

Fig. 3 .... Variation of Coefficient of Performance with Temperature

of Chapter 38 defines the coefficient of performance (CP) of a Carnot cycle heat pump. Applying the relationships given with evaporator and condenser temperatures illustrated in Fig. 2 yields the coefficient of performance (CP) for a Carnot cycle heat pump shown in Fig. 3. An actual heat pump will, as a rough approximation, be about 50 percent as efficient as a Carnot cycle heat pump and will have a coefficient of performance dependent on temperatures, as illustrated in Fig. 3.

System Balance

The performance characteristics of a heat-pump system can be predicted by evaluating and combining the performance characteristics of its individual components.[37] Data available from component manufacturers may be portrayed as shown in Fig. 4.

The conditions of system balance can be established by the following procedure:

1. Choose a combination of evaporator refrigerant temperature t_r and condensing temperature t_c.
2. Determine the compressor refrigerating effect from performance curves similar to *A* of Fig. 4.
3. Determine the compressor power input P_c, in kilowatts, from curves similar to *B* of Fig. 4.
4. Determine the condenser capacity from

$$Q_c = Q_e + 3413\ P_c - Q_{ee} \qquad (1)$$

where

Q_c = condenser capacity, Btu per hour.
Q_e = compressor refrigeration effect (evaporator capacity), Btu per hour.
Q_{ee} = heat loss from compressor, Btu per hour. (Q_{ee} may have to be approximated if unavailable from compressor manufacturer. For many compressors Q_{ee} is negligible.)

5. Plot Q_e obtained from Equation 1 on a chart similar to *C* of Fig. 4. (See Fig. 5.)
6. Select other condensing temperatures in combination with the original evaporator temperature from Step 1 and repeat Steps 2 to 5 as necessary to determine the condenser capacity at which the system balances. Points *A* and *B* on Fig. 5 represent the results of these calculations. Two points will normally be sufficient to determine the balancing Q_e.
7. Select other evaporator temperatures and repeat Steps 1–6 (See Fig. 5.)
8. For each evaporator temperature find the corresponding heat source temperature t_s from chart similar to *D* of Fig. 4.

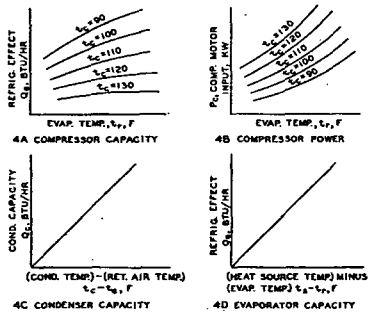


Fig. 4 .... Performance Characteristics of Heat-Pump Components

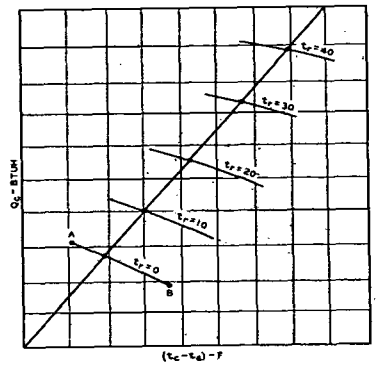


Fig. 5 .... Heat-Pump System Balance

With the conditions of system balance found from the foregoing procedure, it is a relatively simple matter to establish the heating performance characteristics. The net heating effect may consist only of the condenser heat, or, depending upon the system design, may also include heat losses from the compressor and motors, and the heating effect of a refrigerant subcooler coil.

The cooling performance can be determined in a similar manner.

For a heat pump which employs a constant temperature heat source, a few computations will generally establish the balancing conditions for t_r and t_c. For a heat pump having source temperature subject to considerable variation (e.g. air source), the balancing conditions for a wide range of t_r will be necessary.

Fig. 6 shows the performance characteristics of a typical heat pump determined either from actual system tests or

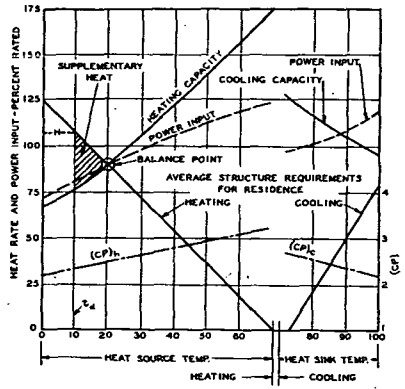


Fig. 6 .... Operating Characteristics of Single-Stage Unmodulated Heat Pump

from an analytical procedure such as already described. Also shown are the heating and cooling loads for a typical residence. The temperature at which the heat-pump capacity and the structure heat requirement are equal is referred to as the *balance point*. If the balance point is above the heating design temperature, t_d, then supplemental heat will be required as denoted by the shaded area.

Seasonal Performance

Fig. 6 illustrates some of the basic factors important in evaluating seasonal power consumption. Following the principles given in Chapter 37 the heating power consumption for any period of time may be estimated from

$$F = \frac{24HD}{3413(t_s - t_d)(\mathrm{PF})} \qquad (2)$$

where

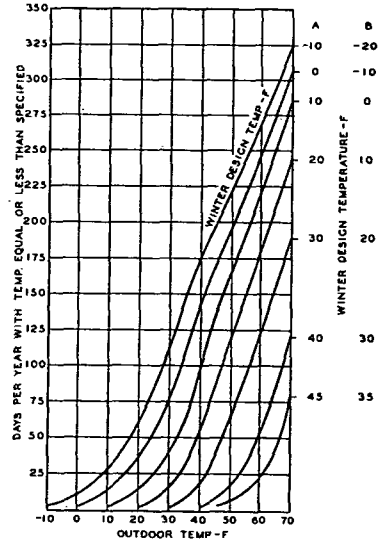
F = heating kilowatt hours
H = structure design heat loss, Btu/hr.
D = degree days for specified period.
t_s = outdoor temperature at which structure heat loss is zero (approximate indoor temperature when heat gain from other sources is small), Fahrenheit.
t_d = outdoor design temperature, Fahrenheit.
(PF) = performance factor for specified period.

For a heat pump with a constant heat-source temperature, the heating capacity will be essentially constant and the performance factor (PF) can be taken as the heating coefficient of performance $(\mathrm{CP})_h$.

For an air-source heat pump, with its varying heat source temperature, it is necessary to either break down the period of operation into relatively narrow temperature spans and to compute the power consumption in each, or, alternatively, to find the performance factor (PF) by weighted average of the different coefficients of performance (CP) and operating hours that apply at various temperatures. In either case it is necessary to have data on the time distribution of outdoor-air temperatures. The number of hours that will apply within a given temperature range may be based on past weather data for a specific location. For example, such data are available for a number of cities broken down by month and time of day.[38] However, where the required weather data are not available and when it is not necessary to break the heating season down into shorter periods, generalized data such as portrayed on Fig. 7 may be employed.

Fig. 7 is based on an analysis of 114 weather stations in the United States from Reference 38, in which the heating-season days were correlated with the TAC design temperatures. The TAC design temperatures shown in 1948 to 1958 editions of THE GUIDE were suggested by the ASHAE Technical Advisory Committee on Weather Design Conditions. They were temperatures which were equalled or exceeded during 97½ percent of the hours in December, January, February, and March chiefly for airport stations.

Maximum deviation for any single location from the averages portrayed is on the order of 5 deg at 70 F outdoor temperature and is due mainly to variations in summer climate. Since curves must pass through points representing the winter TAC design temperatures, their accuracy is best in the low-temperature range. The vertical scale also gives the outdoor design temperatures for heating, as given in



Scale A = Outdoor design temperatures suggested by the former TAC on Weather Design Conditions.
Scale B = Outdoor design temperatures as given in Chapter 12, based on probability of occurrence.

Fig. 7 .... Annual Cumulative Winter Temperature Distribution in the U. S.