

taken research projects in allied areas such as heat sources, utilization of solar energy as a supplementary heat source, and thermal storage methods.

The Joint Committee has lent encouragement to publication of two textbooks<sup>1,2</sup> on the technology of heat pumps, and to the maintenance of a comprehensive bibliography,<sup>3</sup> a reference library, and installation statistics. Additional bibliographies and installation studies have been made by The Heat Pump Steering Committee of the Southeastern Electric Exchange.<sup>4</sup>

The summer air-conditioning load has high electric power demand and low annual load factor, and in addition, the highest demand peaks will occur on the relatively few extremely hot days during summer months, when the load-carrying capacity of the whole utility system (generation, transmission and distribution) is considerably lower than on cold days in winter. For example, the average annual load factor on a noncoincident basis for summer air conditioning can be expected to remain between limits of 6 and 15 percent. This is far below the 64 percent present-day annual load factor for the total electric load of utility systems. Consequently, the large utility companies are giving support to the advancement of heat-pump technology as a means of broadening the field of application of the heat pump with its beneficial effect on the electric system load factor.<sup>5</sup>

#### Present Status

Large central heat pumps of modern design, within the capacity range of about 100 to approximately 1000 horsepower of compressor-motor rating, are now operating in a substantial number of buildings. Among noteworthy installations are those in the Oregonian Building and Equitable Building, both in Portland, Oregon; Appalachian Electric Building in Roanoke, Virginia; Columbus and Southern Ohio Electric Building in Columbus, Ohio. Detailed information on their design and performance has been presented in ASHRAE papers<sup>6,7,8,9,10</sup> and in technical magazines.

In the Southdale Shopping Center in Minneapolis, Minn., a 700-ton heat pump installation with its associated deep wells providing the heat sink and heat source, has a coefficient of performance on the heating cycle of approximately 4. Internal combustion engine driven heat pumps in this installation have been found to provide additional heating capacity because of the recoverable heat in the engine cooling water and the muffler.

Compressor types employed in large central systems vary from one large centrifugal unit to as many as eight multicylinder reciprocating units. A single or central system is generally used throughout the building, but in some instances the total capacity is divided among several separate heat-pump systems to facilitate zoning. Both well water and air are used as heat sources. Compression is accomplished in two stages for a few recent projects. Frequently provision is made for heating and cooling service to be supplied simultaneously to separate zones of the building.

Unitary heat pumps, available from or under development by many manufacturers, account for the large majority of residential and small commercial installations. Outdoor air is the heat source in the majority of installations, but models are built also for well water. Capacities cover the range from 2 to about 25 horsepower. Both hermetic and open-type compressors are used. The entire heat-pump circuit may be charged with refrigerant and sealed at the factory, or individual factory-sealed subassemblies may be connected together in the field. Some models are arranged

for remote location of the outdoor-air heat exchanger that serves alternately as evaporator and as condenser. In appearance and dimensions, casings of unitary heat pumps closely resemble those of conventional air-conditioning units having equal capacity.

The normal design basis is to select the size of compressor and motor for the summer cooling and dehumidification capacity requirement. For heating service with outdoor air as the heat source, supplementary electric resistance heating elements are normally provided for use during such periods of low temperature as may be required by the climate and heating load of the structure. These heaters are sometimes objectionable to the utility because the resulting seasonal electric consumption is low in comparison with the electric input demands they create on the electric service facilities. Consequently, it is important that the application engineer for such installations give careful attention to minimizing the installed capacity of heating elements, as discussed later in this chapter.

With unitary systems, defrosting of the evaporator coils at suitable intervals with minimum interruption of heat supply to the building is usually accomplished automatically by admitting hot refrigerant gas taken directly from the compressor discharge.

Minimum industry performance standards of unitary heat pumps are covered by ARI Standard 240-57, *Unitary Heat Pump Equipment*, issued 1957 by Air-Conditioning and Refrigeration Institute. It applies to factory-made heat pumps and to matched assemblies as defined in the Standard, for residential, commercial and industrial service, but is not applicable to field-modified cooling units converted to heat-pump operation, nor to room air conditioners. The Standard provides that both heating and cooling capacity be expressed in Btu per hour under specific conditions, and includes minimum performance standards such as the ability to operate under maximum load conditions or adverse power and temperature conditions, and describes safety codes to which such equipment should be designed. It also outlines several performance requirements that are considered good practice in the design of either unitary heat pumps or built-up systems.

Window-type, or in-the-wall type heat pumps, now in factory production in 1/2 to 2 hp size range, resemble conventional units for summer air conditioning, similarly installed. Heretofore, capacity of these units on heating service has generally been less than needed in extremely cold weather to maintain the required temperature within the space served adequately by the same unit in summer. Except in regions having mild climate, they were useful principally for intermediate-season operation or to supplement the main heating system of the building. Some recently introduced models, however, have characteristics more suited to complete year-round operation.

As a result of more than a decade of experience gained in product development, factory production, field operation, and maintenance, heat pumps have become firmly established throughout a large part of the country. Moreover, heat pumps are being adopted for entire housing developments. As many as 1500 units have been installed for a single project.

The estimated number of central system heat-pump units operating at the end of 1958 throughout the United States is approximately 40,000. Installations have been made in practically every state, with the southeastern, southwestern, and west coast states predominating. It is probable that at

least two-thirds of total units take heat from outdoor air, and, of the remainder, nearly all use water, with ground coils almost negligible among the more recent installations. Aggregate connected load may well reach 400,000 kilowatts. Approximately 150 domestic heat pump water heaters, mostly experimental or pilot-type models, are in operation.

#### BASIC CIRCUITS

##### Fundamentals

Since, from the refrigeration standpoint, a heat pump is similar to a conventional refrigeration system, its basic circuit may be represented by Fig. 3 in Chapter 38. Changeover between heating and cooling services may be accomplished by: (a) actuating valves in the refrigerant lines, so as to interchange the positions of heat exchangers constituting the evaporator and the condenser, respectively, in the refrigerant flow circuit, or (b) by switching the paths of air, water, or other fluid that convey heat from source to evaporator and from condenser to sink, respectively. The interchange function inherent in heat-pump control led to use of the term *reversed-cycle refrigeration* during the early development period of the heat pump, but this inaccurate name is now obsolete.

The operating principle of the heat pump is identical with that of the heat-power thermodynamic cycle governing the conversion between heat energy and mechanical work. It is derived from the Second Law of Thermodynamics (see Definitions, Chapter 1). The operating efficiency, or coefficient of performance (CP), of an elementary perfect refrigeration system for both cooling and heating effects is given by Equations 2 and 3, Chapter 38.

In actual systems, the coefficients of performance are defined in the following terms:

The *heating coefficient of performance*, (CP)<sub>h</sub>, of an installed heat pump may be defined as the ratio of the total instantaneous useful heating effect produced by the heat-pump system at stated conditions, to the heat equivalent of the total energy input rate required to drive or operate the system. If total energy input of all auxiliaries such as fans and pumps is not included, it should be so stated.

The *cooling coefficient of performance*, (CP)<sub>c</sub>, of an installed heat pump may be defined as the ratio of the instantaneous useful refrigeration effect produced by the heat-pump system at stated conditions to the heat equivalent of the total energy input rate required to drive or operate the system.

The *term performance factor*, (PF), is similar to coefficient of performance, but is used when referring to values based on an extended period of time, such as a day, month, or season. The period of time covered should be given when using this term. If supplemental heat is involved, its effect should also be specified.

#### Heat Pump Types

Heat pumps for air-conditioning service may be classified according to (a) type of heat source and sink, (b) heating and cooling distribution fluid, (c) type of thermodynamic cycle, (d) type of building structure, and (e) size and configuration. The more common types are shown in Table 1.

The *air-to-air* type is the most common type of system. It is particularly suitable for factory-built unitary heat pumps and has received favorable acceptance for residential and commercial applications. The first diagram in Table 1 is

typical of the refrigeration circuit employed. In smaller unitary heat pumps, it is common to replace the expansion and check valves with a capillary tube refrigerant control. A few installations have been made in which the forced-convection indoor heat-transfer surface has been replaced by a radiant panel.

In *air-to-air* heat-pump systems, as shown in second diagram of Table 1, the air circuits may be interchanged by means of dampers (motor-driven or operated manually) to obtain either heated or cooled air for the conditioned space. With this system one heat-exchanger coil is always the evaporator while the other is always the condenser. The conditioned air will pass over the evaporator during the cooling cycle while the outdoor air will pass over the condenser. The change from cooling to heating is accomplished by positioning the dampers.

A *water-to-air* heat pump uses water as a heat source and sink and uses air to transmit heat to or from the conditioned space.

*Air-to-water* heat pumps are commonly used in large buildings where zone control is necessary, and are also sometimes employed for the production of hot or cold water in industrial applications.

*Earth-to-air* heat pumps may employ direct expansion of the refrigerant in an embedded coil as illustrated in Table 1, or they may be of the indirect type described under the *water-to-air* type.

A *water-to-water* heat pump uses water as the heat source and sink for both cooling and heating operation. Heating-cooling changeover may be accomplished in the refrigerant circuit, but in many cases, it is more convenient to perform the switching in the water circuits such as is illustrated in Table 1.

An *earth-to-water* heat pump (not shown in Table 1) may be like the *earth-to-air* type shown except for the substitution of a refrigerant-water heat exchanger for the finned coil shown on the indoor side. It may also take a form similar to the *water-to-water* system shown when a secondary-fluid ground coil is used.

Some heat pumps which use earth as the heat source and sink are essentially of the *water-to-air* type. An antifreeze solution is pumped through a loop comprised of a pipe coil embedded in the earth and the chiller-condenser.

Many variations are possible in the refrigeration circuit and in the heat-source and sink arrangements. Some of these are described in later sections of this chapter.

Other types of heat pumps in addition to those listed in Table 1 are possible. An example is one which utilizes solar energy as a source of heat; its refrigerant circuit may resemble the *water-to-air*, *air-to-air*, or other types depending on the form of solar collector and the means of heating and cooling distribution which is employed.

Another variation is the use of more than one heat source. Some heat pumps have utilized air as the primary heat source, but are changed over to extract heat from water (e.g. from a well or storage tank) during periods of peak load. The use of solar energy requires another heat source during periods of insufficient solar radiation.

#### Industrial and Agricultural Heat Pumps

While the principal use of heat pumps may always be in space heating and cooling, the heat-pump principle also has applications in the industrial and agricultural fields, particularly in the process industries where large quantities of low