



Figure 3-2 - Water as Heat Source-Sink and Water as the Medium to to Provide Simultaneous Heating and Cooling (Fixed Refrigerant Circuit — Water Flow Reversed)

The compressor (not shown) delivers the hot compressed gas to the condensed-liquid receiver where it is liquefied, giving up its latent heat of condensation to the circulating water. From the condenser the liquid refrigerant flows through an expansion valve to the cooler (where it changes into a gas), absorbing the heat of vaporization by reducing the temperature of the circulating water, and then returns to the compressor.

The heat pump system can be a versatile cooling system and is cleaner and as quiet as comparable fossil fueled systems but the heat pump system may require more maintenance (see Section V).

## SECTION IV

## POTENTIAL OF HEAT PUMP TO REPLACE FOSSIL FUELED EQUIPMENT

If air conditioning is not necessary, a heat pump heating system is not competitive with a comparable fossil fueled heating system based on capital cost and operating cost. Therefore, only the total space comfort-conditioning concept will be considered in the subsequent discussion.

### 4.1 NEW SYSTEMS

Utilization of the heat pump system is most economical when the system is designed as the initial space comfort-conditioning system in the new home or the new commercial facility. Once the decision to utilize electric air conditioning has been made, the decision to use a heat pump system over a fossil fueled/electric air conditioning system can be made by considering the total annual cost of each system, the availability of fuel, the dynamics of the fossil-fueled/electric price ratio and the climate (which affects both the amount of heating and cooling required and the efficiency of the system) (Refs. 1, 5). (See Section V for economic analysis.)

### 4.2 IN PLACE OF OUTMODED FOSSIL HEATING/ELECTRIC AIR CONDITIONING SYSTEMS

In discussions with heating and air conditioning contractors, there are many factors to consider in replacing an outmoded fossil fueled heating/air conditioning system with a heat pump system.

If the air circulation system already exists, installation of the heat pump can be very competitive with replacing the outmoded system. However, if the air handling system does not exist, installation can be very difficult and expensive.

In many cases, either the outmoded fossil fueled heating system or the electric air conditioning system may need replacing but not both. It may be difficult to justify the capital expense of a heat pump system as opposed to replacing only the fossil fueled furnace or an electric air conditioner.

If a home or business was wired initially for a fossil fueled heating system, a heat pump system requires an additional electrical load which may necessitate the additional expense of rewiring.

Thus heat pump retrofit is most attractive if the air handling system is already in place and both the fossil fueled heating and electric air conditioning systems need replacement.

## SECTION V

## ECONOMIC COMPARISON OF HEAT PUMPS WITH FOSSIL FUELED SYSTEMS

The heat pump should only be sold under the aegis of a total-space comfort-conditioning concept. The heat pump system can be economical except when air conditioning is excluded. In that case, the total annual cost of owning and operating a heat pump system will be higher than that of a gas fired heating system without air conditioning, thus making the heat pump unattractive economically to the homeowner.

To the average homeowner paying 3¢/kWhr for electricity but only 0.82¢/kWhr for gas, the fact that electricity can be competitive with gas for space heating is difficult to accept. The disparity between the two seems even greater when the higher installation and maintenance costs of the heat pump are considered. However, there are several other factors in an electric/gas cost analysis that, more often than not, offset the basic cost differential. Among them are special rates for space heating and water heating, the decision to use electric air conditioning, and the dynamics of the relative gas/electric price ratio where the price of gas has grown faster than that of electricity. With a worsening of the gas shortage, escalation in gas prices is likely to continue.

An economic analysis was made by Lockheed-Huntsville comparing the heat pump, gas fired and oil fired furnaces with electric air conditioning on the total-space comfort-conditioning concept. Equipment efficiencies assumed are: gas fired furnace, 45%; oil fired furnace, 45%; electric air-conditioning, 300%. The heating value of natural gas was assumed to be 1000 Btu/ft$^3$. Figure 5-1 shows the result of economic comparison of the heat pump and the gas fired furnace. The current retail cost of natural gas for residential use is about 24¢/therm (equal to .82 ¢/kWhr) and for electricity is about 3¢/kWhr giving a unit energy cost difference ratio of 8. At an energy cost difference ratio of 8 (see dashed lines in Figure 5-1), the heat pump is more expensive to operate by about 25% for a coefficient of performance (COP) of 3. However, if electric rates increase by 1.5 and gas rates triple by 1980 as forecast (Refs. 6 and 7), the heat pump will be more economical than the gas fired furnace as shown in Figure 5-1. Figure 5-2 shows the results of a comparison of the heat pump and an oil fired furnace burning No. 2 fuel oil with a heating value of 140,000 Btu/gal. The current retail cost of No. 2 oil is about 39¢/gal and 3¢/kWhr for electricity giving a unit energy cost ratio of 13. If the cost of electricity increased by 1.5 and the cost of No. 2 fuel oil triples by 1980 (Refs. 7, 8), the heat pump will be more economical on a total space-comfort conditioning concept. Figures 5-1 and 5-2 do not account for captial cost, depreciation and maintenance.

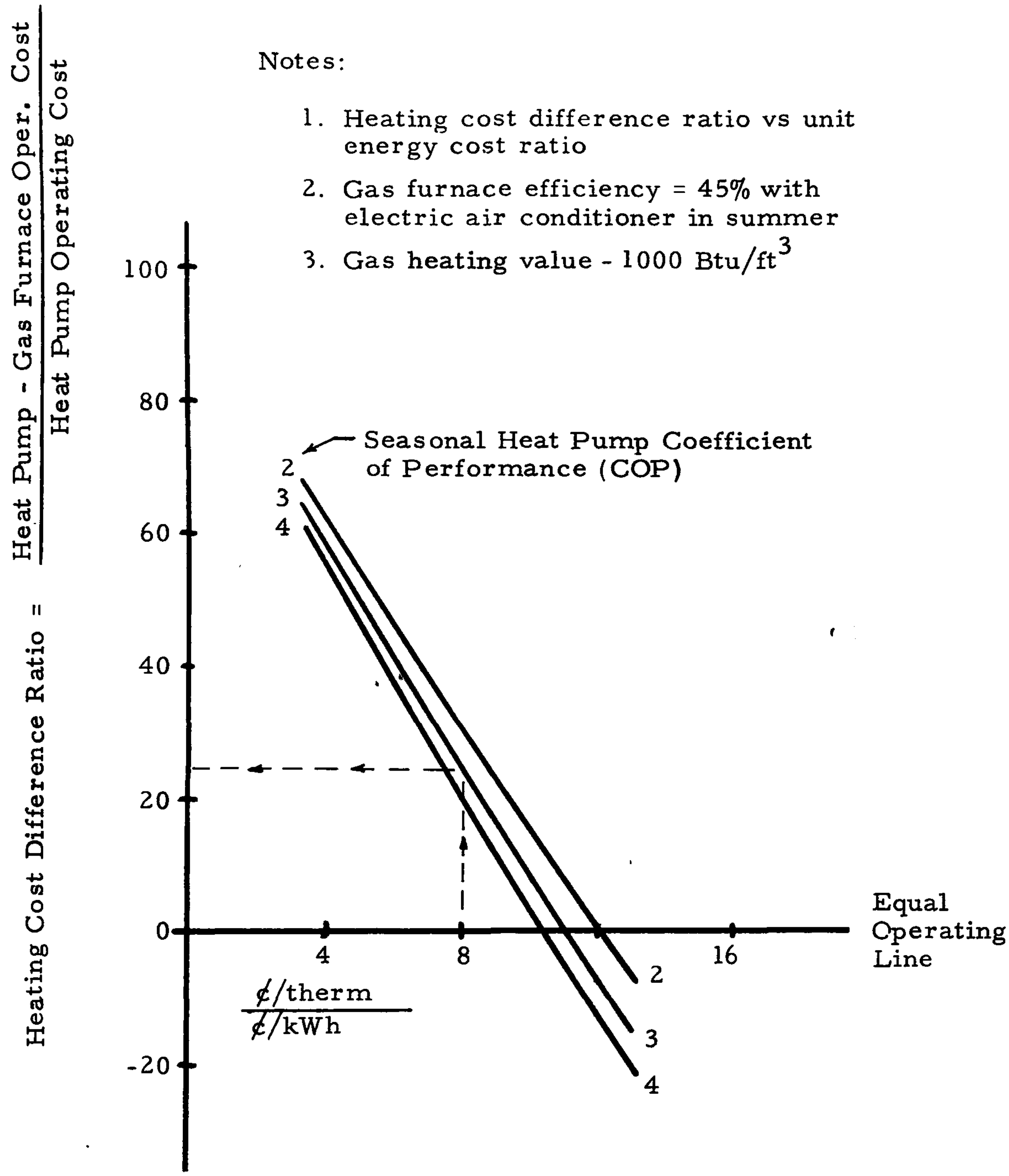



Figure 5-1 - Seasonal Heating Cost Comparison for Residential Application — Heat Pump vs Gas-Fired Furnace

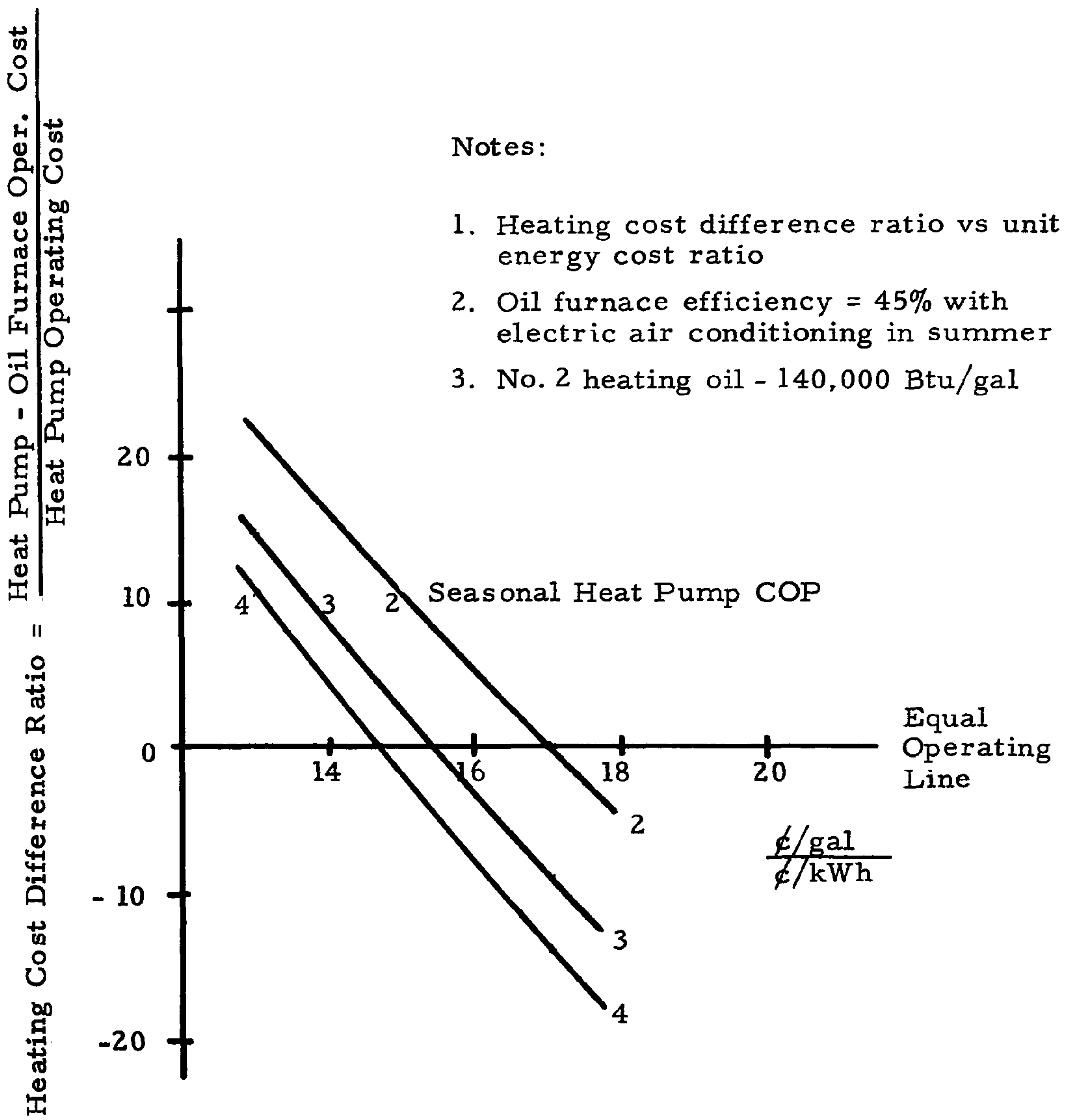



Figure 5-2 - Seasonal Heating Cost Comparison for Residential Application — Heat Pump vs Oil-Fired Furnace

Table 5-1 shows a comparison of the annual cost of operating a heat pump, a gas furnace with electric air conditioning and an oil furnace with electric air conditioning in a residential application. Depreciation has been figured on a 15-year equipment life and 40-year life for duct work. Capital cost has been figured on a 7% mortgage ratio of the total installed cost. Maintenance has been figured on a percentage of the original equipment cost with a factor based on relative equipment complexity. Data were obtained by surveying Heating and Air Conditioning Contractors in the Southeastern United States. Note that the heat pump system is more expensive to own and operate based on 1975 retail fuel prices. Assuming a threefold price increase in natural gas and fuel oil as compared to a 1.5 increase in electricity by 1980, the heat pump will be less expensive to own and operate than both oil and gas furnaces with electric air conditioning.

Annual costs for heating and air conditioning depend upon the location within the U. S. In the Northern U. S. the mean temperature may be 10 to 20 degrees lower than in the Southern U. S. Therefore, heat pump efficiencies would be somewhat less but fossil furnace efficiencies would be somewhat greater than in the South. Therefore the operating cost for the alternatives presented may change by as much as 20% depending on location but the trends would not change. In Alaska, almost no homes are equipped with air conditioning; based on the low efficiency of a heat pump at low ambient temperatures and the current fuel prices, a heat pump is not economical compared with a similar fossil fueled system when considering the heating mode only.

On the other hand, in Southern Florida many homes and commercial businesses do not have a heating system; more than 95% of air conditioning systems are conventional electric.

In some locations, homes and commercial businesses utilizing electric heating receive reduced electric rates due to the utility's reduced costs in delivering larger amounts of electricity to a customer. Although the actual operating cost would depend on the particular rate, the reduced rates can make heat pumps more economical (Ref. 7).

Table 5-1

HEATING COSTS, SINGLE FAMILY RESIDENCE, 1500 $FT^3$, SOUTHEASTERN UNITED STATES

| Item | Heat Pump | Gas Furnace with Electric Air Conditioning | Oil Furnace with Electric Air Conditioning | Energy Costs | | |
|---|---|---|---|---|---|---|
| | | | | Electric | Gas | Fuel Oil |
| **Operating Costs** 1975 | $ 281 | $ 237 | $ 260 | 3¢/kWH | 24¢/therm | 40¢/gal |
| 1976 | $ 422 | $ 535 | $ 603 | 4.5 | 72 | 120 |
| 1977 | $ 632 | $ 803 | $ 905 | 6.75 | 108 | 180 |
| Depreciation | $1,800 @ 6.7% = $120 | $1400 @ 6.7% = $ 93 | $1400 @ 6.7% = $ 93 | | | |
| | $1,200 @ 2.5% = $ 30 | $1200 @ 2.5% = $ 30 | $1200 @ 2.5% = $ 30 | | | |
| Capital Cost | $3,000 x 0.07 = $210 | $2600 x 0.07 = $182 | $2600 x 0.07 = $182 | Annual Load | | |
| Maintenance | $1,100 x 0.04 = $ 44 | $ 200 x 0.02 = $ 4<br>$ 500 x 0.03 = $ 15 | $ 800 x 0.03 = $ 4<br>$ 500 x 0.03 = $ 15 | Heating – $0.4 \times 10^8$ Btu/yr<br>Cooling – $0.4 \times 10^8$ Btu/yr | | |
| Total Annual Cost | | | | | | |
| 1975 | $ 685 | $ 561 | $ 604 | | | |
| 1980 | $ 826 | $ 859 | $ 947 | | | |
| 1985 | $1036 | $1127 | $1249 | | | |

SECTION VI

# PROJECTIONS OF THE RATE OF MANUFACTURE, SUPPLY AND INSTALLATION OF HEAT PUMPS IN THE COMMERCIAL AND RESIDENTIAL SECTOR AS REPLACEMENTS FOR OUTMODED FOSSIL FUEL FIRED EQUIPMENT

## 6.1 PROJECTIONS OF THE RATE OF MANUFACTURE OF HEAT PUMPS

In communicating with representatives of companies manufacturing heat pumps, about 154,000 heat pump units were manufactured during 1975 (Refs. 6, 9, and 10). Approximately 139,000 units of 5 tons or less were manufactured and sold for residential use and about 15,000 units of greater than 5 tons were sold for use in commercial applications. Thus, 90% of all heat pumps manufactured during 1975 were for the residential market.

Due to the reduced supply of natural gas and heating oil, manufacturers of heat pumps are projecting an industry-wide production rate of 250,000 to 275,000 (Refs. 6, 9) heat pump units for supply and installation during 1976. The manufacturers feel that the percentage of residential and commercial heat pumps will remain the same. Less than 5% of this is for retrofit application.

## 6.2 REPLACEMENT RATE

In order to estimate the rate at which outmoded fossil fueled heating systems could be replaced with heat pumps in the residential and commercial sector, let

$N_t$ = total number of heat pump units needed for both residential and commercial sector

$N$ = maximum nuber of residential heat pumps units required

$N_r$ = maximum number of replacement heat pump units in residential sector

$L_g$ = gas heating system life

$L_o$ = oil heating system life

$N_n$ = number of heat pump units needed for new homes

$N_g$ = number of residential gas customers

$F_g$ = fraction of residential customers using gas for space heating

$N_o$ = number of residential oil customers

$F_o$ = fraction of residential customers using oil for space heating

Then the maximum number of heat pumps required for replacement of of outmoded fossil fired equipment in the residential sector is

$$N_r = \frac{N_g \cdot F_g}{L_g} + \frac{N_o \cdot F_o}{L_o} \tag{1}$$

Data from the American Gas Association (Ref. 6) indicate that there were 41,336,500 residential gas customers in the U.S. in 1974; of those, 84% of the customers used natural gas for space heating with an average consumption of 1140 therms. Data from the Department of Commerce (Ref. 8) indicate that there were 16,827,000 residential heating oil customers in the U.S. in 1975; of those, 99% of the customers used oil for space heating with an average annual consumption of 900 gallons.

Assuming an average life of a gas and an oil heating system to be 15 years (Ref. 2), the maximum number of replacement heat pump units required in the residential sector for outmoded fossil fueled systems is

$$\begin{aligned} N_r &= \frac{41{,}336{,}500\ (0.84)}{15} \\ &+ \frac{16{,}827{,}000\ (0.99)}{15} \\ &= 3.43 \times 10^6\ \frac{\text{heat pump units}}{\text{year}} \end{aligned} \tag{2}$$

$N_r$ represents the maximum number of heat pump units needed per year to replace all of the outmoded fossil heating systems in the residential sector during the next 15 years. Since data were not available for 1975, $N_r$ is based on the number of gas customers in 1974. Due to the gas shortage, it is unlikely that this number has increased. Obviously, not every fossil fueled heating system installed in 1965 will be replaced in 1980; some will be replaced sooner, others later. However, assigning finite lifetimes to each type of fossil fueled heating system should not affect the relative replacement rate.

Table 6-1 (Ref. 8) shows the annual number of new housing starts during the last four years and an estimate of starts for 1976. Although the number of new housing starts has been decreasing since 1972, the estimate for 1976 is up. For simplicity, assume that the number of new housing starts per year during the next 15 years is 1,250,000. If heat pumps are installed in all new homes, the number of units required will be

$$N_n = 1{,}250{,}000 \text{ units year.} \tag{3}$$

Table 6-1

NEW HOUSING STARTS (REF. 8)

| Year | Number of New Housing Starts |
|---|---|
| 1972 | 2,378,500 |
| 1973 | 2,057,500 |
| 1974 | 1,352,500 |
| 1976 (Est.) | 1.3 to 1.7 x $10^6$ |

Therefore, the number of residential heat pump units needed as replacements for outmoded fossil fueled heating systems and for installation in new homes is

$$N = N_r + N_n \qquad (4)$$

$$= 4.68 \times 10^6 \ \frac{\text{heat pump units}}{\text{year}}$$

If one assumes that the ratio of the number of residential units manufactured to the number of commercial units remains 9/1, the total numbers of units needed is

$$N_t = N\,(1 + 1/9) \qquad (5)$$

$$= 5.15 \times 10^6 \ \frac{\text{heat pump units}}{\text{year}}$$

In order to put this number into perspective, Table 6-2 (Refs. 10, 11) shows the number of heat pump units manufactured in the U.S. from 1972 to 1975 and an estimated production for 1976. The numbers include both single and split units for residential (i.e., less than 5 tons) and commerical use. It is apparent that the number of heat pumps needed for replacement and new applications is $5.15 \times 10^6/154{,}000 = 33$ times greater than the total number of units manufactured in 1975.

Several comments are in order at this point. Although heat pump manufacturers feel that their industry could respond to any demand rate for heat pump units by the general public (Refs. 10, 11), several of the large manufacturers expressed concern about a large number of untested and unreliable heat pump units on the market today; with a high demand for heat

Table 6-2

NUMBER OF HEAT PUMP UNITS MANUFACTURED IN U. S.
(Commercial and Residental, Single and Split Units)

| Year | Number of Units |
|---|---|
| 1972 | 97,000 |
| 1973 | 120,000 |
| 1974 | 128,000 |
| 1975 | 154,000 |
| 1976 (Est.) | 250,000 |

pump systems, sale of a large number of these units could cause a similar situation that developed in the heat pump market in the 1950s (see Section 3.2). The second point is that possibly as many as one-third of the outmoded fossil fueled heating systems in both the residential and commercial sector cannot be replaced due to the problems in the physical arrangement of the existing fossil fueled heating system using hot water pipes, convection radiators, etc. Also, it may not be practical to replace another third of the outmoded fossil fueled heating/electric air conditioning from an economic standpoint because only the heating or the cooling system may need replacing, not both. A more realistic manufacturing rate may be less that 25% of $N_t$ or less than $1.3 \times 10^6$ heat pump units per year which is still 8.4 times the 1975 industry-wide heat pump manufacturing rate.

## 6.3 ESTIMATES OF POSSIBLE REDUCTION IN DEMAND OF PREMIUM FUEL

Assume that all of the residential customers using natural gas and heating oil for space heating replace their outmoded fossil fuel equipment at the time of failure with heat humps. As indicated in Section 6.2, there were 41,336,500 natural gas customers in 1974 where 84% of the customers used natural gas for space heating with the average annual usage of 1140 therms. Assuming a heating value of 1000 Btu/ft$^3$, the maximum savings of natural gas would be

$$\text{Saving}_{\text{res. gas}} = \frac{41{,}336{,}500\ (0.84)\ \left(1140\ \frac{\text{therm}}{\text{year}}\right)\left(10^5\ \frac{\text{Btu}}{\text{therm}}\right)}{10^3\ \text{Btu/ft}^3} \tag{6}$$

$$= 8.8 \times 10^{12}\ \text{ft}^3/\text{yr}$$

Similarily, there were 16,827,000 residential heating oil customers in 1974 where 99% of those customers used oil for heating with an average annual consumption of 900 gal year (Ref. 12). The maximum savings of heating oil would be

$$\text{Saving}_{\text{res. oil}} = 16{,}827{,}000\ (.99)\ (900\ \text{gal/year}) \tag{7}$$

$$= 1.5 \times 10^{10}\ \text{gal/year}$$

Data on the number of residential gas customers for 1975 have not been finalized, but due to the shortage of supplies, the totals have not increased. There were 3,392,000 commercial users of natural gas in 1974 with an average annual consumption of 6,761 therms. The American Gas Association (Ref. 13) estimates that two-thirds of this consumption was used for space heating. The maximum savings of natural gas in the commercial sector is

$$\text{Saving}_{\text{comm. gas}} = \frac{3{,}392{,}000\ (0.667) \left(6{,}761\ \frac{\text{therms}}{\text{year}}\right) \left(\frac{10^5\ \text{Btu}}{\text{therm}}\right)}{10^3\ \text{Btu/ft}^3} \tag{8}$$

$$= 1.529 \times 10^{12}\ \text{ft}^3\text{/year}$$

Since there is no information on commercial fuel oil consumption for space heating, assume the ratio of the number of commercial to residential fuel oil customers is the same as the ratio of the number of commercial to residential gas customers.

Then, the number of commercial fuel oil customers =

$$16{,}827{,}000 \left(\frac{3{,}392{,}000}{41{,}336{,}500}\right) \tag{9}$$

$$= 1{,}380{,}000$$

Also, assume that the ratio of the average annual consumption of commercial to residential natural gas is the same as the ratio of the average annual consumption of commercial to residential fuel oil for space heating.

Then, the average consumption of fuel oil for commercial space heating =

$$900\ \frac{\text{gal}}{\text{yr}}\left(\frac{0.667}{0.84}\right)\left(\frac{6761}{1140}\right) = 4238\ \text{gal/year} \qquad (10)$$

If all of the commercial fuel oil heating systems were replaced with heat pumps, the maximum savings of heating oil would be

$$\begin{aligned}\text{Saving}_{\text{comm. oil}} &= 1{,}380{,}000\ (4238) = \\ &\quad 0.585 \times 10^{10}\ \text{gal/year}\end{aligned} \qquad (11)$$

Therefore, the maximum savings in the commercial and residential sector that may be realized by replacing the outmoded gas heating systems with heat pumps is from (8) and (6)

$$\text{Savings}_{\text{gas}} = 10.3 \times 10^{12}\ \text{ft}^3/\text{year} \qquad (12)$$

Similarity, the maximum savings of heating oil from (7) and (11) would be

$$\begin{aligned}\text{Savings}_{\text{oil}} &= 2.08 \times 10^{10}\ \text{gal/year} \\ &= 1.357 \times 10^{6}\ \text{barrels of premium fuel oil/day}\end{aligned}$$

The above savings would be realized at the end of a 15-year period when all of the outmoded fossil fueled systems had been replaced. As indicated in Section 6.2, the actual savings of natural gas and heating oil due to the replacement of outmoded fossil fueled systems with heat pumps would probably be less than the maximum due to the inability to install heat pumps in some residences and the failure of only one component of the total space heating system. A conservative savings of 25% of the maximum might be more realistic.

## SECTION VII

## SUGGESTION FOR FUTURE RESEARCH AND DEVELOPMENT

Significant improvements have been made in the design of heat pumps since 1950. The compressor has been redesigned to withstand high stresses. Safety devices such as high and low pressure cutoff switches have been added to heat pump systems to prevent operation at abnormal conditions. However, more research and development is still needed to make the heat pump more economical relative to other systems.

Improvements are needed in the area of low temperature operation. As indicated in Figure 7-1, the coefficient of performance decreases rather dramatically as the ambient temperature decreases. Evaporator icing is a problem at temperatures below 32 F.

Research is also needed in the area of improved working fluids and improved materials to extend compressor component life.

Additional studies should be made to assess the impact of space heating electrification on local and regional air quality due to increased load at electric generation plants. Since a significant number of fossil fueled heating customers do not use electric air conditioning presently, electrification of space heating could significantly increase the demand for electricity. Thus, an analysis should be made to determine if the nation's electrical generating capacity could be expanded rapidly enough to meet increased demand since some utilities have drastically reduced their construction schedules. Current lead times for bringing base electric generating plants on line are more than seven years for fossil fueled plants and 12 years for nuclear plants.

In order to encourage the use of heat pumps to conserve premium fossil fuel, to reduce air pollution from stationary sources and to help meet the national goal of reducing our dependence on imports of natural gas and oil, a study should be made on the use of direct incentives to encourage customers to convert outmoded fossil systems to heat pump systems. Such incentives could be provided by the various federal agencies in the form of: (1) reduced electric rates for heat pump customers; (2) tax deductions or an increased depreciation rates for conversion; and/or (3) lower VA and FHA interest rates for conversion to heat pump systems; or (4) tax credits for heat pump installation and insulation improvement to applicable standards where appropriate.

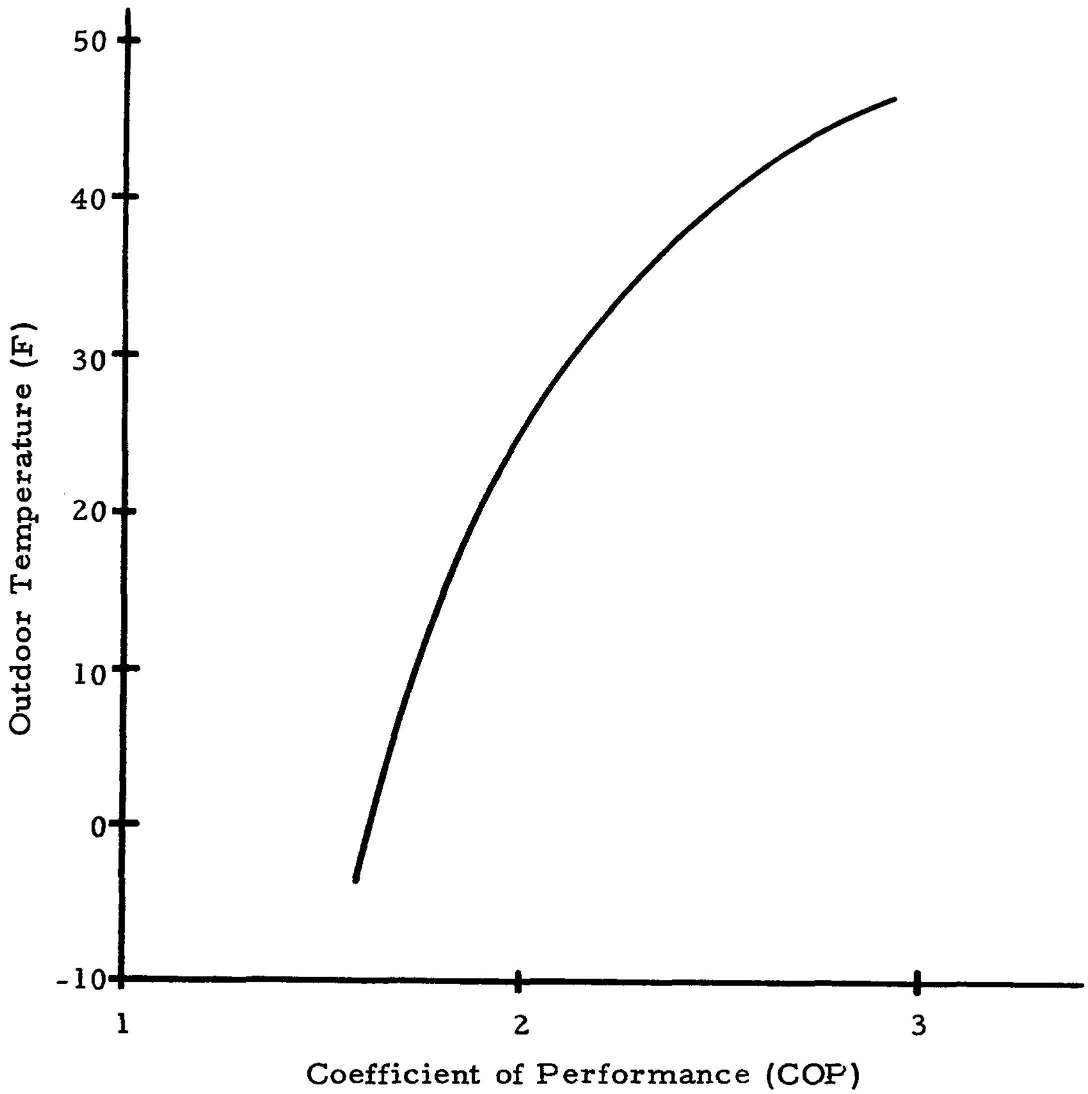



Figure 7-1 - Typical Heat Pump COP vs Outdoor Temperature, 5 ton Split System

## SECTION VIII

## RESULTS AND CONCLUSIONS

The widespread use of the heat pump in both the residential and commercial sectors as a total comfort conditioning system will, to a large extent, be controlled by the consumer. Modern heat pump systems are as reliable and competitive in capital cost as fossil heating/electric air conditioning systems. Although residential heat pump systems currently cost about 25% more to operate than comparable fossil heating/electric air conditioning systems based on current retail energy costs, the future availability of natural gas and oil for space heating is questionable. Even today, many utilities have decided not to add any more residential natural gas customers to their system until further notice; in those cases many contractors are installing heat pumps exclusively in new homes. Certain commercial heat pump systems are already more economical today than fossil fueled heating/electric air conditioning systems especially when both heating and cooling are required in different areas of a building at the same time.

The retail price of natural gas and oil has increased much faster than the price of electricity. Also, the natural gas and petroleum industry may be deregulated in the future which may cause a significant increase in the retail price of natural gas and oil relative to electricity. Therefore, heat pump systems may be as economical to operate as fossil fueled heating/electric air conditioning systems in the near future.

Heat pumps may be used to replace outmoded fossil heating/electric air-conditioning systems especially in those locations where the air handling system already exists. By converting outmoded fossil heating electric air conditioning systems to heat pump systems, the premium fossil fuel saved may be used in applications where conversion is not possible and where a "critical" shortage already exists such as the manufacture of fertilizer.

Assuming that the energy needed for space heating electrification comes from new coal fired or nuclear units, spacing heating electrification using heat pumps could reduce the nation's consumption of natural gas by $10.3 \times 10^{12}$ $ft^3$/year and premium fuel oil (i.e., No. 2 or better) by $1.357 \times 10^6$ barrels/day. Since current base load power plant lead times are so great and utilities have drastically cut their construction schedules, it is questionable at this time if the utilities can meet the increased demand due to space heat electrification. Electric generation capacity currently exists for those customers using electric air conditioning. However, there are many customers in areas such as the densely populated Northeastern U. S. where fossil fueled heating is utilized without electric air conditioning; in these cases, electrification of the heating systems would result in the need for additional generating capacity.

Although the projected demand for heat pump units may be significantly greater than the current industry growth rates due to electrification of space heating with heat pumps, this demand (see Section 5) can be met by current heat pump manufacturers.

## SECTION IX

## COMPARISON OF RESULTS WITH THOSE ARRIVED AT IN EPA REPORT NO. 200-045-013

This study agrees with the results arrived at by EPA Report No. 200-045-013 that electrification of fossil fueled heating systems in the residential and commercial sector can result in a significant reduction in the demand for premium fuels for use in those areas where conversions cannot be made and shortages already exist. If the electrical energy required for these conversions were provided by coal-fired or nuclear power plants, these reductions in end use consumption of premium fossil fuels would represent a real reduction in our national consumption of natural gas and fuel oil.

Although the projected rates of manufacture, supply and installation of heat pump units needed for replacement of outmoded fossil fueled systems and new applications may be more than eight times the industry wide heat pump manufacturing rate during 1975, it is felt that the heat pump industry could meet this projected demand.

This study disagrees with the EPA Report No. 200-045-013 conclusion that the promotion of electrification of space heating should be instituted at the present time. A brief study should be made to determine how much additional generating capacity is needed and if it will be available in view of reduced utility construction programs and increased power plant lead times. Information necessary for this study will be available in the near future from the Department of Commerce and the Federal Power Commission (See Section VIII).

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APPENDIX

TYPICAL HEAT PUMP ARRANGEMENTS

An air heat source-sink design using air as the heating and cooling medium illustrated in Figure A-1, is by far the most universally used, particularly for the residential and smaller commercial installations having a cooling load of about 25 tons, or lower..

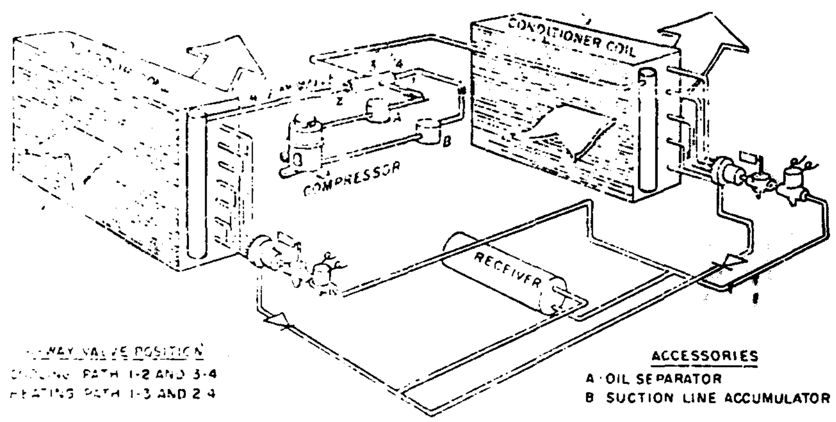


Figure A-1 Air as Heat Source-Sink and Air as Heating and Cooling Medium (Fixed Air Circuits — Refrigerant Flow Reversed). Throttling Valve Used to Regulate Refrigerant Effect

Conventional refrigerant practice can be followed in the selection and arrangement of the equipment, except that it is desirable to have gravity drainage of the liquid refrigeration from the outdoor coils and the conditioner coils to the liquid receiver. The diagram also indicates the probable location of an oil separator in the discharge line, and of a liquid refrigerant-oil accumulator in the suction line. These accessories are generally used on all except the small integral designs in order to assure proper oil return and prevent liquid flood-back to the compressor.

In this design, heating and cooling are obtained by changing the direction of the refrigerant flow. Two fixed independent air circuits are employed, consisting of the outdoor coil circuit and the conditioner coil circuit. During the cooling cycle the four-way valve is positioned to paths 1-2 and 3-4. The compressor delivers the hot compressed refrigerant gas through the four-way valve, path 1-2, to the outdoor coil where it is condensed, giving up the latent heat of condensation to the outside air. From the outdoor air coil the liquid refrigerant flows through the check valve to the liquid receiver and then through the throttling valve to the conditioner coil. In the conditioner coil the liquid refrigerant is changed into a gas that absorbs the heat of vaporization from the air going to the conditioned space. From the conditioner coil the refrigerant gas returns through the four-way valve, path 3-4, to the compressor to repeat the cycle.

During the heating cycle the four-way valve is positioned to path 1-3 and 2-4. The compressor delivers the hot compressed refrigerant gas through the four-way valve, path 1-3, to the conditioner coil where it is condensed, giving up the latent heat of condensation to the air going to the conditioned space. From the conditioner coil the liquid refrigerant flows through the check valve to the liquid receiver and then through the throttling valve to the outdoor coil. In the outdoor coil the liquid refrigerant changes into a gas that absorbs the heat of vaporization from the outside air. From the outdoor coil the refrigerant gas returns through the four-way valve, path 2-4, to the compressor to repeat the cycle.

Figure A-2 is a modification of the basic air-to-air heat pump cycle. Two additional check valves and a liquid throttling valve have been added to the basic cycle and the expansion valves, solenoid valves, liquid receiver, and oil separator have been eliminated. In this design the liquid refrigerant is used both to boil the condensed refrigerant from the suction line accumulator and to superheat the suction gas entering the compressor. The throttling valve, C, regulates the refrigerant flow by maintaining a predetermined liquid temperature leaving the condenser. The heat source coil, either the indoor or outdoor coil depending upon the cycle, will operate in a flooded condition because of the absence of an expansion valve. It is important, therefore, that the suction line accumulator be adequately designed to prevent liquid floodback to the compressor.

The main advantage cited for this design is the elimination of the thermostatic expansion valves and the need for a pressure-suction differential to obtain the desired refrigeration effect. Consequently, the system can operate on the cooling cycle at extremely low outdoor temperatures, and by maintaining the predetermined liquid temperature can operate at reasonably constant head pressures during both the heating and cooling cycle.

Figure A-3 shows a typical flow diagram of a system employing water as the heat source-sink and using air as the heating and cooling medium.

In this cycle, heating and cooling are obtained by changing the direction of the refrigerant flow. Two separate fixed circuits are employed, consisting of a water circuit through the condenser-cooler and an air circuit over the conditioner coil. During the cooling cycle the four-way valve is positioned to paths 1-2 and 3-4. The refrigerant path is from the compressor through the four-way valve, path 1-2, the condenser-cooler, the check valve, the liquid receiver, the expansion valve, the conditioner coil, the four-way valve, path 3-4, back to the compressor to repeat the cycle. The refrigerant gas is liquefied in the condenser-cooler by giving up its

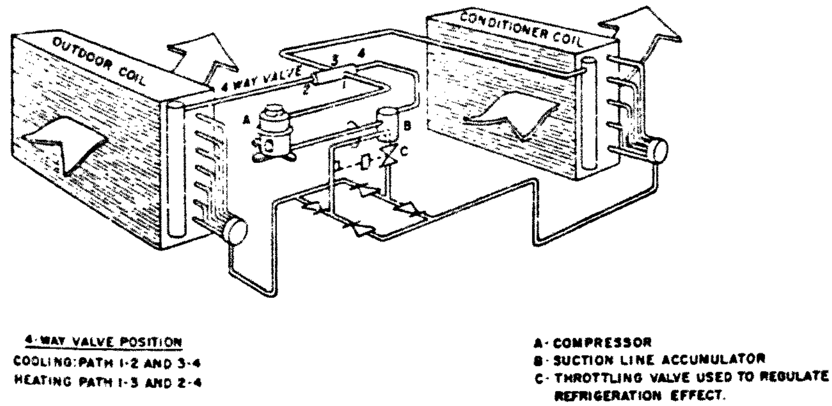


Figure A-2 - Air as Heat Source-Sink and Air as Heating and Cooling Medium (Fixed Air Circuits Refrigerant Flow Reversed)

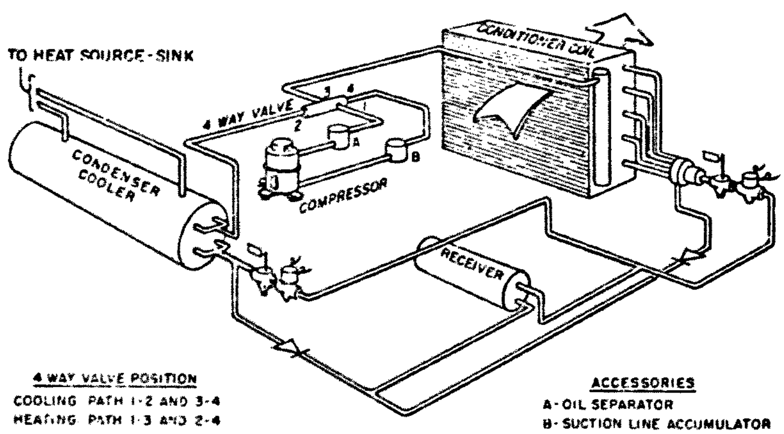


Figure A-3 - Water as a Heat Source Sink and Air as Heating and Cooling Medium (Fixed Air and Water Circuits — Refrigerant Flow Reversed). Throttling Valves Used to Regulate Refrigerant Effect

latent heat of condensation to the water and is changed back into a gas in the conditioner coil by absorbing its heat of vaporization from the air going to the conditioned space.

During the heating cycle the four-way valve is positioned to paths 1-3 and 2-4. The refrigerant path is from the compressor through the four-way valve, path 1-3, the conditioner coil, the check valve, the liquid receiver, the expansion valve, the condenser-cooler, the four-way valve, path 2-4, then back to the compressor to repeat the cycle. Conversely to the process of the cooling cycle, the hot compressed refrigerant gas from the compressor is liquefied in the conditioner coil by giving up its heat of condensation to the air going to the conditioned space, and is changed back into a gas in the condenser-cooler by absorbing the heat of vaporization from the well water.

During both the cooling and heating cycles well water is circulated by a pump through the preconditioning coil (if used to precool or to preheat the ventilation air), then through the condenser-cooler to the drain.

## TECHNICAL REPORT DATA
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16. ABSTRACT The report reviews the state-of-the-art relative to development, capacity, and adequacy of the heat pump as a potential replacement for outmoded fossil-fueled heating and cooling systems in the residential and commercial sector. Projections are made of the rate at which heat pumps need to be manufactured and installed in the commercial and residential sectors as the projected service life of fossil-fuel equipment expires. The conclusion is reached that the heat pump is economical only as a total space comfort system. Based on January 1, 1976, fuel prices, the heat pump is about 25% more expensive to operate than comparable fossil-fueled heating systems. If the trend of increasing fuel prices continues, the heat pump will be more economical to operate than comparable fossil-fueled heating systems by 1980.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Air Pollution | Air Pollution Control | 13B |
| Heat Pumps | Stationary Sources | 13A |
| Heating | | |
| Cooling | | |
| Energy Conversion | | 10A |
| Energy Conversion Heat Sources | | 10B |
| Refrigerating Machinery | | |

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