Table 4 .... Approximate Combined Operating and Maintenance Cost for Large Air-Conditioning Installations, Using High-Quality Equipment[a]

	Dollars per (Ton) (Year)
Repairs for refrigeration machinery	1.07
Refrigerant	0.40
Oil and grease	0.11
Painting (Water boxes and dehumidifiers)	0.45
Filters, clean and re-oil 4 times per year	1.50
Controls, outside service	0.26
Cleaning air conditioners	1.38
Total	5.17

[a] Estimated for 1955.

operations is well justified in medium and larger plants by economies achieved in maintenance and energy costs.

ENERGY COSTS

Energy costs include the costs for power, steam, gas, coal, oil, etc., consumed to operate the system.

Methods of calculating the energy costs for heating are discussed in Chapter 12.

Constant Loads

In any air-conditioning system, a large part of the auxiliary equipment will be in constant operation regardless of fractional loading of the refrigerating plant, and these auxiliaries will usually be driven by electric motors. Their annual power costs can be calculated from the following equation:

$$\text{annual power cost} = \frac{0.746(\text{bhp})HR}{\eta} \tag{1}$$

where

bhp = brake horsepower.
H = annual operating hours.
R = power rate, dollars per kwhr.
η = motor efficiency (decimal).

In using Equation 1 it must be pointed out that the electric rate, R, must reflect the proper combination of energy and demand rates. These vary widely between the utility companies, and sometimes the rate structure is such that it is largely the demand charge which determines the proper value of R to use in Equation 1.

Electrically-Operated Refrigeration

In an air-conditioning system the refrigerating equipment is usually the largest power consuming item to be considered. Also, the prediction of operating cost is more difficult because the power required for summer cooling is affected by many factors of a variable nature.

The major difficulty is that the refrigeration equipment often operates at its full capacity during no more than 10 to 20 percent of its running time. During the balance of the running time, it will be operating at varying fractions of its full-load capacity with an energy consumption different for each point of fractional loading.

A precise method for determining annual energy cost involves examination of weather records for a period of years to determine the hourly occurrence of outdoor temperatures during the cooling season. A procedure of this type is recommended for heat pump systems and is described in Chapter 4. A similar procedure could be used to calculate seasonal energy consumption for other electrically-operated air-conditioning systems. It should be noted that the use of weather records for a specific year may lead to large inaccuracies, since there may be wide variations from year to year.

For air-conditioning systems other than heat pumps, an approximation of annual energy costs, much more easily arrived at and sufficiently precise for most purposes, will result from the *equivalent full-load hours* concept.

Table 5 gives the equivalent full-load operating hours of refrigerating equipment used for summer cooling for the period of May 15th to October 15th. This table was calculated from the following equation:

$$H_e = m(b + cf) \tag{2}$$

where

H_e = equivalent full load operating hours of refrigeration equipment used for summer cooling during period May 15 to October 15.
m = total hours during period May 15 to October 15 that the establishment is open for business.
b = fraction of maximum load from internal heat under average operating conditions.
c = fraction of maximum load that is due to external sources at maximum design conditions.
f = ratio of the number of hours for a particular city, when the outdoor wet-bulb exceeds 65 F, during the period June 1 to October 1 to the total number of hours during that same period. Total hours are assumed as 8 hr per day period for barber shops, department stores, funeral parlors, offices, short-hour restaurants, and specialty shops, and 12 hr per day period for drug stores, long-hour restaurants, and theaters.

Table 5 .... Equivalent Full Load Operating Hours of Refrigeration Equipment Used for Summer Cooling May 15 to Oct. 15,[a]

Application	Hr Open for Business	Atlanta	Boston	Chicago	Detroit	Los Angeles	New Orleans	New York	Philadelphia	Oklahoma City	St. Louis	Washington D. C
Barber Shops	1280	1010	650	720	720	680	1080	830	860	1020	890	940
Department Stores	940	840	560	610	610	580	890	700	720	840	750	780
Drug Stores	2100	1630	950	1060	1060	980	1790	1280	1330	1650	1420	1530
Funeral Parlors	600	440	300	330	330	310	470	370	380	440	400	410
Offices	1100	1030	660	720	720	680	1060	840	880	1040	910	960
Restaurant (Short Hour)	1290	970	535	620	620	570	1060	760	800	980	830	880
Restaurant (Long Hour)	2100	1510	820	930	930	850	1690	1170	1210	1530	1300	1400
Speciality Shops (5 & 10)	1090	800	530	590	590	560	860	670	690	810	720	750
Theaters—Continuous	1500	1010	700	750	750	720	1080	850	870	1020	910	950
Theaters—Neighborhood	900	640	420	450	450	430	650	500	520	650	550	580

[a] *Modern Air Conditioning, Heating and Ventilating*, by W. H. Carrier, R. E. Cherne, W. A. Grant, and W. H. Roberts (Pitman Publishing Corp., 1959, p. 519).

It should be pointed out that certain southern cities may have seasons longer than the 5-month period indicated in Table 5. If it is desired to consider a longer season of operation, the ratio of full-load operating hours to hours open for business is smaller; in other words, the *refrigeration load factor* is lower. This is true because the extra increment of days added will be a relatively light load, since the table already includes the more severe part of the season.

It should also be pointed out that there is an increasing tendency in large office buildings to operate the refrigeration plants through hours much longer than those of normal occupancy, often 24 hr a day. Where this practice is to be observed, another set of variables is introduced and Table 5 is not applicable. However, where Table 5 is applicable, the season electrical power cost for refrigerating equipment is then given by the following equation:

$$\text{season power costs} = \frac{0.746(\text{bhp})_t TH_e R}{\eta} \tag{3}$$

where

$(\text{bhp})_t$ = brake horsepower per ton (see Fig. 1) for *average* load during period. (Due allowance should be made for poorer compressor efficiency at light load.)
T = maximum refrigeration design load, tons.
H_e = equivalent full load refrigeration operating time, hours (from Table 5).
R = power cost, including demand and energy charges, dollars per kwhr.
η = motor efficiency at average load (decimal).

Heat-Operated Refrigeration

If the refrigeration is heat operated, whether by steam turbine, gas turbine, absorption, or combination thereof, the same general method can be followed, taking into account energy consumption per ton of refrigeration and cost.

WATER COSTS

The quantity of water used in an air-conditioning installation for purposes other than heat rejection is a negligible cost item.

In a refrigerating plant utilizing water-cooled condensers, heat is generally rejected either to purchased water which is subsequently wasted, to well or surface water, or by means of cooling towers or spray ponds. Often, water conservation equipment must be used regardless of economics because of: (1) a lack of adequate water supply, (2) local regulations intended to conserve existing supply, or (3) taxes or service charges attendant upon wasting to sewer. Certain municipalities will remit the sewer tax or service charge if the condensing water is discharged into a storm sewer or used for process purposes.

Whatever the means of producing refrigeration and whatever the ultimate heat sink, if water-cooled condensers are involved, the quantity of water through the condenser is a function of its inlet and outlet temperatures and their relationship to each other. Fig. 1 shows the typical variation with condensing temperature of the brake horsepower per ton required by an electric driven compressor. Since condensing temperature can never equal leaving water temperature but can only approach it, it follows that if, in the interest of economy, the leaving temperature of the condensing water is raised by reducing its quantity per ton, there is an offsetting increase in the cost of producing refrigerating effect.

Where condensing water rejects its heat to the atmosphere and is recirculated, the inlet temperature is a function of the heat rejection equipment and of the wet-bulb temperature.

In the case of either purchased water or of surface or well water, inlet temperature can vary widely and the quantity selected must be based on its probable maximum value. Approximate maximum water main temperatures are given in Chapter 32 of the 1961 GUIDE AND DATA BOOK but they should always be verified locally.

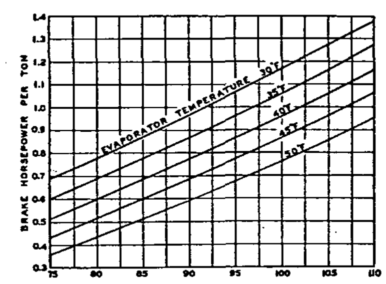
In the case of purchased water which is wasted after use, control is usually provided to vary the quantity supplied so as to hold the leaving water temperature (or condensing temperature) constant. The cost of water, once its maximum quantity per ton has been established, can also be estimated on a basis of equivalent fuel load operating hours of the refrigerating equipment. In this connection the following formula is useful:

$$B = 0.060\,a\,T\,H_e\,C \tag{4}$$

where

B = cost of water for refrigeration during period, dollars.
a = average gallons per (minute) (ton).
T = tons of refrigeration at maximum design load.
H_e = equivalent full load refrigeration operating hours (Table 5).
C = water cost, dollars per 1000 gal.

In the case of a well or lake, the cost of condensing water is usually simply the cost of pumping. Depending on the plant design, energy costs for pumping may vary with the quantity of refrigeration developed or they may be constant for all degrees of loading.



Values given are representative of dichlorodifluoromethane (Refrigerant 12) reciprocating machines of about 25 tons capacity in air-conditioning applications. Requirements of smaller machines are usually higher, and for larger machines may be lower. Values shown are for liquid refrigerant at condenser temperature (no subcooling). Subcooling of the liquid may decrease these values approximately 0.3 percent to 0.5 percent for each Fahrenheit degree the liquid temperature is lowered.

Fig. 1 .... Typical Brake Horsepower Requirements for Refrigeration[a]