HEAT PUMPS—WHO USES THEM AND WHY?

G. C. Groff, Groff Associates, Cazenovia, New York, U.S.A.
President, IIR Section E: Heat Pumps and Air Conditioning

ABSTRACT

Heat pumps have been applied in industry and as building space-conditioning systems since the latter part of the 19th century. Today, more than 130 million heat pumps are installed worldwide with more than 15 million new heat pump systems installed each year. Attributes of this technology include energy savings, environmental benefits and the opportunity to provide a self-contained complete heating and cooling system for residential and commercial buildings. This paper reviews the historical development of heat pump applications and, through this historical overview, attempts to answer the question: "who uses heat pumps and why?" The question is timely as construction of new buildings and industrial processes continues to grow worldwide, requiring increasing quantities of energy. Comments on the future prospects of heat pumps and on impediments and opportunities for market growth are offered.

Key Words: ***heat pumps, air conditioning, energy systems, thermal engineering***

1 INTRODUCTION

It is estimated that there are more than 130 million heat pumps installed and operating worldwide, serving industry, homes and businesses. With approximately 15 million heat pumps now sold annually in Asia, 2 million in North America and several hundred thousand in Europe and other parts of the world, it is clear that a robust market for these systems has been established. With economic developments occurring in a number of countries with large populations and continued growth in the industrially developed economies, increasing quantities of energy will be required to fuel this growth. The expanding global challenge of ensuring adequate energy supplies, the cost of fuel, and the attendant environmental matters suggest that heat-pumping technologies can be valuable assets in the toolboxes of system designers and engineers. In the following, a historical review of heat pump applications is undertaken with a view to understanding what motivates heat pump use and what results have accrued from use of this technology over the past 150 years since the heat pump concept was first proposed.

2 HEAT PUMP AWAKENING – THE FIRST CENTURY (1852–1950)

Important milestones in the history of thermal engineering were the manuscript of Sadi Carnot on heat machines in 1834 and, in 1835, Jacob Perkin's British patent for his mechanical vapour compression cycle refrigeration machine. It was not until 1852, however, that the first proposal to use refrigeration systems for heating purposes was made by William Thomson (Lord Kelvin), in a paper to the Glasgow Philosophical Society titled "On the Economy of the Heating or Cooling of Buildings by Means of Currents of Air." Later Lord Kelvin would add a note to his paper saying: *"The method of heating air described in the article remains unrealized today. When Niagara is set to work for the benefit of North America through electric conductors, it will no doubt be largely employed for the warming of houses over a considerable part of Canada and the United States. But it is possible that it will also have applications though less large in other cold countries to multiply the heat of coal and other fuel, and to utilize wind and water power for warming houses."* Thus, by the middle of the 19th century, Lord Kelvin had already presupposed the usage of heat pumps as they have developed over the past century and a half; namely electrical heat pumps and heat pumps driven by primary energy.

One of the earliest known applications of the heat pump cycle was for a salt works in the village of Ebensee, in Upper Austria (Krenn, Ritter, Schneeberger, 1986). The engineer Peter Ritter von Rittinger determined that, in comparison with the direct firing of wood, considerable energy savings could be achieved by supplying the heat for evaporation of water from the brine solution by an open-cycle heat pump and, after vapor compression and condensation, supplying the heat of condensation back to the brine evaporators (Figure 1). The two 4 MW compressors were driven by hydropower.

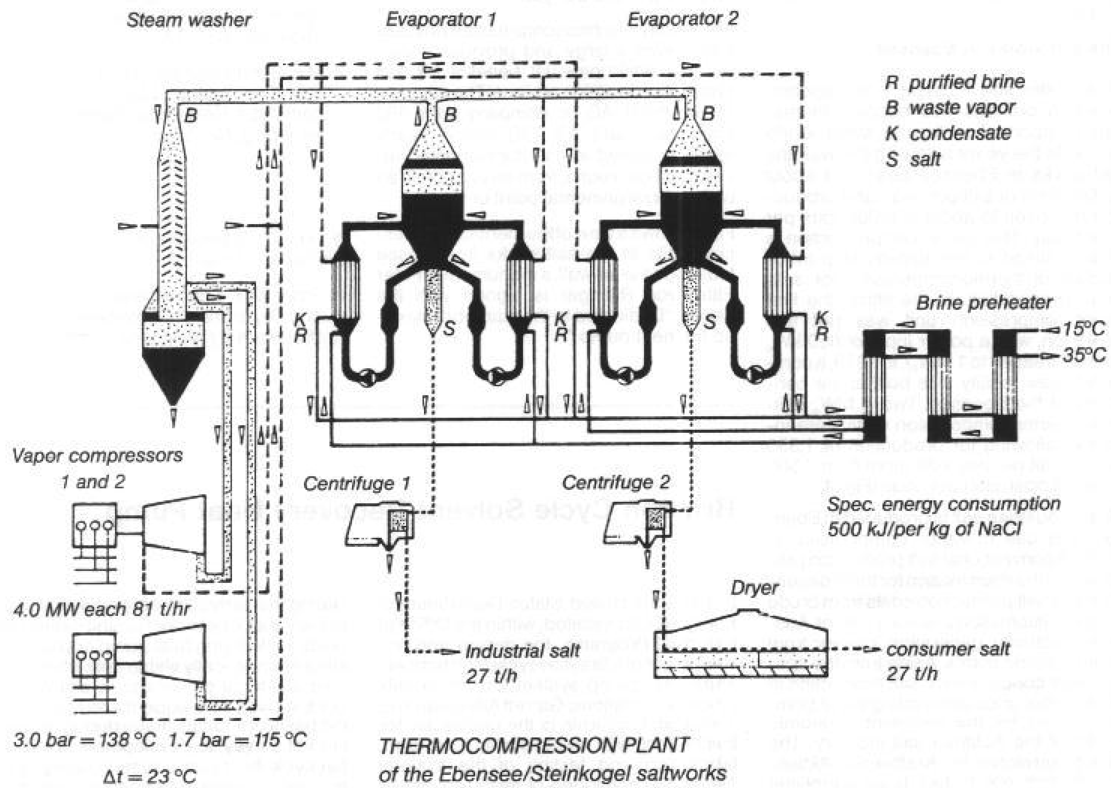

Fig. 1. Thermocompression Plant in the Saltworks of Ebensee/Steinkogel – system schematic

This application of a thermodynamic principle to achieve more efficient utilization of energy for industrial processes was an outgrowth of the industrial revolution, where mechanization of processes permitted much greater production output than with manual labor (with attendant greater need for energy to fuel these processes). The quest for ways to conserve energy became paramount as wood and coal sources were depleted. A shortage of coal in Switzerland during World War II due to the cut-off of supply from Germany led to the application of heat pumps, such as a vapor compression system installed in Zurich for a swimming pool in that period. Here an ammonia evaporator used the Limmat River as the heat source and, after compression, the condenser heat was used to heat the showers, floors, etc. as well as the pool water. After the war, heat pumps were applied in Switzerland for industry, such as the compression heat pump at the Fischer Schaffhausen steel plant. The cooling water of air compressors used for the steel production was accumulated and supplied via a pump to both the evaporator and the condenser of a vapor compression system with a stationary-vane compressor. The water stream going to the evaporator of this plant was cooled down and released to the ambient. The condenser water was heated to temperatures suitable for supplying the showers for the steel workers.

In 1931, a heat pump was installed in the office building of the Southern California Edison Company in Los Angeles and in 1932, Willis Carrier installed his first heat pump at a Utility Company in Uji, Japan. The first European heat pump for space heating and cooling was installed, in 1938, for the city hall in Zurich. This unit is still operating.

One of the earliest residential installations was made by T. G. N. Haldane in 1928 (Thevenot 1979) where he used a closed vapor compression cycle on his Scottish home. Modern technology was applied in the application of a heat engine as the prime mover with the possibility of ice production for cooling. The first applications of heat pumps in buildings in the United States occurred in the 1930s. Here, together with the possibility of air conditioning, they offered the advantage of clean electrical heating. Different approaches from those used today were employed for handling the winter and summer requirements. One system approach changed the airflow streams according to the heating or cooling task, with the refrigerant circuit unchanged. Another approach used two condensers and two evaporators, together with one compressor. The perfection of a reversing refrigerant circuit was not to be achieved for another 25 years.

3 EMERGENCE OF A MASS MARKET (1950–1960)

Prior to World War II there were only about 20 heat pumps installed in the United States, but after World War II the number grew rapidly as the demand for housing, accumulated from the war years, provided impetus to large mass-produced housing developments. This, in turn, stimulated development of heating and cooling systems that were factory-assembled and easily installed at the building sites. In the southern regions of the U.S., where both heating and cooling is required during the year, heat pumps were very attractive in comparison to separate electric cooling units and gas- or oil-fired warm air furnaces. By the mid-1950s, unitary heat pumps for residential and small commercial buildings were available from several U.S. manufacturers. Two thousand heat pumps were sold in the U.S. in 1954; this grew to 76,000 by 1963 and to 325,000 by 1976.

A booming economy in the U.S. and abroad during the 1950s, and the emergence of nuclear power generation, with the promise of very low cost electricity for industry and consumers, stimulated high interest in electric heating for northern climates and for heat pumps in the southern areas. The strong economic environment after the war provided stimulus for extensive building projects (commercial as well as residential) and heat pump systems gained increasing recognition as an energy-efficient solution for many of these projects. Champions of these systems emerged, such as the engineer J. Donald Kroeker of Portland, Oregon who employed heat pumps successfully on a number of high-profile buildings, including the Equitable Savings and Loan building in Portland (1948) and the Southdale Center in Minneapolis (1956). The Equitable building, which is now a National Historic Mechanical Engineering Landmark, is cited as the first commercial heat pump installation in the U.S. During World War II, there had been a moratorium on the construction of commercial buildings in the U.S. In 1946, a partial relaxation on commercial building was granted under a permit system, and the chairman of Equitable went to Washington D.C. seeking such a permit. Approval was given and the Equitable building was the first large commercial building permitted after the war. It was special in a number of ways, including the architectural style, which used natural colored aluminum sheathing, cast-in anodized aluminum spandrels and heat absorbing green-tinted glazing. As the building had no operable windows, it required an air conditioning system capable of providing comfort year-round. The Equitable chairman had learned about heat pumps being used in England and he pressed for the use of such a system on his new building. The office of J. Donald Kroeker was selected as the engineering firm to design the hvac system. The system uses well water as the heat source, a solution that Kroeker used on numerous subsequent building system designs. A description of the building and heat pump system may be found at www.asme.org/history/brochures/h046.pdf. See also (Graham, C.E., Kroeker, J.D. and Chewning, R.C. 1949).

The Southdale Center marked the construction of the first fully enclosed, environmentally controlled, shopping mall design, with 80,000.sq. meters of retail area (now expanded to 160,000 sq. meters). The concept for the center also arose from changes occurring after World War II. Minneapolis, like most growing cities, was undergoing population growth and other changes that meant increased dispersion to areas outlying the city. These changes provided increased demands for suburban shopping facilities.

Business was moving to the suburbs to meet the new trends. The idea of the Dayton brothers who managed Minneapolis' largest department store, was to create a unique shopping environment, which would be part of a larger development. It would meet suburban needs and, at the same time, relieve some of the pressures on the city center. After extensive study of population trends, income and purchasing power, etc. the project was announced. Victor Gruen, an Austrian-born architect, was chosen to head the design of the center and J. Donald Kroeker was selected to design the environmental-control system (Floreth, J. J. 1957). Kroeker again used well water as the heat source. Natural gas-fired engines drive the compressors and waste heat is captured from every possible source within the building. Fresh air supply ducts were eliminated by using the enclosed three-story Garden Court as a giant air plenum, providing primary summer cooling and winter heating. The fresh air was filtered through foliage of the trees in these areas. The center was opened in the fall of 1956. Based on the success of this building design, the developer used many of the same system concepts on subsequent projects.

Fig. 2. Southdale Center in Minneapolis, Minnesota

The years 1949 to 1958 were productive in the exploration of new energy systems and applications to serve burgeoning industrial, commercial and residential sectors. The ASHRAE Composite Index of publications lists 45 publications specifically devoted to heat pumps in this period. The titles are indicative of the range of interests of researchers in that era, e.g.: "Animal heat offers source for heat pump operation," "Heat pump efficiency improved with variable capacity compressor", "The heat pump water heater," "Sizing earth heat pumps," "One year with the air-source heat pump," "Solar heat pump promises better competition", "Potentiality of the window air conditioner as a heat pump," etc.

As mentioned earlier, the advent of nuclear power added impetus to efforts to introduce heat pumps. Moreover, this interest extended well beyond the U.S. A note in a 1956 British publication (Komedera, M., 1956) stated, *"A possible method of using electrical energy in a more efficient manner is by employing the heat pump cycle. The high coefficient of performance (COP), which usually lies between 2 and 5, raises the overall efficiency for electrical heating from 28% to over 100%, and at the same time, all of the advantages of electrical heating are retained. Since the heat pump also gives cooling with the same equipment that is used for heating, it offers a substantial advantage over other methods. It is easy to see, therefore, why the electrical industry is taking more and more interest in the developments that are carried out in the field. The heat pump seems to be the only logical answer to the present fuel economy problems, since nearly all the heat losses at the power station can be regained by the consumer."*

By the latter part of the 1950s heat pump products were being produced by a number of U.S. manufacturers, including companies with experience with air conditioning and refrigeration products and some with no such experience. The enthusiasm with which the power utility companies embraced heat pumps as a potential source of increased electricity sales, and the apparent business opportunity afforded to manufacturers who wished to take advantage of this market development, combined to produce a large market influx of products of questionable quality and performance. This situation was exacerbated by the lack of trained installers and service people who understood refrigeration circuits and the special aspects of heat pump applications. Unfortunately, some catastrophic failure situations cast a cold shower on this exuberant effort. Although there were many individual heat pump problem installations that emerged by 1960, the failures experienced at some large military housing installations gained perhaps the greatest notoriety and produced far-reaching consequences. The U.S. government applied strong pressure on the electrical utilities and the air conditioning manufacturers to resolve the massive field failure situation. The Edison Electric Institute (organization of electric power utilities) and the Air Conditioning and Refrigeration Institute, the manufacturer’s trade organization, joined forces and quickly formulated a plan of action that included the award, to two manufacturers, of contracts to develop split-system and packaged-heat pump models (one manufacturer for each type) that would provide much improved reliability and performance in a wide range of climates and operating situations. Carrier Corporation undertook the development of the single-package unit and Westinghouse the development of the improved split-system unit. A trial program to test these units in actual applications was then mobilized together with the power utilities. This program was arguably the most important step in the history of unitary heat pump development, as the design concepts employed became the standard for nearly all heat pump products manufactured for many years.

Sadly, the notoriety of the catastrophic failures, along with the “once-burned” reaction of many power utilities, essentially snuffed-out the momentum and market interest for heat pumps until the mid-1970s. The cost of the repair and resolution of the heat pump field failures left a very bad taste in the mouth of all parties, manufacturers, utilities, homebuilders, and consumers. Those manufacturers who had stepped-up to effect the necessary improvements to their products continued to sell heat pumps throughout the next decade and a half, but these were installed primarily where the heat pump served special situations. One interesting result was that there was virtually no motivation to change the product designs throughout this period, a fact that became very important in the study of heat pump reliability when interest in heat pumps reoccurred following the oil embargoes of the mid-1970s. However, the development of a robust market for small heat pumps, that appeared so promising in the early 1950s would have to wait. The perceived value of this technology for mass-market growth was at its nadir.

4 THE CALM BEFORE THE STORM (1960 – 1975)

The respite period for heat pumps lasted for approximately 15 years, during which time there was little public attention given to these systems. This is not to imply that heat pumps installations had ceased; to the contrary many installations were made where heat pumps were promoted by local or regional utilities, as in the Pacific Northwest of the U.S. where hydropower and special climatic considerations made such systems attractive. Similarly, in Southwestern U.S. areas where the climate is very dry, hot in the summer and with chilly days in the winter, heat pumps became the system of choice for large home developments. Most of these residences had no basements and the packaged heat pumps were installed on the roofs of the homes, often in combination with evaporative coolers.

It was during these years that severe competition arose between electric utilities and the gas utilities, driven by the continued belief that electricity generated from nuclear power plants would become the primary energy supply for residential and small commercial buildings, with fossil fuel usage increasingly limited to industrial use. Extensive programs to launch “all-electric homes” were prevalent during this period in the U.S., Canada and Western Europe. The gas utilities bitterly fought this trend, investing extensively in research on gas-fired cooling systems and programs to maintain the market share for the attractive residential and commercial sectors. In these years it seemed to many that the gas interests were fighting a losing battle, as size and cost of the gas-fired systems represented a major competitive barrier.

A large inventory of homes and commercial buildings dependent on electricity without back-up fuel supplies accumulated during this decade and a half. Slowing of the trend occurred only as the concerns over nuclear power generation began to be significant and it was realized that high electricity demands during peak periods resulted in very high generation costs. By the early 1970s the appetite for energy had become ubiquitous with the increase in energy-consuming appliances in homes and commercial buildings. This growth in consumption placed the U.S. and other industrialized countries that were dependant on oil at increased risk, since a large percentage of the energy supply was imported. Imports were stimulated by the availability of relatively low cost imports from the expanded mid-eastern and South American oil fields).

This situation became critical in 1973, when the supplies of imported oil from the mid-east were abruptly cut-off. In 1974 the IEA was established by OECD countries to attempt to deal with the management of the now-scarce oil supplies. The electric power utilities in colder climates were under severe duress as they had large constituencies dependent on them for electricity and new power plant construction had been slowed and, in the case of nuclear plants, virtually stopped. Many of these utilities initiated efforts to find more efficient means of heating their electric homes and to find ways to manage peak power usage. Of the various alternate energy system possibilities only heat pumps seemed to have been developed to the point, and could be considered to have reasonable cost, so as to be candidates for broad market use. Thus, many individual utilities, utility groups or organizations, and government agencies, began serious inquiries into the possibility of a new heat pump era. The IEA identified heat pumping technologies as one of the key strategies for building energy conservation and as a priority area for collaborative international R&D. This was the beginning for the Heat Pumping Technologies Implementing Agreement under which this conference is organized.

Some notable studies undertaken in this period include a report on “Assessment of R&D Needs Related to Heat Pump Technology for Space Heating and Cooling” (Crane, R.E., Lorsch, H.G., and Steigelmann, H. W. 1976) for the Executive Office of the President, Council on Environmental Quality, a report on “Evaluation of the Air-to-Air Heat Pump for Residential Space Conditioning” (Gordian Associates 1976) for the Federal Energy Administration, and a report on “Heat Pump Technology, A Survey of Technical Development Market Prospects” (Gordian Associates 1978) for the U.S. Department of Energy. These studies were commissioned to provide policymakers with information on potential solutions to the impending fuel supply shortage and increased winter load on electric power utilities.

5 REDISCOVERY OF A USEFUL TECHNOLOGY (1976 – 1990)

Paralleling these government-instituted studies, major program initiatives were also undertaken, as early as 1975, by electric power utilities and utility consortia such as Niagara Mohawk Power Corporation and ESERCO in New York State and by the Electric Power Research Institute. These investigations were directed to design and development of heat pump systems for improved performance and reliability in northern climate applications. These groups sought collaboration with major U.S. manufacturers in undertaking these studies, with a view toward rapid qualification and commercialization of new products to meet their desire for higher efficiency electric heating appliances. Manufacturers who participated in such programs gained a great deal of knowledge (as usually occurs during crisis situations) concerning heat pump operating conditions occurring in a broad range of application situations and the need for designs that could effectively handle these situations. One program, undertaken with EPRI sponsorship and in conjunction with Niagara Mohawk Power Corporation, involved detailed monitoring of a number of actual residential heat pump installations across the northern United States. In this program methods were developed to measure, for the first time, in-situ performance and efficiency, as well as a number of important refrigerant circuit parameters. Computer simulation programs were developed that could be adjusted to provide performance information corresponding to the field data (Groff, G. C. and Bullock, C. E. 1976; Groff, G. C. and Reedy, W.R 1978; Bullock, C. E., Wroblewski, D. E. and Groff, G. C. 1983).

The simulation program was then used to study broad sets of application situations. Early in the program the researchers arranged collaboration with Alabama Power Company who had an extensive data base of heat pump reliability information (Lovvorn, N. 2005). Through this collaboration detailed analysis of individual heat pump product defects and failure modes was undertaken, providing insights into the design of components as well as system design and operation for improved reliability and performance. These were subsequently incorporated into products manufactured by the researcher's company.

By the end of the 1970s new heat pump designs with improved features and benefits were beginning be sold in large numbers (sales in the U.S. reached 325,000 units in 1976). Heat pumps finally had become a significant part of annual unitary space-conditioning product sales. Figure 3 below shows the growth of annual U.S. heat pump sales through 1980. Although sales of 1 million heat pumps per year by 1980 were projected by trade journals, after 1978 the renewed availability of natural gas at attractive prices, together with a turn-down in building, resulted in declining heat pump sales.

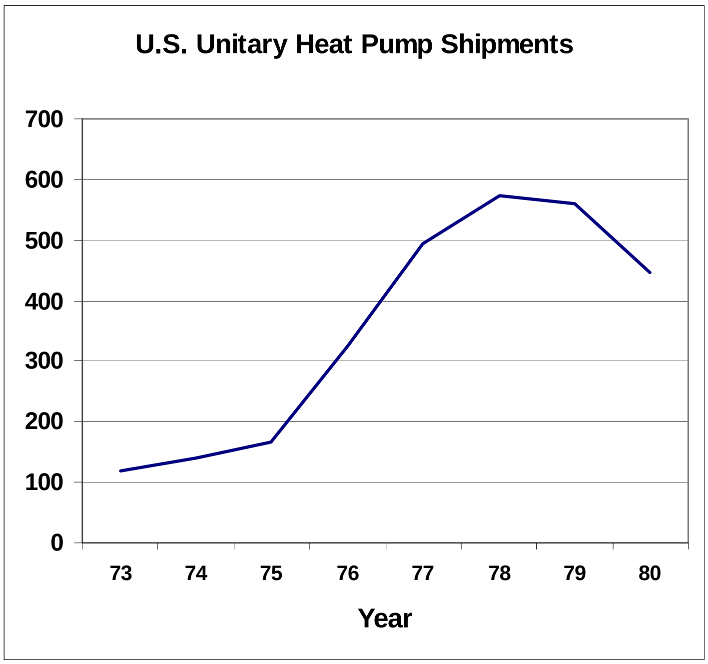

Fig. 3. U.S. Unitary Heat Pump Shipments

Following the oil shocks of the mid-1970s governments of industrialized countries launched energy conservation programs that included proposals for minimum appliance efficiency standards and testing and certification programs. In Sweden growing public sentiment directed against nuclear power generation resulted in strong initiatives to reduce building and industrial energy consumption so as to enable dismantling of existing nuclear power plants. Heat pumps were identified as a key strategy in the effort to replace the power production of these existing plants. EdF, the large French national utility, initiated a special program called P.E.R.C.H.E. (Vidal 1984) to introduce heat pumps in the tertiary sector (residential and small businesses). Manufacturers were urged to develop heat pumps suitable for these applications, with particular emphasis on substitution for inefficient oil boilers, direct electric heaters and electric boilers. By 1980 substantial government-directed programs to encourage heat pump usage were underway in Germany and Austria, and in Japan, where Tokyo Electric Power Company spearheaded a major program to introduce heat pumps for residential heating. Increasing winter peak loads and concerns over cost and availability of traditional natural gas and oil supplies were the common factors in all of these programs. With the exception of Japan, these initiatives all followed the American experience with too many unqualified products from inexperienced manufacturers and too little installer/service infrastructure and training. At the ISH Exhibition in Frankfurt in 1983 heat pump models (for both space-and water-heating) from more than 130 manufacturers were displayed. Sales of heat pumps in these countries increased very rapidly, and then fell, by the mid-1980s, just as rapidly. Renewed supplies of oil and gas, at attractive costs, accelerated the decline.

The research activity described earlier, with monitoring of U.S. northern climate homes, was extended, in 1980, to a similar effort in France, in conjunction with EdF and CETIAT. During the ensuing three or four years this program produced studies on air-to-water heat pumps designs for existing and new French homes, for commercial buildings such as banks, offices and large multi-family residential buildings (Groff, G.C., Bullock, C.E. and Hough, R. E. 1984; Groff, G.C. and Moreau, J.P. 1983; Groff, G. C., Bullock, C.E. and Reedy, W. R. 1978). From this program advanced heat pump designs for application to French homes were proposed and prototype units were constructed, installed on existing buildings and monitored for two heating seasons. Design features incorporated in these units included advanced refrigerant-to-water heat exchangers and electronic defrost controls. Companion units were installed in the U.S. and were similarly monitored to obtain comparative information. Interest in heat pumps had been stimulated by the potential energy conservation benefits of heat pump technology and the growing sales in North America and Japan.

Internationally, researchers were anxious to explore component and system designs and applications to achieve lower cost, more reliable and higher performance heat pumps. In the wake of the oil shocks policymakers were exploring approaches to ensure that adequate energy resources would be available to their constituents and quickly initiated a variety of energy conservation measures. Manufacturers became interested in new business opportunities that could accrue from the heightened public awareness for energy conserving products. All of these groups were, of course, interested in what was going on in these respective areas in other countries. This led to a convergence of these interests. In 1979, for example, Carrier Corporation held an International Symposium on “Heat Pumps and Space Conditioning Systems for the 1990s” (Carrier 1979) in which a number of experts from Europe and North America were invited to present papers concerning activities and projections for the future on those topics. It was a remarkable milestone for a U.S. manufacturer. Also, in the late 1970s the IEA Advanced Heat Pump Program initiated a study to collect and evaluate data on advanced heat pumps to assess their market potential and to derive relevant proposals for desirable developments and a future IEA collaborative R&D program. This study was published in 1980 (International Energy Agency 1980) titled “Common Study on Advanced Heat Pump Systems.” General conclusions from the study were:

1) *In the 13 participating countries there is a large and extremely diverse R&D programme covering most of the possible advanced heat pump systems. The present situation is that following the stimulus for the first energy (i.e. oil) crisis of 1973 is that heat pump technology is emerging from many years of neglect.*
2) *The background situation in the participating countries is a continuing high degree on oil, mainly light oil, for domestic and commercial heating, particularly in Belgium, Canada, Denmark, Germany, Italy and Switzerland.*
3) *Electric heat pumps (for both heating and cooling) hold a predominate position in the U.S.A. as replacement for boilers and furnaces. In W. Germany a similar situation is developing with bivalent-alternative heating only heat pumps.*
4) *The first priority in most countries is to substitute for oil and a second priority is to conserve all energy forms. Present electric heat pump types meet the first priority but rarely contribute anything to energy conservation, unless compared to direct electric heating. Advanced heat pump types are capable of conserving between 30% and 50% prime energy and the best systems from this aspect are internal combustion engine driven. ………*
5) *Most advanced heat pumps are not due to commercialization until around 1985. Since they cannot be expected to make a significant contribution rapidly, the possibility of achieving worthwhile energy savings before 1990 appears low. Thus the accelerated development of the systems with greatest potential for each application is desirable, even if in the short term their use would not be justifiable solely on economic grounds.*
6) *The economic potential for all the advanced heat pump systems, although significant, is limited by strong competition from conventional systems, especially natural gas boilers and conventional electric*

heat pumps. …….. The overall conclusion of the study for R&D policy in participating countries is relatively clear. To expand the market share for advanced heat pumps as a group, R&D efforts should be focused on advanced heat pumps most likely to generate market potential by 2000, such as the absorption, Rankine-Rankine, and Diesel-Rankine systems. …………..

7) *From the Market Study it was not possible to estimate the total energy saving potential by the year 2000. However, it was estimated by the Executive Committee from data collected in the study that the prime energy saving potential lies in the region of 5%, depending on the successful competition of R&D and commercialization of the systems.*

8) *The capital costs of the advanced systems in general are still high compared with the conventional boiler or furnace costs. The reduction of first cost, a major factor influencing choice, should be a specific R&D priority. Good design and mass production should also greatly reduce costs.*

9) *The reliability, lifetime, service and maintenance of advanced heat pumps will in most cases prove initially troublesome. Suitable service and maintenance facilities and guarantees during the acceptance phase are essential factors in their acceptability. Pilot installations and close monitoring of earlier installations will assist in the controlled and orderly growth of the market and the necessary infrastructure.*

10) *There exists a diversity of financial, fiscal and other incentives to the development and use of energy conserving technologies, including heat pumps, in the participating countries. The effectiveness of these policies and possible alternatives in promoting the objectives of substitution for oil and conserving energy need investigation.*

11) *There are no international heat pump standards. There is a pressing need for uniform standards for performance and for definitions of terms and symbols. A further requirement is a code of practice for advertising and promotion to prevent the market for heat pumps being spoilt by misleading claims or unscrupulous promoters.*

12) *There is still insufficient activity to develop heat pump systems for industrial applications where large energy savings are possible through the use of this technology.*

Note that thermally operated heat pumps were a major element of the “advanced heat pump” family considered in this study.

This set of conclusions provides considerable insight into the thinking of representatives from the 13 participating countries – industrial countries in Europe, North America and Asia – at that time. It also provides a view of the reasons why the governments of those countries thought that heat pumps should be used, and why – the specific focus of this paper. Finally, many of the conclusions have withstood the test of time and are valid today. An update study was undertaken by the IEA in 1982 (IEA 1982) to examine progress and trends in participating IEA countries.

Another example of international cooperation on heat pumps was a conference on technology and application of electric heat pumps, organized by RWE, the German Power Utility, and EPRI, in 1980 (EPRI/RWE 1980). Heat pumps were also well-represented in an IEA New Energy Conservation Technologies Conference held in Berlin in 1981. A number of papers (IEA 1981) on heat pumps explored energy saving benefits in a number of application areas and countries (primarily North America and Europe). Unfortunately, the timing of this Berlin conference was coincidental with a substantial U.S. government energy-conservation-research budget reduction.

But, despite renewed supplies of oil and natural gas at very competitive prices, international research efforts directed to heat pump technologies continued and sales of these products continued to grow. In 1984 a unique event occurred. A special international conference devoted to “heat pumps – current and future prospects” was held in Graz, Austria. This conference was organized by the IEA Advanced Heat Pump Programme Executive Committee, in follow-up to the above-referenced study. Nearly 400 attendees traveled to Graz for this conference to hear lectures by 48 key government, industry, university and utility speakers. The conference was organized in three themes: Residential and Commercial Applications; Industrial and District Heating Applications; and Policy. The proceedings (IEA 1984) of this bellwether meeting are a valuable primer on heat pump technology, applications and policy that remains useful to the present day. Meeting participants included many key international people who would provide leadership in the promotion of heat pump technologies in ensuing years. It was a significant opportunity for discussion of mutual interests in the energy system field. Attendees returned from the meeting to their respective institutions with their batteries charged with ideas developed at the conference.

As noted earlier heat pump sales in the U.S. and Japan had already grown rapidly by 1984. This experience was an important stimulant for activity in other countries and the interest of other industrialized countries was a further validation to the U.S. and Japanese attendees. Of particular note was the presentation at the Graz conference of an outline of technologies that a Japanese manufacturer was pursuing in their quest to improve the economics, performance and reliability of heat pumps, especially for residential applications. This outline proved to be a preview of technological advances that would be introduced by the Japanese manufacturers during the next twenty years.

The success of this conference gave impetus to the institutionalization of the conferences as a major element of the IEA Heat Pump Technologies Programme, and this international conference has been held every 3 years since 1984.

The remainder of the 1980s reflected continuing efforts directed to heat pump improvements, with North America and Japan representing the major world market and manufacturing centers. Interest in heat pumps grew also in southern Europe with growth of demand for cooling. The reversible (mostly air-to-air) units sold in this region were sold primarily as air conditioners. Portable units became popular also, for small stores and boutiques. The outdoor section of these units was often wheeled indoors during the lunch period and at night. Flexible refrigerant and electric lines connected these sections with the indoor fan coils. Those countries that had established strong electric economies (France, e.g.) had embraced heat pumps to provide summer load for the electric generating stations to balance the large winter electric heating loads. This had not received a positive reception, since air conditioning was considered at that time unhealthy and an unnecessary luxury throughout most of Europe. Nevertheless, with the load demand-management needs of the power utilities, interest in air conditioning and heat pumps quietly, but steadily, grew. In Japan, the saturation of the market for space conditioning units followed the pattern of other appliances such as televisions and kitchen appliances and, by the late 1980s, reached more than 90% of target households. By the early 1990s heat pumps represented 90% of the total cooling and heating unit sales and they have continued near that level to the present.

6 NEW CHALLENGES – RESPONDING TO ENVIRONMENTAL ISSUES (1990 – 1999)

Availability and cost of competing fuels (primarily natural gas) adversely affected the market growth for heat pumps in most developed countries during the 1980s. The 1990s also brought new challenges for manufacturers and utilities in the imposition of new requirements for reduced environmental impact. In 1987 the Montreal Protocol brought world attention to the issue of ozone layer depletion and introduced limits to the production of CFC (chlorofluorocarbon) refrigerants. This was followed in a few years by the Copenhagen agreement which limited HCFCs (hydrochlorofluorocarbons). These two agreements essentially provided a death knell for the traditional safe and friendly (non-toxic, non-flammable) refrigerants upon which most of the world production of air conditioning and refrigeration equipment depended. Manufacturers were faced with the dual problem of finding suitable alternatives to these traditional refrigerants and developing product designs with higher performance to meet increasing government minimum efficiency standards. Utilities had also encouraged higher product efficiencies by use of incentives in order to positively address their growing load demands. New power plant construction had become prohibitively expensive and permits for such plants had become very difficult to obtain.

There was a period of economic difficulty worldwide in the early 1990s, and this was reflected in declines in building and in sales of air conditioners and heat pumps. The combination of these factors distracted manufacturers from pursuing new heat pump designs except as these products could be easily adapted from their cooling-only companion units. During the 1990s, working fluids comprised of azeotropic mixtures and blends became popular, and much effort was devoted to qualifying these designs in the field. In Europe, especially, interest was directed to HCs (Hydrocarbon refrigerants) such as propane and iso-butane, particularly where the quantity of refrigerant was not large (domestic refrigerators, e.g.), since these fluids are flammable. In North America and some other countries this alternative was not well received due to the risk of legal recourse in case of accidents.

The commercial interest in industrial heat pumps in North America and in many other many other countries has been disappointing. In 1993 the IEA Heat Pump Programme launched a collaborative study of potential applications. Through this effort a screening tool was developed to assist engineers in assessing energy savings benefits (IEA Heat Pump Programme 1995). Although a large number of potential cost-effective application areas were identified, little evident commercialization has occurred. The fact that such installations are capital intensive and require dedicated engineering efforts perhaps has limited interest except by individual cases where energy-conscious engineers in large corporations have become interested in the technology. In the early 1980s a number of heat pump products, such as heat recovery chillers, were introduced by manufacturers to attack perceived new business opportunities arising from the heightened interest in energy conservation. These heat pumps were installed in breweries, printing plants, wine production facilities, greenhouses and a wide variety of other applications. Some applications continue but there is little publicity given to the marketing of such products in most countries today.

In 1992 the IEA Heat Pump Programme undertook a major study (IEA Heat Pump Center 1994) to assess the status of global markets, technologies and policies. This was a very important endeavor and showed that despite the many barriers to heat pump acceptance heat pump sales were increasing in many parts of the world. A follow-up study was undertaken in 1997 (IEA Heat Pump Center 1999).

By 1990 the annual sales of heat pumps in North America for add-on and replacement equaled sales for new homes. This condition has continued, and increased substantially, during the past 15 years as heat pumps installed in the late 1970s and 1980s have reached their economic replacement age (in relation to repair frequency and cost, or reduced operating cost due to more efficient new models). Despite the fact that many of these older heat pumps continue to operate satisfactorily (Lovvorn 2005), many homeowners choose to purchase newer units for improved features and benefits including higher efficiency. Since the oil shocks of the 1970s concern over security of home and business heating systems has increased and many heat pumps are now sold together with a standard gas- or oil-fired warm air furnace. This gives a back up for the electric heat pump and the choice of fuels at lower outdoor temperature, depending on relative fuel cost and the efficiency of the heat pump at those temperatures.

Heat pump (and air conditioner) efficiency has increased dramatically since the early 1970s (Figure 4), driven by government minimum performance standards and utility incentive programs. From a shipment-weighted seasonal efficiency of 2.0 or less in the 1970s, heat pump *cooling* seasonal COPs (coefficients of performance) in the U.S. have increased steadily to a shipment-weighted level of over 3.0 by 2000. The step increase in 1992 resulted from a new minimum efficiency standard that took effect that year. Further increases are expected as a result of a new minimum *cooling* seasonal Coefficient of Performance level of 3.8 (hspf 7.7) which manufacturers must meet in January 2006.

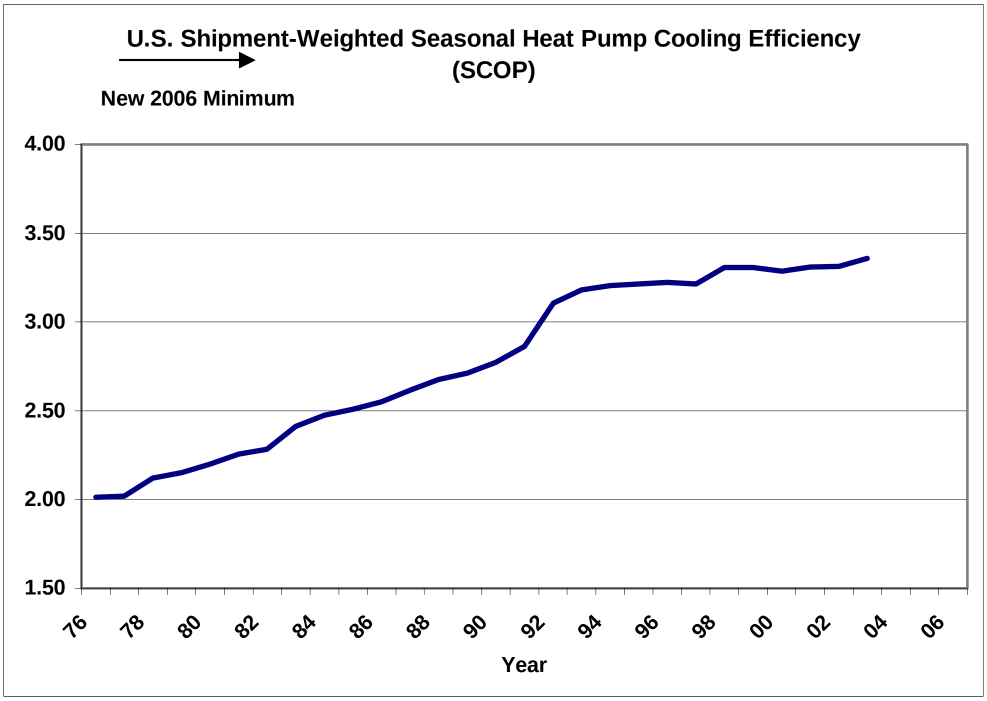

Fig. 4. U. S. Shipment-Weighted Unitary Heat Pump Seasonal Efficiency

7 SOLUTIONS FOR DEVELOPING NATIONS (2000–PRESENT)

At the IEA Heat Pump Conference held in Berlin in 1999 overviews of heat pump market and technology advances in various parts of the world were presented (IEA 1999). Notable in these reviews was the market growth in several emerging countries and regions (e.g., Southeast Asia, the Indian sub-continent and Eastern Europe). In most of these countries limitations in the energy system and infrastructure for design, installation and service of air conditioning and heat pumps represent barriers to growth. On the other hand these applications represent societal advances and there are not competing technologies or imbedded interests (other than cultural customs) to challenge the introduction of new technologies (Igarashi 1996). These countries and regions also present good possibilities for trial of new systems and technologies (Dinghuan, S, and Iwatubo, T. 1999). Energy savings and related environmental benefits of heat pumping technologies provide excellent reasons for use of these technologies in these developing countries. Attendees at the 7th IEA Heat Pump Conference held in Beijing (IEA 2002) in 2002 had the opportunity to see and hear of these advancements first hand. The broad and rapid expansion of activity underway in China with heat pumps was astonishing; especially the growth experienced in new buildings with attendant need for air conditioning and the introduction of ground-source units and industrial heat pumps for a wide range of applications. The climatic situation in China and other southeastern Asian countries, coupled with high urban population density, favor air conditioning. Sales have reached 18 million units each year with 60% of these reversible heat pumps. Rapidly growing power needs, to fuel the strong economic growth, demand that building and industrial systems be energy efficient. Heat pump technologies should have a very bright future in these regions, facilitating both societal and economic advances. Policymakers will have to be educated, however, on the benefits of heat pump technology and the importance of providing education and appropriate programs to stimulate its use and acceptance.

8 SUMMARY

As we bring this historical review of heat pump activities over the past 150 years to a close we may return to the rhetorical question posed in the title of this paper: "Who uses heat pumps – and why?." The motivation for early applications of heat pumps in the late 19th century and through World War II, for industrial processes is clear. As these processes were mechanized and improved for higher production the energy needs grew rapidly and, in many cases, exceeded readily available sources of supply. Nevertheless, it required good engineering and entrepreneurship (and a great deal of faith) to bring these installations into being. Similar factors stimulated growth in the application of heat pumps for a broad range of other applications in the first half of the 20th century. Space-conditioning heat pumps were a natural evolution of the growing interest for air conditioning in the period following World War II. The need for factory assembled, single-package heating and cooling systems for residences and commercial buildings in the period to 1973 gave impetus to the consideration of such systems. Engineers with vision, such as Willis Carrier and J. Donald Kroeker, who were conscious of the advantages of heat pumping technologies in larger building system environments, saw heat pumps as a valuable tool to be used in providing innovative solutions to new problems. Success with these applications also required great entrepreneurial spirit, coupled with very competent engineering skills.

A highly regarded text book on refrigeration published in 1956 (Jordan and Priester 1956) noted that: *"Practical considerations seem to limit present heat pump systems using air to climates like those of the extreme southern parts of the United States, where temperatures under 20F are not encountered."* Progress in heat pump designs for cold climates during ensuing years would render this comment obsolete. The advent of nuclear power generation, with the promise of abundant, low cost electricity for consumers and businesses, brought the beginning of a burgeoning "electric economy" in the 1950s and 1960s. This prevailed in North America and other parts of the world until the combination of the oil shocks in the 1970s and growing concern over safety of nuclear plants stifled this movement. The oil shocks brought a renewed interest in heat pumps to fulfill a need for a more efficient form of electric heating. Early problems with heat pump reliability and performance were surmounted and the heat pump once again was recognized as a useful alternate to traditional fossil-fired heating systems for homes and businesses.

Growth of heat pump sales in North America and Asia (Figure 5), and more recent market advances in Europe (IEA Heat Pump Centre 2004), demonstrate that today heat pumps are a respectable and increasingly popular space-conditioning system approach. Heat pump popularity is likely to gain with increased concern and interest in energy systems that offer reduced environmental impacts and energy conserving benefits.

Dr. Hermann Halozan, President of the IIR Commission E2 on heat pumps, notes (IIR Bulletin 2004) that today there are more than 130 million heat pumps installed worldwide, with this total growing rapidly each year. He estimates that these units currently reduce CO_2 emissions by about 0.13 Gt/yr, and with increased market growth to reach 30% of the building sector, the potential (with current technologies) is for 6% of worldwide CO_2 emissions of 22 Gt/yr. This could grow, with future technologies, to as much as 16%.

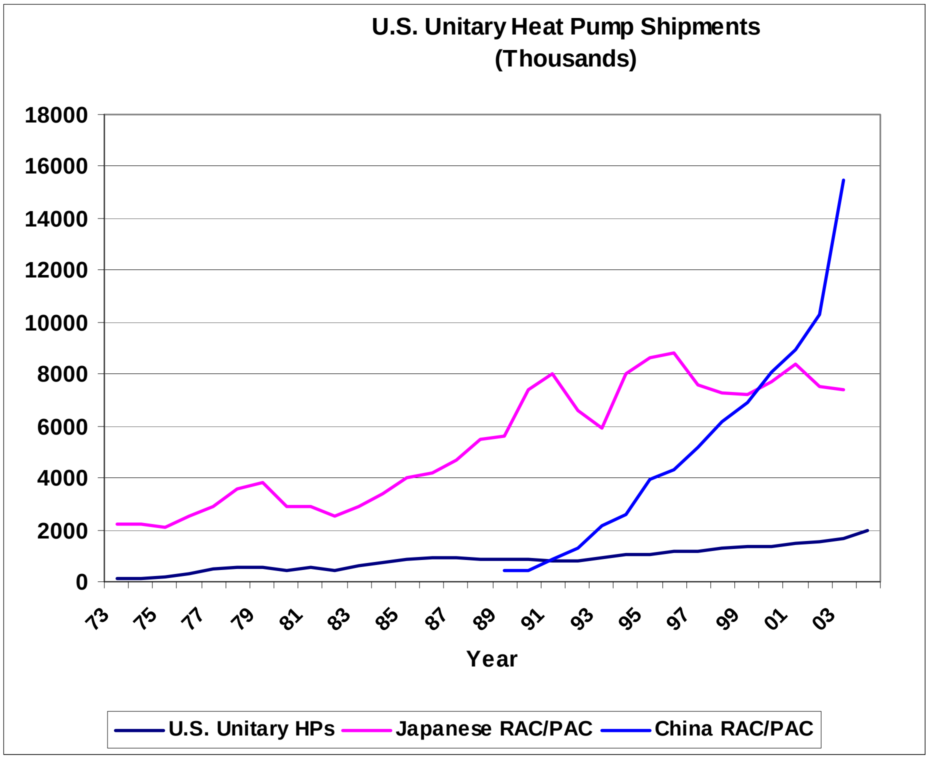

Fig. 5. Growth of Unitary Heat Pump Sales in the U. S., Japan and China

In the U.S. and Japan there is a growing replacement and add-on market for heat pumps as older, lower efficiency models installed during the past 25 years reach their economic lifetime. All of these factors suggest that the future prospects for heat pumps and related system technologies are very bright. Continuing improvements in products and components, larger manufacturing volumes that can produce economies of scale and designs that enable more trouble-free installation and service, will assist in broadening acceptance.

An acquaintance commented to me recently that he assumes that the answer to our question of who uses heat pumps can be answered as "those who do not have natural gas lines to their properties." At least in the United States this does not seem to be the story, since electric utilities are very active in their competition with gas utilities for the residential and commercial building market. Builders who exert influence on the choice of heating and cooling system for their customers are courted by utilities that are anxious to have the winter electricity demand for load management purposes. In 2003 heat pumps were installed in 42% (260,000 houses) of the 614,000 new one-family houses completed in the southern U.S. and 23% (309,000) of the 1,325,000 nationwide (ARI 2004). Of the 1,626,000 total unitary heat pumps sold in 2003, it would appear that approximately 1,300,000 were sold for add-on and replacement, and for small commercial and multi-family buildings. In comparison, a total of 3,265,000 gas furnaces were sold in the U.S. in 2003, but examination of the shipment statistics indicates that heat pump sales increase when gas prices rise (usually with some delay). Since 87% of new one-family homes completed in the U.S. in 2003 were equipped with central air-conditioning (58.5% of the more than 105 million homes in the U.S. now have central air conditioning) the prospects for heat pumps are excellent. With increased education concerning energy savings (heating cost savings) benefits and positive reliability and customer satisfaction experiences, there is a good market opportunity for these systems. Heat pump installations are growing strongly in Southeast Asia. More than 20 million units are now being sold each year in this region, and China has become both the largest market in the world, and largest producer of air conditioning and heat pump units. In Europe there is also evidence of a growing market. Sales of heat pumps in Norway achieved 55,000 units in 2003, more than twice the 2002 level. In Sweden heat pump sales exceeded 50,000 units in 2003, an increase of 25% over 2002 sales. The European Heat Pump Association (Rose 2002) estimates that there are more than 4.5 million heat pumps installed in Europe and has set a goal of increasing this to 15 million by 2010. Air conditioning is becoming more popular in Europe (aided, no doubt, by the extraordinarily hot summer of 2003). This will certainly stimulate interest and sales for heat pumps.

The name "heat pump," and the lack of familiarity of most people with this term, continues to be a major impediment to end-user acceptance. Governments, utilities and conservationists who wish to accelerate heat pump market growth must provide educational programs and initiatives to overcome this problem and other long-standing market barriers.

REFERENCES

ARI (Air Conditioning & Refrigeration Institute) Statistical Profile; October 7, 2004

Carrier Corporation: G.C. Groff (Ed.), Heat Pumps and Space Conditioning Systems for the 1990s, 1979

Crane, R. E., Lorsch, H. G., and Steigelmann, W. H., Assessment of Research and Development Needs Related to Heat Pump Technology for space Heating and Cooling, Franklin Institute Research Laboratories Report (1976), Executive Office of the President, Council on Environmental Quality

EPRI/RWE: The Electric Heat Pump, Report on the First German-American Conference on Technology and Application of the Electric Heat Pump, June 1980

Floreth, J. J., Southdale: Minneapolis' Unique Heat Pump Installation, ASRE Journal Vol. 65, No. 1, 1957

Gordian Associates, Inc., Evaluation of the Air-to-Air Heat Pump for Residential Space Conditioning, Prepared for Federal Energy Administration, Washington, D.C. April 1976

Gordian Associates, Inc., Heat Pump Technology, A Survey of technical Development Market Prospects, Prepared for U.S. Department of Energy, June 1978

Graham, C. E., Kroeker, J. D. and Chewning, R.C., Heat Pump Results in Equitable Building, ASHVE Transactions Vol. 55,, 1949 and ASHVE Journal Vol 21, No. 7, 1949

Groff, G. C. and Bullock, C. E., A Computer Simulation Model for Air-Source Heat Pump System Seasonal Performance Studies, Proceedings 2nd Oklahoma State University Heat Pump Technology Conference, October 1976

Groff, G. C. and Reedy, W. R., An Investigation of Heat Pump Performance in Northern Climate Applications Through Field Monitoring and Computer simulation, ASHRAE Transactions, Vol. 84, Part I, 1978

Groff, G. C., Bullock, C. E., and Reedy, W. R. Heat Pump Performance Improvements for Northern Climate Applications, Proceedings of the 13th Intersociety Energy Conversion Engineering Conference, Society of Automotive Engineers, Inc. September 1978

Groff, G. C. and Moreau, J. P., In Investigation of Air-to-Air Heat Pumps for New and Existing French Homes, ASHRAE Transactions, Vol. 89, Part 1, 1983.

Groff, G. C., Bullock, C. E. and Wroblewski, D. E., A dynamic Simulation Model for Residential Air-to-Water Heat Pump Systems, Proceedings XVIth International Congress of Refrigeration, Paris, 1983

Groff, G. C., Bullock, C. E. and Hough, R. E., "An Investigation of Electric Heat Pumps Applied to Commercial Buildings," Proceedings IEA Heat Pump Conference, Graz, Austria 1984.

Halozan, Hermann, and Rieberer, Rene, Energy-efficient heating and cooling systems for buildings, IIR Bulletin 2004-6, 2004

IEA Heat Pump Centre Newsletter, Vol. 22, No. 2/2004

IEA Common Study on Advanced Heat Pumps, July 1980; Kernforschungsanlage Jülich GmbH

IEA Heat Pump Conference Proceedings – Current Situation and Future Prospects; W. Hochegger (Ed.) 1984

IEA Heat Pump Conference Proceedings – Heat Pumps – Better by Nature; May 2002

IEA New Energy Conservation Technologies and Their Commercialization, J.P. Millhone and E. H. Willis (Eds.), 1981

IEA Heat Pump Systems: A Technology Review, OECD, Paris, 1982

IEA Heat Pump Programme Report HPP-AN 21-1, Industrial Heat Pumps: Experiences, Potential and Global Environmental Benefits, IEA Heat Pump Centre 1995

Igarashi, Yoshio, Present Situation and Market Trends in East Asia, Proceedings, 5th IEA Heat Pump Conference, September 1996

International Heat Pump Status and Policy Review, IEA Heat Pump Centre Report AR-3, 1994

International Heat Pump Status and Policy Review 1993-1996, IEA Heat Pump Centre Report AR-7, 1999

Iwatubo, Tetsushiro and Shi, Dinghuan, Markets in Asia Pacific, Proceedings, 6th IEA Heat Pump Conference, May 1999

Jordan, R. C. and Priester, G. B., Refrigeration and Air conditioning, 2nd Edition, Prentice-Hall, Inc., 1956

Komedera, M., The Domestic Heat Pump – Standard Equipment of the Future, Engineering, Vol. 182, No. 4720, 1956

Krenn, K., Ritter, W., and Schneeberger, M., The World's First Industrial Heat Pump, IEA Heat Pump Centre Newsletter, V. 4, No. 2, June 1986

Lovvorn, Nance, Increasing Consumer Confidence in Heat Pumps, Proceedings, 8th IEA Heat Pump Conference, May 2005

Rose, Roar, Heat Pumps in Europe – An Overview, 7th IEA Heat Pump Conference, May 2002

Thevenot, Roger, A History of Refrigeration throughout the world, International Institute of Refrigeration, 1979

Vidal, C., Heat Pumps added to existing boilers: The PERCHE G.T.I. program, IEA Heat Pump Conference Proceedings, W. Hochegger (ed.) 1984