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Abstract

The status of the residential heat pump industry is reviewed. Some potential improvements in energy efficiency, operational reliability, and initial cost are described and delineated. These possible innovations include two-speed or variable speed compressors, reliable defrost initiation and termination, improved system components, modifications to the basic thermodynamic cycle, add-on-heat pumps, solar assisted heat pumps, annual cycle energy system, chemical heat pumps, and gas fired heat pumps.

1. INTRODUCTION

A heat pump, in the common thermodynamic sense, is a system in which cyclic refrigeration equipment is used in such a manner as to take heat from a source and give it up to a heat sink which is at a higher temperature than the source. There are many variations of the heat pump available for a wide variety of applications in industry, commercial buildings, and residences (3, 4, 15). This paper is concerned with only those types of heat pumps which are designed for residential applications.

A residential heat pump is a heat transfer device that transports heat from where it is not needed to a point where it is needed, or can be dissipated. In summer, the heat pump works as an air conditioner, transferring heat from inside the residence to the outdoors. In the heating season, the process is reversed, and the heat pump collects heat from outdoor air, even when it is very cold, and transfers the heat into the home.

The heat pump concept was first devised by Kelvin in the early 1850's. It took eighty years before the concept of the heat pump was developed to such a level that it could be used in practical customized applications. An additional twenty years elapsed before unitary or off the shelf heat pumps became commercially available (5).

During the 1950's the residential heat pump gained a poor reputation as far as reliability was concerned. During this period there were exceptional maintenance problems (short compressor life, short fan motor life), misapplications of the heat pump, poor installation practices, lack of qualified repair personnel, and in some instances poor design decisions. However, during the last fifteen years manufacturers have carried out a tremendous heat pump development program which has been responsible for improved heat pump designs. This improvement in the residential heat pump as well as the worldwide concern for energy conservation has resulted in tremendous growth in sales and availability of sizes as well as manufacturers. This fifteen year time period has also provided a wealth of experience in installation and repair of residential heat pumps.

In the following sections the status of the residential heat pump industry will be reviewed and then the direction in which it is heading will be discussed.

2. HEAT PUMP TYPES

There are many types of residential heat pumps and they can be classified according to (a) type of heat source and sink, (b) heating and cooling distribution fluid, (c) type of thermodynamic cycle, and (d) size and configuration. The air-to-air heat pump is the most common type of residential unit and is particularly suitable for factory built unitary devices. This type of unit uses air for the source and the sink and is constructed such that it can provide both heating and cooling for the residence. The air-to-air heat pump can also be used in the utilization of waste heat from industrial processes for comfort air conditioning applications. The water-to-air heat pump uses water as a heat source and sink and uses the air to transport heat to or from the conditioned space. The air-to-water heat pump uses air as the source or sink and water as the distributing fluid. The water-to-water heat pump uses water as the heat source and sink for both cooling and heating operations. The earth-to-air and earth-to-water heat pumps use the earth as the heat source or sink and the air or the water as the distributing fluid (3, 4).

2.1 AIR-TO-AIR HEAT PUMPS

Figure 1 shows an air-to-air heat pump operting in the heating mode. The hot gas leaves the compressor and passes through the reversing valve and is condensed within the inside coil providing heat for the conditioned air. The condensed liquid is then expanded through a valve and boils in the evaporator gaining heat from the outside air. The cool gas then enters the compressor for continuation of the cycle.

In Figure 2 the air-to-air heat pump is depicted operating in the cooling mode. The reversing valve now directs the hot gas from the compressor to the outside coil where heat is removed from the refrigerant. Cooling of the conditioned air now takes place in the evaporator or indoor coil.

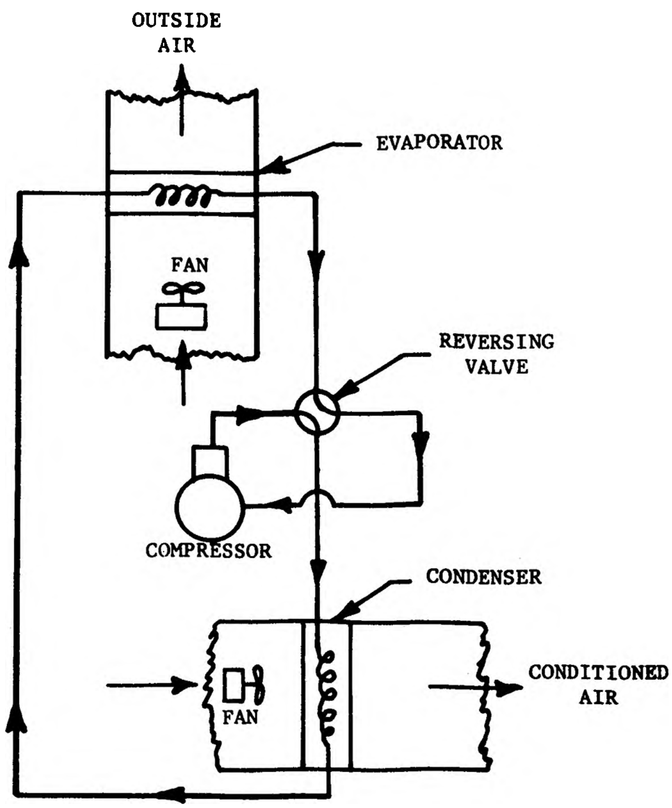

Figure 1. Air-to-Air Heat Pump - Heating Mode

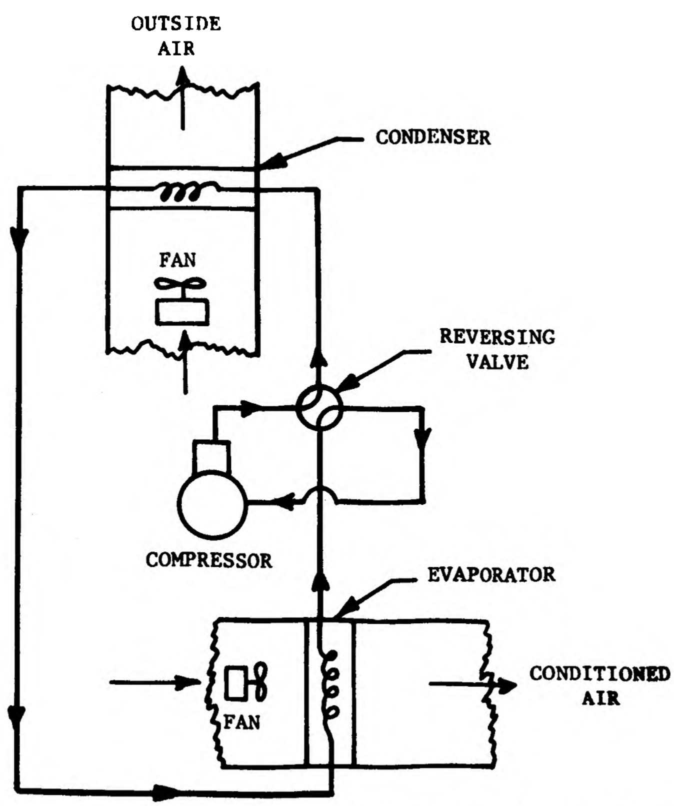

Figure 2. Air-to-Air Heat Pump - Cooling Mode

Table 1 lists selected manufacturers of air-to-air heat pumps and the unit sizes available. There are at least twenty six manufacturers producing heat pumps in the size range from 1½ tons to 45 tons. This list was compiled from the ARI Directory of Certified Unitary Heat Pumps (16) and is presented and discussed by Christian (1). The space requirements for typical units are shown in Table 2.

Nine heat pump models were selected from the list of manufacturers in Table 1 and have been analyzed (1) with respect to performance and cost. These nine models are listed in Table 3 with their nominal heating COP and nominal cooling EER.

TABLE 1 Selected Heat Pump Manufacturers and Unit Sizes [Ref. 16]

Company	Available Sizes (Tons)
Addison Products Co.	2.0 - 5.0
Air Temp Division	2.5 - 3.0
Amana Refrigeration, Inc.	2.0 - 5.0
Bard Manufacturing Co.	1.5 - 5.0
Bryant Air Conditioning	2.0 - 5.0
Carrier Air Conditioning	1.5 - 45
Fedders Corp.	2.0 - 4.5
Fraser & Johnston Co.	2.0 - 5.0
Friedrich Air Conditioning & Ref. Co.	2.5 - 5.0
General Electric Co.	2.0 - 20
Goettle Bros. Metal Products, Inc.	1.5 - 10
Heil - Quaker Corp.	2.0 - 5.0
Henry Furnace Co.	2.0 - 5.0
Lennox Industries, Inc.	2.0 - 15
Luxaire, Inc.	1.5 - 5.0
Mueller Climatrol Corp.	2.0 - 4.5
Payne Air Conditioning	1.5 - 5.0
Rheem Manufacturing Co.	1.5 - 5.0
The Ruud Co.	1.5 - 5.0
Singer Co.	2.0 - 5.0
Stewart-Warner Corp.	2.0 - 5.0
Tappan Co.	2.0 - 5.0
Trane Co.	2.0 - 5.0
Westinghouse Electric Corp.	1.5 - 5.0
Whirlpool Heating and Cooling Prod.	2.0 - 5.0
Williamson Co.	2.0 - 3.0

2.1.1 Heating Performance

The heating capacity of these nine models of air-to-air heat pumps were integrated into a nominal value at rated conditions (17). The indoor air is at 70 F with a flow rate of 450 CFM/Ton and the outdoor air at rated performance is at 47 F and 85% relative humidity. Figure 3 depicts the performance of the nine models at varying outdoor air temperatures. The shaded area represents the deviation in capacity between the nine models at different outdoor air temperatures. These differences arecaused by the following variables: quantity of heat transfer area,

TABLE 2 Unitary Heat Pump Space Requirements [Ref. 1]

Heat Pump	Length x Width x Height (ft)	Weight (lb)
3-ton split system		
Indoor unit		
Horizontal	3.5 x 5.0 x 3.5	100
Vertical	4.0 x 3.5 x 5.0	100
Outdoor unit	7.0 x 7.0 x 4.0	225
15-ton split system		
Indoor unit		
Horizontal	7.0 x 6.5 x 3.5	740
Vertical	7.0 x 4.5 x 5.5	795
Outdoor unit	8.5 x 7.5 x 3.5	1300
15-ton package unit	22.0 x 8.5 x 4.0	2200
45-ton split system		
Indoor unit		
Horizontal	12.0 x 5.0 x 8.0	840
Outdoor unit (3-15 ton units)	14.6 x26.0 x 5.0	3030

TABLE 3 Heating and Cooling Performance of Nine Heat Pump Models [Ref. 1]

Nominal Capacity Size Range (Tons @ 47°F)	Nominal Heating COP	Nominal Cooling EER
1½ - 2	2.8	7.1
2 - 3	2.4	7.1
3 - 4	2.4	6.5
4 - 5	2.8	8.1
5 - 10	2.6	7.4
10 - 15	2.7	8.6
15 - 20	2.9	8.7
20 - 25	2.8	8.6
25 - 45	2.6	8.6

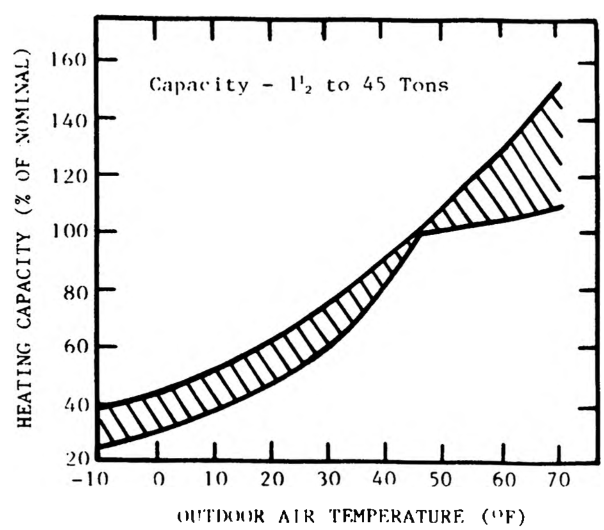

Figure 3. Heating Capacity of Nine Air-to-Air Heat Pump Models (1)

efficiency of the compressor, the instrumentation and control philosophy used by the manufacturer, type of refrigerant used, and the refrigerant circuiting in the two coils.

The heating COP for these same nine models are compared in Figure 4. Again significant variations in the coefficient of performance is noted between the nine representative models. The variation at rated outdoor temperature (47 F) was from 2.4 to 2.9 (see Table 3). These variations are again determined by unit design and operating characteristics as mentioned above. Changes in the heating capacity and the COP will occur as the indoor temperature changes and also as the indoor air flow rate changes (1).

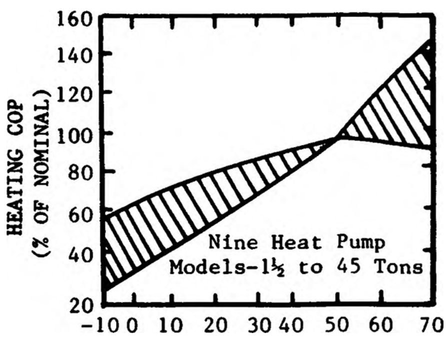

Figure 4. Heating Coefficient of Performance of Nine Heat Pump Models (1)

2.1.2 Cooling Performance

The cooling capacities of these nine air-to-air heat pump models are depicted in Figure 5. The common or nominal point is at 95 F where the cooling function of the heat pump is rated. The indoor conditions for rating purposes are at 80 F DB and 67 F WB with 450 CFM/Ton air flow rate. Again, significant differences in cooling capacities exist between different models.

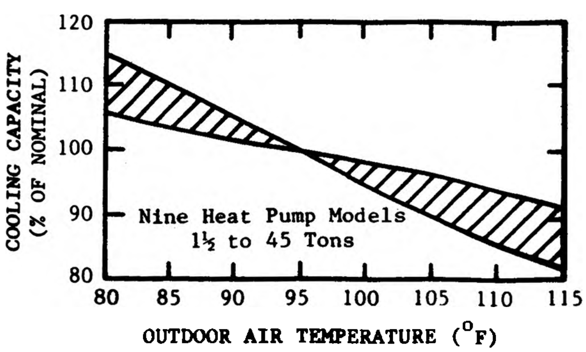

Figure 5. Cooling Capacity of Nine Air-to-Air Heat Pump Models (1)

The energy efficiency ratios (EER) for the nine heat pump models are shown in Figure 6 as a function of the outside air temperature. The EER is the ratio of the cooling effect (Btu/hr) and the total electrical power (watts) required to produce that cooling effect. Changes in the cooling capacity and the EER will occur as the indoor dry bulb and wet bulb temperatures are changed (1).

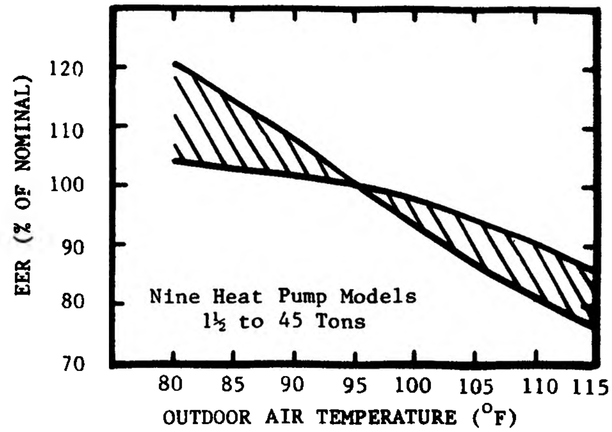

Figure 6. Cooling EER of Nine Air-to-Air Heat Pump Models (1)

2.1.3 Seasonal Performance, Costs, and Reliability

The heat pump is normally sized to meet the cooling load so that proper humidity can be maintained during the cooling season. This procedure results in the heat pump being unable to supply all of the heat required during the heating season. This requires that some form of auxiliary heat must be used in colder climates when the outdoor temperature is below 30 F to 40 F. The colder the climate the more auxiliary heat is required. Figure 7 shows a seasonal performance factor as a function of the number of degree days. The seasonal COP is the total heating output divided by the sum of the total input power to the heat pump and the auxiliary heat for the complete heating season. It is seen from Figure 7 that the heat pump suffers from significant reductions in SPF in Northern climates.

Estimates of installed costs and equipment costs for air-to-air heat pumps are given in Figure 8. These results are based on 1976 dollars and a labor rate of $13 per hour. In Figure 9 estimated operation and maintenance costs are given as a function of the size of the heat pump. These are charges for

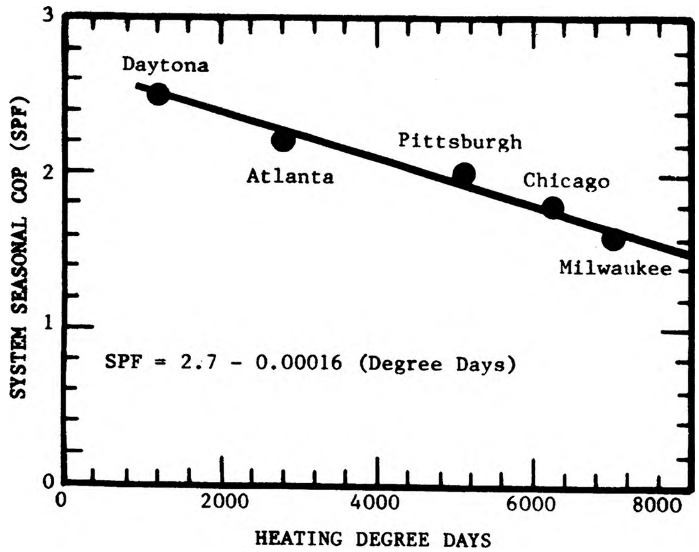

Figure 7. System Seasonal Performance of Air-to-Air Heat Pumps

filter changes, lubrication, and adjustments only and it does not include the operating power costs. Service contracts are generally available from some manufacturers at a cost of \$55 to \$60 per year.

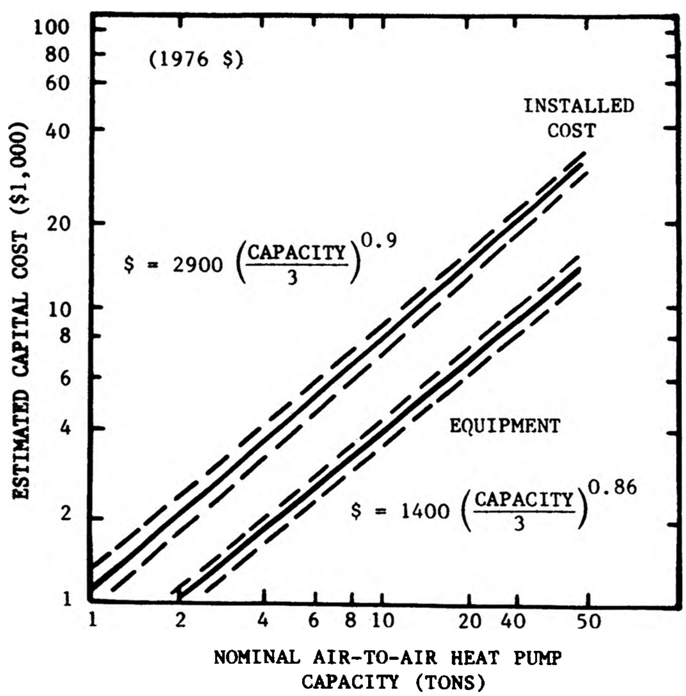

Figure 8. Estimated Capital Costs for Air-to-Air Heat Pumps (1)

Air-to-air heat pumps have had improved reliability in the last fifteen years. The compressor failure rate has been decreasing and is approaching an industry average of 5% which appears to be acceptable. Most manufacturers will indicate a life expectancy of about ten years for air-to-air heat pumps.

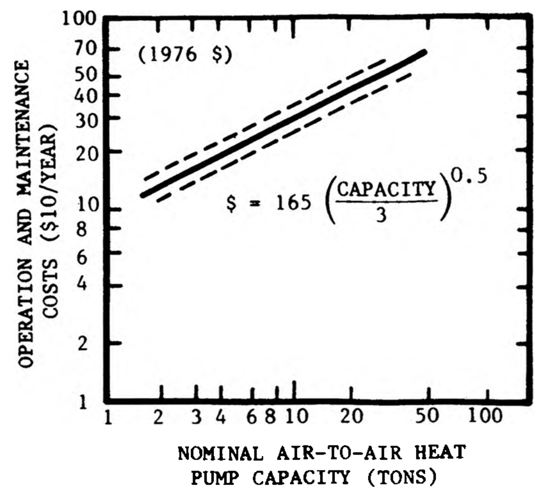

Figure 9. Operation and Maintenance Costs of Air-to-Air Heat Pumps

2.2 WATER-TO-AIR HEAT PUMPS

Figure 10 depicts a water-to-air heat pump operating in the cooling mode. In this case, the outside coil has been replaced by a water to refrigerant heat exchanger.

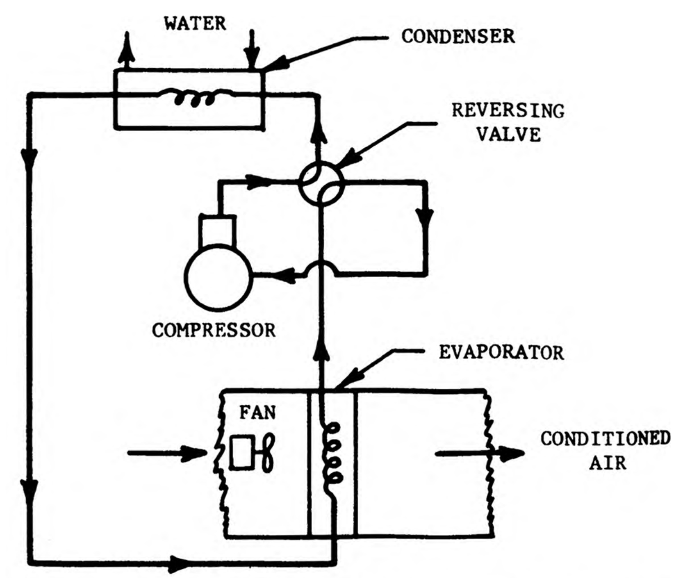

Figure 10. Water-to-Air Heat Pump - Cooling Mode

2.2.1 Water-to-Air Heat Pump Availability

Table 4 lists selected manufacturers (2, 16) of water-to-air heat pumps and the ranges of sizes which are available. These units are available from at least eight manufacturers in a size range from one-half ton to twenty six tons. In Table 5 is listed the space required for typical or representative water-to-air heat pumps. These units appear to require less space and have less weight than air-to-air heat pumps.

TABLE 4 Selected Manufacturers of Water-to-Air Heat Pumps [Ref. 16]

Company	Size Range (ton)
American Air Filter Company	3/4 - 4.25
Dunham-Bush, Incorporated	1 - 5
Command-Aire Corporation	3/4 - 26
FHP Manufacturing Corporation	3/4 - 10
Friedrick Air Conditioning and Refrigeration Company	1/2 - 10
Heat Exchangers, Incorporated	3/4 - 5.3
Singer Company	3/4 - 4.3
York Division	1 1/2 - 3.6

TABLE 5 Selected Water-to-Air Heat Pump Space Requirements [Ref. 2]

Water-to-air heat pump	Length-width-height (ft)	Weight (lb)
1 1/2-ton vertical unit	6.0 x 2.0 x 3.0	180
3-ton vertical unit	3.0 x 5.0 x 4.0	250
3-ton horizontal unit	6.0 x 2.0 x 3.5	250
5-ton vertical unit	6.0 x 2.5 x 4.5	330
11-ton vertical unit	6.0 x 3.5 x 3.0	720
26-ton vertical unit	6.0 x 5.0 x 3.5	1550

TABLE 6 Performance of Nine Representative Heat Pump Models at ARI Standard (240-75) Test Conditions*

Manufacturer	Heating Capacity MBtu/h	COP	Cooling Capacity MBtu/h	EER Btu/Wh	Water Flow (gpm/ton)
1. Singer CC-100	9.5	2.50	10.0	8.33	3.5
2. Dunham-Bush AQM-22	22.0	2.74	21.5	8.60	3.3
3. Singer CC and FV 400	41.0	2.73	40.0	9.09	3.5
4. American Air Filter - VW 40	46.5	2.89	40.0	8.69	3.3
5. American Air Filter - VW 51	58.3	2.91	51.0	8.64	3.3
6. Command-Aire SWP/H-800	126.0	3.1	100.0	8.50	3.2
7. Command-Aire SWP/H-1100	170.0	3.4	128.0	8.50	3.2
8. Command-Aire SWP/2000	274.0	3.1	210.0	8.5	3.2
9. Command-Aire SWP/2500	408.0	3.1	315.0	8.5	3.2

*

Test	Entering indoor air DB	WB	Water source In	Out
Cooling	80°F	67°F	85°F	95°F
Heating	70°F	60°F (max)	60°F	**

**Existing water temperature depends on the water flowrate as determined in the cooling test.

Future water-to-air heat pump ratings will be based on ARI Standard (320-76) which calls for a 70°F inlet water temperature instead of the 60°F called for in Standard (240-75).

2.2.2 Heating and Cooling Performance of Water-to-Air Heat Pumps

Listed in Table 6 are nine representative models of water-to-air heat pumps in the full range of sizes available to the consumer (2, 16). From these results one notes a trend of increasing heating COP with size which was not present in the air-to-air heat pump. The EER for cooling performance does not show this trend for water-to-air heat pumps where as it did increase with size for air-to-air heat pumps. The rating conditions for these heat pumps are given in the notes at the bottom of Table 6. Significant changes in output and performance are obtained if changes in the source water temperature occur.

2.2.3 Costs and Reliability

Estimated capital and installed costs for water-to-air heat pumps are shown in Figure 11 as a function of size. Shown in Figure 12 are the operation and maintenance costs for water-to-air heat pumps. The capital and installed costs are less for water-to-air heat pumps than for air-to-air heat pumps. However, for cooling applications, additional equipment (cooling tower) may be required on this type of system. Again, for these types of heat pump systems, the reliability is apparently quite good and more than likely is better for water-to-air systems than for air-to-air systems.

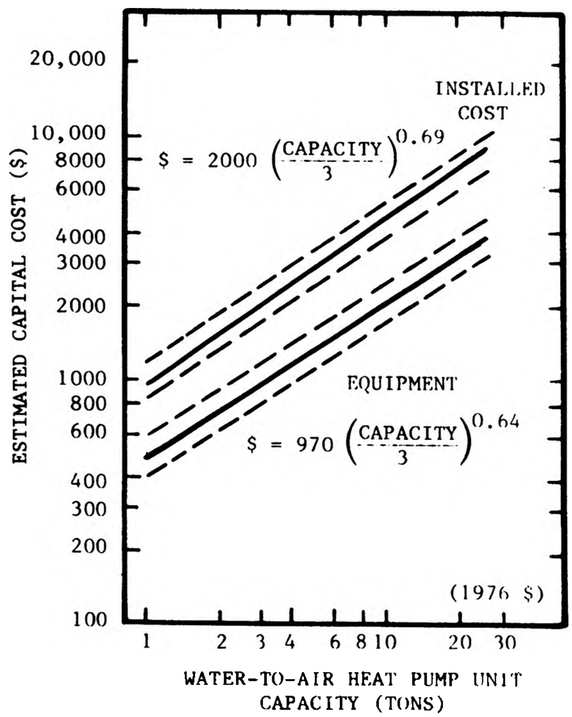

Figure 11. Estimated Capital Cost for Water-to-Air Heat Pumps

3. INNOVATIONS

Several authors (1, 2, 6, 7, 9, 12, 13) have recently discussed improvements and innovations in heat pump design and utilization. There is the possibility for large improvements in the performance of heat pumps. Table 7 compares the actual integrated COP to the theoretical COP for air-to-air heat

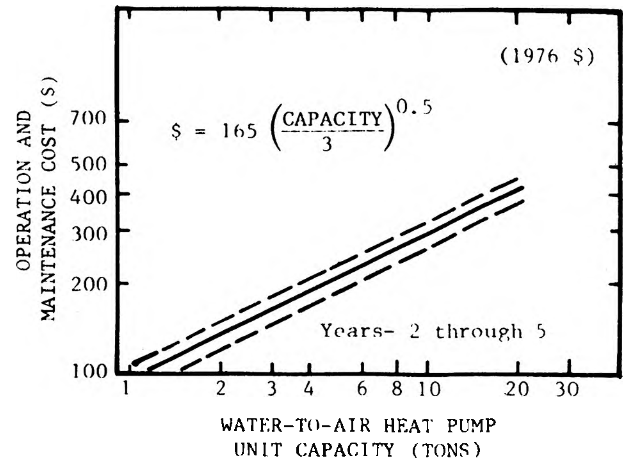

Figure 12. Estimated Operation and Maintenance Costs for Water-to-Air Heat Pumps

pumps at different outdoor air temperatures. There is significant room for improvement with the application of innovative design concepts.

TABLE 7 Theoretical and Actual Coefficients of Performance [Ref. 1]

Outdoor Air Temperature (°F)	Theoretical Maximum COP	Actual Integrated COP
60	12.1	3.48
50	9.95	2.93
40	8.46	2.61
30	7.37	2.46
20	6.51	2.32
10	5.85	2.03

For the air-to-air heat pumps opportunities are present for improvement in compressor efficiency at part load operation of the heat pump, defrost initiation and termination, interface between heat pump and solar space heating systems, and storage augmented air-to-air heat pumps. For the water-to-air heat pump similar opportunities exist.

3.1 MULTI-SPEED COMPRESSORS

In order to accommodate the variable load required by heat pumps some method other than on-off cycling could be used. Infinitely variable speed compressors would be ideal for heat pumps, however, they are not economically feasible at this point in time. Two-stage or two speed compressors are new in the heat pump market and are able to better handle the variable loads required of heat pumps. Compressor manufacturers estimate a 13% to 18% advantage in heat pump seasonal ratings with a two speed compressor over those of a single speed model. The low speed compressor is used for cooling and for heating when the outside temperature is above the balance point and the high speed compressor is used when the outside temperature is below the balance point. With this type of operation there is less cycling of the heat pump and thus an improvement in the seasonal performance factor. This improvement in seasonal ratings will have to be weighed against the increased size and cost of the improved compressor.

3.2 DEFROST CONTROL

Defrost control, which is generally considered a major problem in air-to-air heat pumps, is being given wide spread attention since it has experienced difficulty in operation reliability and efficiency losses. It is not unusual for a heat pump to go through 400 to 500 defrost cycles per year. In common use today are defrost control operations based upon time/temperature, temperature differential, air pressure differential, and other combinations. A new approach, which shows promise of being more reliable in terms of initiation and termination of defrost, is to sense the electrical loading of the heat pumps condenser fan motor. Some manufacturers are also investigating electric heater defrost rather than hot gas defrost. Another innovation being studied is coating (teflon) of the surfaces on the frost forming coil in order to accelerate the removal of the frost.

3.3 SYSTEM COMPONENT MODIFICATIONS

Some proposed modifications to the heat pump system components show promise of giving excellent performance characteristics with reduced defrost time. These modifications consist of redesigning the accumulator/receiver and the use of capillary tubes for expansion of the refrigerant. Other investigators have suggested modifications such as: parallel compression processes for increased capacity, cascade cycles which use two different refrigerants over the large temperature range, multi-stage compression for reduced overall pressure ratios, and two stage compression with intercooling and flash gas removal.

3.4 ADD-ON HEAT PUMPS

In recent years add-on heat pumps have been developed and are now commercially available. The add on units are designed to be added to existing furnaces. The add-on heat pump is designed to operate with the existing furnace from the balance point down to about 10°F. When auxiliary heat is required the existing furnace is used. Below 10°F the existing furnace takes over the full heating load. In this manner the existing gas or oil furnace can supply the heating load at low temperatures, where the heat pump is inefficient, and avoid electric resistance heating as the supplementary heat.

3.5 ANNUAL CYCLE ENERGY SYSTEM

The Annual Cycle Energy System (ACES) also shows promise of making residential heating and cooling more energy efficient (8). During winter operation ice is generated and stored in a tank and the generated heat is used for heating purposes. During the summer operation the ice is used for providing space cooling. The system has the capabilities of combining solar collectors with air-to-air heat pumps and/or dual source heat pumps. Currently, there are seven experimental ACES systems in operation and another six under construction.

3.6 SOLAR ASSISTED HEAT PUMPS

Solar assisted heat pumps for residential applications have received a great deal of attention during the past five years. This type of system combines a solar heating system with a heat pump in order to provide the necessary heating and cooling requirements. Both air-to-air and water-to-air heat pumps can be used in this system. The solar system basically collects the energy for the heating requirements and the heat pump supplies this energy at the proper time and temperature and also helps to improve the efficiency of the solar collector in the water-to-air operation mode.

In Figure 13 several possible combinations of solar assisted heat pumps are depicted. A <u>parallel</u> system would use solar energy in the heat exchanger first and then the air-

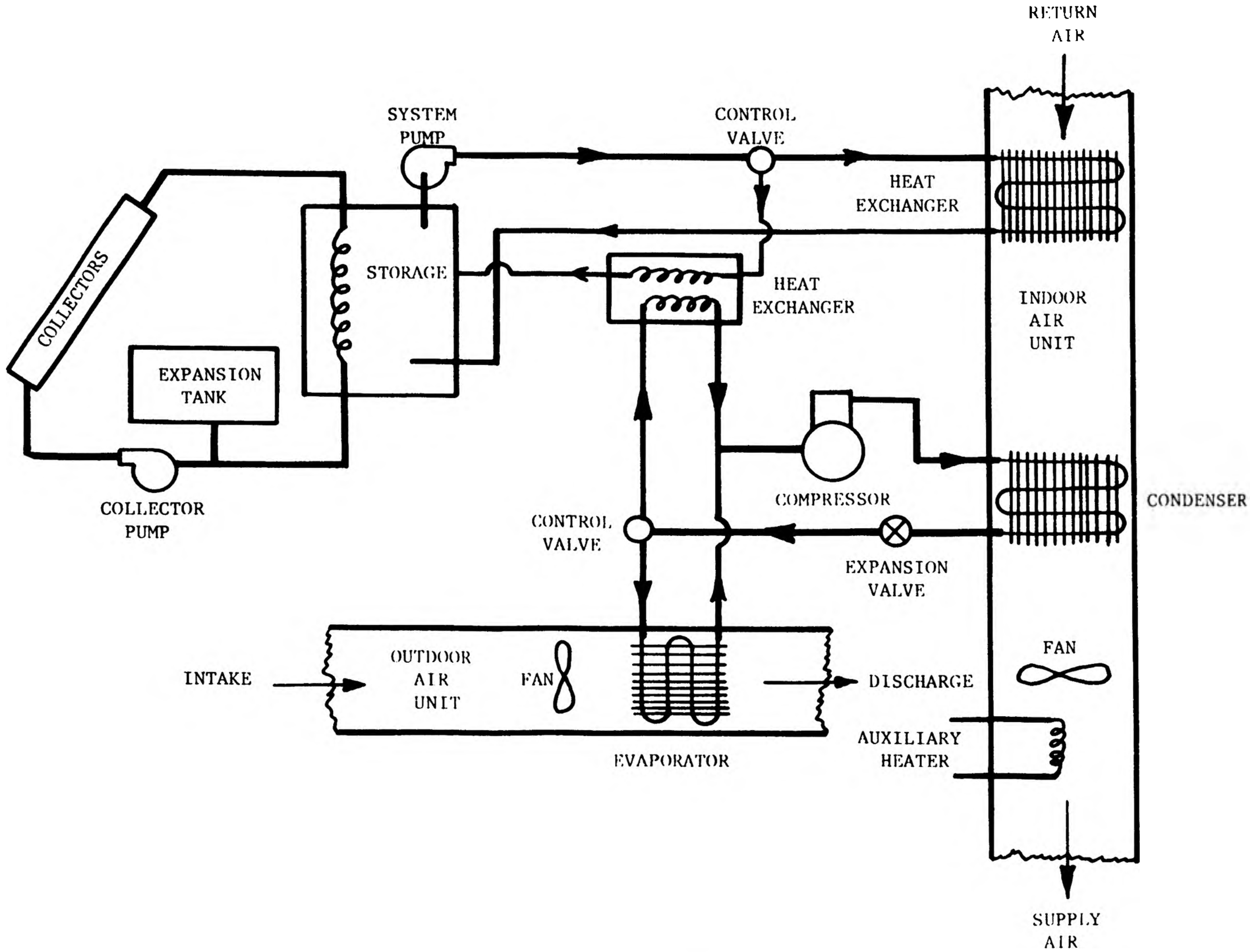

Figure 13. Solar Assisted Heat Pump Combinations

to-air heat pump when the solar coil is unable to provide the necessary heat. A <u>series</u> system would use the solar energy in the heat exchanger first and then the water-to-air heat pump when the solar coil is unable to provide the necessary heat. A <u>dual source</u> system would have the choice of either an air heated coil when warm air is available or a water heated coil when warm water is available. Dual source heat pumps are currently in the development stage. In this type of system the source for heating can come from either air or water. This type of capability would be advantageous in the solar assisted heat pump, the ACES system, and applications where well water is available as a source during the heating season. This type of heat pump system would also alleviate the need for a cooling tower when the heat pump operates in the cooling mode.

It is not unusual for the solar assisted heat pump to save up to 20% in operating costs during the heating season when compared to an air-to-air heat pump. This represents a heating coefficient of performance of almost three. It has been reported that parallel systems can save up to 50% of the energy required (10) when compared to electric resistance heating. Series systems can save up to 60% of the energy normally required (11). Dual source systems can save (10, 11) up to 70% of the energy normally required.

3.7 CHEMICAL HEAT PUMPS

Chemical heat pumps are a new concept that utilize reversible chemical reactions for absorbing and releasing low level energy at two different temperature levels (6, 14). Very little power is required to operate the system and preliminary calculations show that the seasonal coefficient of performance may be in the range of 1.5 to 1.8. Two major problems exist; corrosion and the ability of storing the energy for when it is needed.

3.8 GAS FIRED HEAT PUMPS

Gas-fired heat pumps have been under investigation for many years (6, 7). These are in the form of the Stirling-Rankine heat pump, the organic fluid absorption heat pump, and the Brayton-Rankine heat pump. These types of heat pumps are in the feasibility and development stage at this time.

4. CONCLUSIONS

Heat pump technology is currently undergoing a rapid evolution and many of these innovations show promise for improving the energy efficiency of residential heat pumps. During the last fifteen years the performance and reliability of residential heat pumps has improved tremendously. There are promising innovations being developed which will emerge in the near future as standard "off the shelf" devices for residential heat pumps.

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6. BIOGRAPHIES

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