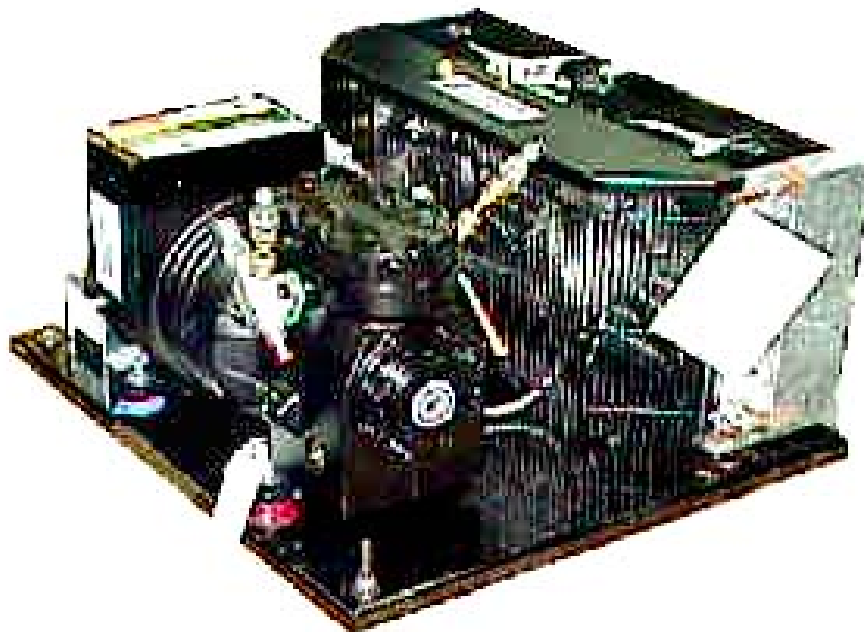


Heat load in Refrigeration System's

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The more complete the information, the better the calculation. Good calculations are the first step in assuring adequate selection in refrigeration equipment for the project.

Heat load in Refrigeration system

Survey

The person involved in heat transfer calculations needs accurately information to predict the heat load on a refrigerated system. The more complete the information, the better the calculation. Good calculations are the first step in assuring adequate selection in refrigeration equipment for the project.

Design ambient temperatures

This would be the ambient surrounding the box necessary for the load calculations. Another ambient to consider is the one surrounding the condensing unit, which will affect equipment selection.

Storage Temperature and Humidity Requirements

Refrigeration equipment by its nature is a dehumidification process. To minimize the drying effect of the refrigeration equipment, by selecting the appropriate temperature difference (T.D.) between the saturated suction temperature of the evaporator and the room air. The T.D. selected approximates the desired relative humidity.

Temperature Difference in Refrigeration Space

The preservation of food and other products in optimum condition by refrigeration depends not only upon the temperature of the refrigerated space but also upon the humidity of the space. When relative humidity in the refrigerated space is too high, the growth of mold, fungus, and bacteria is encouraged. Mold and slime conditions may occur particularly on meats that are in a refrigerated space with higher than 95% relative

humidity and/or low airflow across the product. When relative humidity in the refrigerated space is too low and/or there is an excessive of airflow across the refrigerated product, excessive dehydration will occurs.

Table1

| Class | T.D. | Approximately R H % | Description of product classes |
|--------------|------------------|--------------------------------|---|
| 1 | 7° to 9° | 90% | Results in a minimum amount of moisture evaporation during storage. Includes vegetables, produce, flowers, unpack- aged ice and chill rooms. |
| 2 | 10° to12° | 80 – 85% | Includes general storage and convenience store coolers, packaged meats and vegetables, fruits and similar products. Products require slightly lower relative humidity levels than those in Class I. |
| 3 | 12°to16° | 65- 80% | Includes beer, wine, pharmaceuticals, potatoes and onions, tough skin fruits such as melons and short-term pack- aged products. These products require only moderate relative humidities. |
| 4 | 17°to22° | 50- 65% | Includes prep and cutting rooms, beer warehouses, candy or film storage and loading docks. These applications need only low, relative humidities or are unaffected by humidity. |

The most important factor governing the humidity in the refrigerated space is the temperature difference of the evaporator. The greater the temperature difference of the evaporator the lower is the relative humidity in the refrigerated space. Likewise, the smaller the temperature difference of the evaporator and the closer the temperature of the leaving air of the evaporator is to the refrigerated space, the higher is the relative humidity in the refrigerated space.

Evaporators Temperature Difference in Refrigeration

For humidity control

TABLE 2

| Relative humidity % | Natural Convection | Forced Convection |
|---------------------|--------------------|-------------------|
| 99 - 95 | 5° - 6°F | 4° - 5°F |
| 95 - 91 | 7° - 8°F | 5° - 6°F |
| 90 - 86 | 8° - 9°F | 5° - 7°F |
| 85 - 81 | 9° - 10°F | 8° - 10°F |
| 80 - 76 | 10° - 11°F | 10° - 12°F |
| 75 - 71 | 11° - 12°F | 12° - 14°F |
| 70 - 66 | 12° - 14°F | 14° - 16°F |
| 65 - 61 | 14° - 16°F | 16° - 18°F |
| 60 - 56 | 16° - 18°F | 18° - 20°F |
| 55 - 50 | 18° - 20°F | 20° - 22°F |

For temperature and relative humidity for refrigerated product spaces see ASHRAE 2002 Refrigeration Handbook (Chapter 10) Commodity Storage Requirements

Dimension, Insulation, Type of Construction, Exposure

This criterion lends itself to well-established, straightforward calculations, but the information, while elementary, often omitted from the initial job survey. The transmission load for 4" Styrofoam is double the transmission load for 4" formed in place urethane.

Infiltration or Air Change Load

Heats, both sensible and latent, enter an enclosure through door openings whenever the air surrounding the enclosure is warmer than the box temperature. Knowing the location, size and number of the door openings and the temperature to, which they are exposed will greatly aid in determining the heat load of the infiltrating air.

TOTAL HEAT LOAD

Regardless of its size or complexity, a refrigeration system has one basic function. That function is to remove heat from a place or substance where it is not wanted, and transport it to a location where it can be diffused into air or water. In order to select the proper equipment for a given application, you must carefully estimate the amount of heat to be moved.

The *total heat load* to be handled in any application is the sum of the heat from four sources:

- The heat leakage load is heat that infiltrates the refrigerated area through
 - walls, ceilings, roofs, and floors
- The product load is heat from warm food or other solids or liquids that are being refrigerated.
 - Type- storage requirements
 - Weight
 - Entering temperature
 - Pull down time
- The *miscellaneous heat load* is heat introduced by lights, motors, and other heat-producing devices located in the refrigerated area. Manufacturing processes and human occupancy also may contribute to the miscellaneous heat load.
 - Lights
 - Motors including fan motors
 - fork lifts, conveyers
 - People
 - Glass doors
- The *service load* is heat that enters the refrigerated area when doors or other access means are opened. The door may be opened to put in or take out a product, for example, or for a variety of other reasons. This source is often called the "usage load."

- **Operation**
- **Holding cooler or freezer**
- **Blast cooling or freezing**
- **Preparation, processing or cutting rooms**
- **Distribution warehouses**
- **Reach-in or walk-in boxes**

The relative importance of each of these heat sources varies considerably from one application to another, as does the amount of each heat load. These factors also vary with the application of different types of equipment. With some types of equipment, very little heat may be derived from one of the four sources. If so, that source is of minor importance in estimating the total heat load. Nevertheless, with other types of equipment, the same source may be the major contributor to the total heat load.

As a service technician, you may have to estimate the heat load and select the refrigeration equipment for a prospective job. Alternatively, you may need to make similar calculations when troubleshooting a problem application. In any case, you must consider each of the four sources of heat individually. Then you add the four values together for an accurate estimate of the total heat load.

HEAT LEAKAGE LOAD

The heat leakage load is generally a major factor in refrigeration systems, regardless of whether the application is residential, commercial, or industrial. Before you try to estimate the heat leakage load, you need to know several things:

- **How to calculate heat flow through an insulated wall**
- **The extent of the temperature change within the insulation**
- **The function of a vapor barrier**
- **The amount of insulation required to prevent "sweating" (condensation) in or on the insulation.**

You can use the following equation to calculate the heat leakage load:

$$Q=UxAxTD$$

where:

- Q = total heat transfer, in Btuh
- U = the rate of heat flow through the walls, floor, and ceiling of the refrigerated space, in Btuh per square foot of area per degree of temperature change
- A = the total outside area of the refrigerated space, in square feet
- $T\Delta$ = the difference, in degrees Fahrenheit, between the temperature outside the refrigerated space and the average temperature inside the refrigerated space.

Calculating area

For maximum accuracy in estimating the heat leakage load, measure each wall, the floor, and the ceiling separately. Then add your findings together to get the total area. For example, assume that a walk-in cooler is 8 ft high, 8 ft long and 6 ft wide. Then:

- the area of the floor is 6 ft x 8 ft = 48 ft²
- the area of the ceiling is also 6 ft x 8 ft = 48 ft²
- the area of each end wall is likewise 6 ft x 8 ft =48 ft², or 96 ft² for both end walls
- The area of each sidewall is 8 ft x 8 ft = 64 ft², or 128 ft² for both sidewalls.

The total outside area of the walk-in refrigerator, therefore, is:

Floor 48 ft²

Ceiling 48 ft²

End walls 96 ft²

Sidewalls 128 ft²

Total area = 320 ft²

Calculating temperature difference

Outside daytime and nighttime temperatures can vary greatly, especially during the summer months. In temperature difference calculations, it is customary to use an *average* outside summer temperature for a specific geographical location. This figure is generally a few degrees below the maximum. If you do not know the average outside summer temperature for a given area, the nearest weather bureau can provide this information. Obviously, this practice of using an average outside temperature is not appropriate in all cases. The refrigerator may be located in a hot kitchen, for example, or in a completely air conditioned space. In such applications, calculations must be based on hourly conditions (the temperature in a hotel kitchen, for instance, will be much higher during the hours when the restaurant is open than when it is closed).

Calculating heat flow

Next, you must calculate the rate of heat flow through the floor, ceiling, and walls of the refrigerated space. You must consider several factors in performing this calculation, including the type of insulation used, the thickness of the insulation, and its condition. You also must determine the condition of the existing vapor seal.

For an existing cabinet or walk-in refrigerator, the thickness and type of insulation used should be known. You must evaluate its condition for an accurate estimate of the heat leakage load. Of particular importance is the vapor seal. If broken, it permits the insulation to become damp or even wet. Such a condition can be a critical factor in low-temperature applications, such as freezers or frozen storage compartments. Vapor pressure, which tends to force moisture into insulation, is twice as high in a -10°F frozen food storage room as it is in a 36°F fresh meat cooler (assuming a 90°F ambient temperature in both cases).

Example.

Assume that the 8 ft x 6 ft x 8 ft walk-in cooler mentioned previously is located in a warm climate area. It is situated in a corner of a store, so that two of its walls are exterior walls. The two remaining walls are in a conditioned space. There is an upper level storage space (not fully conditioned) above the ceiling. The floor rests on a 6-in. concrete slab poured over gravel. In order to determine the total heat gain from the cooler's surroundings, you must make calculations for four different conductance's (indoor walls, outdoor walls, ceiling, floor) and four corresponding temperature differences.

Except for the floor, the entire interior of the cooler is lined with stainless steel. The 3/4-in. hardwood floor is laid over 2 in. of expanded extruded polystyrene (EPS), which rests directly on the slab (ignoring the foil and polymer film vapor barrier).

The ceiling and all of the walls of the cooler consist of a 6-in. thickness of well-sealed, expanded extruded polystyrene. A single door of similar construction is centered in the longer interior wall. The two store-side walls are faced with 1/8-in. tempered hardboard. During the cooling season, the surrounding conditioned space is kept at 75°F ($\pm 3^\circ\text{F}$). The out- side walls of the building are constructed of medium-weight aggregate, 8-in. concrete block with molded EPS core inserts, sealed on both the inside and outside faces.

The ceiling is covered with sealed batts of 7-in. glass fiber insulation. The temperature in the partly conditioned space above the ceiling rarely exceeds 90°F.

In order to determine the U-value for each of the cooler's surfaces, you first must find the conductivities and conductances of the materials involved. These values can be found in Table 1 at the end of this chapter. You may find it helpful to list your findings in chart form, as shown above. Note that the stainless steel liner is not listed. This is because metal sheeting has no significant insulating value.

The U-value is the reciprocal of the total resistance. Resistance, in turn, is the reciprocal of conductance. For the indoor walls, therefore, you can calculate the U-value as follows:

Table 3

| Material | C-Value or K-Value | C-Value per Component |
|---|-------------------------------|----------------------------------|
| Indoor wall: 1/8-in tempered hardboard | K = 1.00 | C = 1.00 / 1/8 = 8 |
| Outdoor walls 8-in concrete block | C = 0.37 | C = 0.37 |
| Walls and ceiling: 6-in extruded expanded polystyrene | K = 0.20 | C = 0.20 / 6 = 0.033 |
| Ceiling: 7-in glass fiber batts | C = 0.045 | C = 0.045 |
| Floor: 2-in extruded ex- panded polystyrene | K = 0.20 | C = 0.20 / 2 = 0.10 |
| Floor: 3/4-in hardwood | C = 1.47 | C = 1.47 |
| Floor: 6-in sand and gravel Concrete slab (D= 130 lb/ft ²) | K = 13.0 | C = 13.0 / 6 = 2.17 |

$$R = 1/8 + 1/0.033 = 0.125 + 30 = 30.125$$

$$U = 1/30.125 = 0.0332$$

The two indoor walls measure 8 ft x 8 ft, (64 ft²) and 8 ft x 6 ft (48 ft²), for a total area of 112 ft². Since the temperature on the warm side is never higher than 78°F, and the set point for storing product is 36°F, the maximum temperature difference (TD) across these walls is 42°F. This gives you the information you need to calculate the rate of heat gain through these walls:

$$Q = U \times \text{area} \times \text{temperature difference} = 0.0332 \times 112 \times 42 = 156.2 \text{ Btuh}$$

Now you can make a series of similar calculations for the outdoor walls:

$$R = 1/0.37 + 1 / 0.033 = 2.7 + 30 = 32.7$$

$$U = 1 / 32.7 = 0.0306$$

Like the indoor walls, the two outdoor walls have a combined area of 112 ft². Let us assume that outside temperatures regularly reach and often exceed 100°F. For load calculations, 100°F is selected as the design temperature. Subtracting the product set point of 36°F from 100°F gives you a temperature difference of 64°F across the outdoor walls. The rate of heat gain through the outdoor walls, therefore, is:

$$Q = U \times A \times TD$$

$$= 0.0306 \times 112 \times 64 = 219.3 \text{ Btuh}$$

Now try making your own calculations for the ceiling and floor. Using the procedure explained above, you should arrive at a U-value of 0.019 for the ceiling and 0.09 for the floor. You know the area of the ceiling (48 ft²), so assuming a warm-side temperature of 90°F, you can calculate a TO of 54°F and a resulting heat gain (Q) through the ceiling of 49.2 Btuh.

What about the floor? Its area is the same as that of the ceiling, of course, which leaves the TD as the remaining unknown. Since the desired temperature for the product is 36°F, all you need now is the temperature of the soil or rock below the cooler. A direct measurement with a thermometer can provide a usable temperature if the thermometer bulb is in contact with earth 12 to 18 in. below the surface, and if the measurement is taken after a few seasonally warm days. If this is not convenient, consult a local agricultural extension service for soil temperatures. Let us assume that even on hot days in the cooling season, the ground temperatures remain at about 70°F. Your calculations should give you a TO of 34°F and a Q-value of 146.88 Btuh.

In order to determine the total heat load due to conduction from the environment, simply add the heat leakage loads from all of the surfaces:

$$\text{Indoor walls } 156.2 \text{ Btuh} + \text{Outdoor walls } 219.3 \text{ Btuh} + \text{Ceiling } 49.2 \text{ Btuh} +$$

$$\text{Floor } 146.9 \text{ Btuh} = 571.6 \text{ Btuh}$$

To find the daily load, multiply 571.6 Btuh times 24 hr to get 13,718.4 Btu per day.

THERMAL CONDUCTIVITY

The letter "*K*" represents thermal conductivity, which is the rate of heat transfer through a material as measured in Btuh per square foot of area per degree Fahrenheit of temperature difference per inch of thickness. The total heat transferred by conduction, therefore, varies *directly* with time, area, and temperature difference, and *inversely* with the thickness of the material through which it passes.

Different materials offer varying resistances to heat. Assume, for example, that you want to calculate the heat transfer through a material with a thermal conductivity (K-value) of 0.25. The material in question has an area of 2ft² and is 3 in. thick. If the average temperature difference across the material is 70°F, you will be able to calculate the total quantity of heat transferred (Q) over a 24-hr period with this simple equation:

$$Q = 0.25 (K) \times 2 (\text{ft}^2) \times 24 (\text{hr}) \times 70^\circ\text{F} (\Delta T) / 3 (\text{in. of thickness})$$

$$Q = 840 / 3 = 280 \text{ Btu}$$

It should be apparent from the example that in order to reduce heat transfer, the thermal conductivity must be as low as possible and the material as thick as possible. *Note:* In some technical literature, K-values are based on thickness per foot instead of per inch. Unless otherwise specified, all references to K-values in this chapter are based on heat transfer per inch of thickness.

CONDUCTANCE

The letter "*C*" represents thermal conductance, which, like conductivity, is a measure of the rate of heat transfer through a material or heat barrier. Conductance is used frequently with specific building materials, air spaces, etc., and differs from conductivity in one significant way. Thermal *conductance* is a specific factor for a given thickness of material or structural member. Thermal *conductivity* is a heat transfer factor *per inch* of thickness.

SURFACE FILM CONDUCTANCE

Heat transfer through any material is affected by the resistance to heat flow offered by its surface. The degree of resistance depends on the type of surface, its relative roughness or smoothness, its vertical or horizontal position, its reflective properties, and the rate of airflow over it. It is similar to conductance in that its value is expressed in Btuh per square foot of area per degree Fahrenheit of temperature difference

THERMAL RESISTANCE

The letter "*R*" represents thermal resistance. By definition, the resistance of a material to the flow of heat is the reciprocal of its heat transfer coefficient. In other words, the *R-value* is the reciprocal of either the K-value or the C-value. For example, if a material has a conductance (C-value) of 0.25, then resistance is $R = 1/C = 1/0.25 = 4$

You can see, then, that for this material it would take a 4°F temperature difference across a 1ft² area, or a 1°F temperature difference across a 4ft² area, to result in a heat flow of 1 Btuh. Thermal resistance is important primarily because individual resistance values can be added numerically:

$$R_{\text{total}} = R_1 + R_2 + R_3$$

This makes the use of R-values very convenient in calculating overall heat transfer coefficients.

OVERALL COEFFICIENT OF HEAT TRANSFER

The letter "*U*" represents the overall coefficient of heat transfer, which is the overall rate of heat transfer through a material. U-values usually applied to compound structures, such as walls, ceilings, and roofs, and must include the additional insulating effect of the air film that exists on either side of the surface.

The U-value of a wall is the reciprocal of its total resistance. Resistance, in turn, is the reciprocal of conductivity. Nevertheless, calculating the U-value is complicated by the fact that the *total* resistance to the flow of heat through a wall made of several layers is the sum of the resistances of the individual layers. In order to calculate the overall heat transfer coefficient, you first must find the overall resistance to heat flow. The various heat transfer factors must be taken into consideration when you calculate the total resistance:

CALCULATING HEAT LOADS

For load calculation purposes, the heat transferred through a wall can be determined by using the basic heat transfer equation:

$$Q = U \times A \times TD$$

where:

- **Q** = the total heat transfer (Btuh)
- **U** = the overall heat transfer coefficient
- **A** = the area (ft²)
- **TD** = the temperature differential (sometimes also signified by the symbol ΔT) between the outside design temperature and the design temperature of the refrigerated space (°F).

Consider the wall in the previous example (with a U-value of 0.114). The heat transmission per hour through a 90-ft² area with an inside temperature of 0°F and an outside temperature of 80°F is calculated as follows:

$$Q = U \times A \times TD$$

$$= 0.114 \times 90 \times 80 = 821 \text{ Btuh}$$

You can determine the amount of heat gained by transmission into a refrigerated space in a similar manner. Calculate the U-value for each part of the structure around the refrigerated space, and then proceed with the equation shown above.

Extensive tests have been conducted to determine accurate values for heat transfer through all common building and structural materials. Certain materials have a high resistance to heat flow (a low thermal conductivity). They are used as insulation to reduce the level of heat transfer into a refrigerated space. Many good insulation materials have K-values of 0.25 or less, and some foam insulations have thermal conductivities of 0.12 to 0.15.

Table 4A

| Description | Density, lb/ft ³ | Conductivity (K) | Conductance (C) | Resistance (R) | | Specific heat, Btu/lb°F |
|---|--------------------------------|---------------------|--------------------|-------------------|------------------|-------------------------------|
| | | | | per inch (1/K) | overall (1/C) | |
| BUILDING BOARD | | | | | | |
| Asbestos-cement board | 120 | 4.0 | — | 0.25 | — | 0.24 |
| Asbestos-cement board, . . . 0.125 in. | 120 | — | 33.00 | — | 0.03 | — |
| Asbestos-cement board, . . . 0.25 in. | 120 | — | 16.50 | — | 0.06 | — |
| Gypsum or plaster board, . . . 0.375 in. | 50 | — | 3.10 | — | 0.32 | 0.26 |
| Gypsum or plaster board, . . . 0.5 in. | 50 | — | 2.22 | — | 0.45 | — |
| Gypsum or plaster board, . . . 0.625 in. | 50 | — | 1.78 | — | 0.56 | — |
| Plywood (Douglas fir) | 34 | 0.80 | — | 1.25 | — | 0.29 |
| Plywood (Douglas fir) 0.25 in. | 34 | — | 3.20 | — | 0.31 | — |
| Plywood (Douglas fir) 0.375 in. | 34 | — | 2.13 | — | 0.47 | — |
| Plywood (Douglas fir) 0.5 in. | 34 | — | 1.60 | — | 0.62 | — |
| Plywood (Douglas fir) 0.625 in. | 34 | — | 1.29 | — | 0.77 | — |
| Plywood or wood panels . . . 0.75 in. | 34 | — | 1.07 | — | 0.93 | 0.29 |
| Vegetable fiber board | | | | | | |
| Sheathing, | | | | | | |
| regular density, 0.5 in. | 18 | — | 0.76 | — | 1.32 | 0.31 |
| 0.78125 in. | 18 | — | 0.49 | — | 2.06 | — |
| Sheathing, | | | | | | |
| intermediate density . . . 0.5 in. | 22 | — | 0.92 | — | 1.09 | 0.31 |
| Nail-base sheathing, 0.5 in. | 25 | — | 0.94 | — | 1.06 | 0.31 |
| Shingle backer, 0.375 in. | 18 | — | 1.06 | — | 0.94 | 0.31 |
| Shingle backer, 0.3125 in. | 18 | — | 1.28 | — | 0.78 | — |
| Sound deadening board . . . 0.5 in. | 15 | — | 0.74 | — | 1.35 | 0.30 |
| Tile and lay-in panels, | | | | | | |
| plain or acoustic | 18 | 0.40 | — | 2.50 | — | 0.14 |
| 0.5 in. | 18 | — | 0.80 | — | 1.25 | — |
| 0.75 in. | 18 | — | 0.53 | — | 1.89 | — |
| Laminated paperboard | 30 | 0.50 | — | 2.00 | — | 0.33 |
| Homogeneous board from repulped paper | 30 | 0.50 | — | 2.00 | — | 0.28 |
| Hardboard | | | | | | |
| Medium density | 50 | 0.73 | — | 1.37 | — | 0.31 |
| High density, service-tempered grade and service grade | 55 | 0.82 | — | 1.22 | — | 0.32 |
| High density, standard-tempered grade | 63 | 1.00 | — | 1.00 | — | 0.32 |
| Particle board | | | | | | |
| Low density | 37 | 0.71 | — | 1.41 | — | 0.31 |
| Medium density | 50 | 0.94 | — | 1.06 | — | 0.31 |
| High density | 62 | 0.5 | 1.18 | — | 0.85 | — |
| Underlayment 0.625 in. | 40 | — | 1.22 | — | 0.82 | 0.29 |
| Waterboard | 37 | 0.63 | — | 1.59 | — | — |
| Wood subfloor 0.75 in. | — | — | 1.06 | — | 0.94 | 0.33 |
| BUILDING MEMBRANE | | | | | | |
| Vapor—permeable felt | — | — | 16.70 | — | 0.06 | — |
| Vapor—seal, two layers of mopped 15-lb felt | — | — | 8.35 | — | 0.12 | — |
| Vapor—seal, plastic film | — | — | — | — | Negligible | — |
| FINISH FLOORING MATERIALS | | | | | | |
| Carpet and fibrous pad | — | — | 0.48 | — | 2.08 | 0.34 |
| Carpet and rubber pad | — | — | 0.81 | — | 1.23 | 0.33 |
| Cork tile 0.125 in. | — | — | 3.60 | — | 0.28 | 0.48 |
| Terrazzo 1 in. | — | — | 12.50 | — | 0.08 | 0.19 |
| Tile—asphalt, linoleum, vinyl, rubber | — | — | 20.00 | — | 0.05 | 0.30 |

Table 4B

| Description | Density, lb/ft ³ | Conductivity (K) | Conductance (C) | Resistance (R) | | Specific heat, Btu/lb/°F |
|--|--------------------------------|---------------------|--------------------|-------------------|------------------|--------------------------------|
| | | | | per inch (1/K) | overall (1/C) | |
| Tile—vinyl asbestos | — | — | — | — | — | 0.24 |
| Tile—ceramic | — | — | — | — | — | 0.19 |
| Wood, hardwood finish 0.75 in. | — | — | 1.47 | — | 0.68 | — |
| INSULATING MATERIALS | | | | | | |
| <i>Blanket and batt</i> | | | | | | |
| Mineral fiber, fibrous form processed from rock, slag, or glass | | | | | | |
| approx 3 to 4 in. | 0.4 to 2.0 | — | 0.091 | — | 11 | — |
| approx 3.5 in. | 0.4 to 2.0 | — | 0.077 | — | 13 | — |
| approx 3.5 in. | 1.2 to 1.6 | — | 0.067 | — | 15 | — |
| approx 5.5 to 6.5 in. | 0.4 to 2.0 | — | 0.053 | — | 19 | — |
| approx 5.5 in. | 0.6 to 1.0 | — | 0.048 | — | 21 | — |
| approx 6 to 7.5 in. | 0.4 to 2.0 | — | 0.045 | — | 22 | — |
| approx 8.25 to 10 in. | 0.4 to 2.0 | — | 0.033 | — | 30 | — |
| approx 10 to 13 in. | 0.4 to 2.0 | — | 0.026 | — | 38 | — |
| <i>Board and slabs</i> | | | | | | |
| Cellular glass | 8.0 | 0.33 | — | 3.03 | — | 0.18 |
| Glass fiber, organic bonded | 4.0 to 9.0 | 0.25 | — | 4.00 | — | 0.23 |
| Expanded perlite, organic bonded | 1.0 | 0.36 | — | 2.78 | — | 0.30 |
| Expanded rubber (rigid) | 4.5 | 0.22 | — | 4.55 | — | 0.40 |
| Expanded polystyrene, extruded (smooth skin surface) (CFC-12 exp) | 1.8 to 3.5 | 0.20 | — | 5.00 | — | 0.29 |
| Expanded polystyrene, extruded (smooth skin surface) (HCFC-142b exp) | 1.8 to 3.5 | 0.20 | — | 5.00 | — | 0.29 |
| Expanded polystyrene, molded beads | 1.0 | 0.26 | — | 3.85 | — | — |
| | 1.25 | 0.25 | — | 4.00 | — | — |
| | 1.5 | 0.24 | — | 4.17 | — | — |
| | 1.75 | 0.24 | — | 4.17 | — | — |
| | 2.0 | 0.23 | — | 4.35 | — | — |
| Cellular polyurethane/polyisocyanurate (CFC-11 exp) (unfaced) | 1.5 | 0.16 to 0.18 | — | 6.25 to 5.56 | — | 0.38 |
| Cellular polyisocyanurate (CFC-11 exp) (gas-permeable facers) | 1.5 to 2.5 | 0.16 to 0.18 | — | 6.25 to 5.56 | — | 0.22 |
| Cellular polyisocyanurate (CFC-11 exp) (gas-impermeable facers) | 2.0 | 0.14 | — | 7.04 | — | 0.22 |
| Cellular phenolic (closed cell) (CFC-11, CFC-113 exp) | 3.0 | 0.12 | — | 8.20 | — | — |
| Cellular phenolic (open cell) | 1.8 to 2.2 | 0.23 | — | 4.40 | — | — |
| Mineral fiber with resin binder | 15.0 | 0.29 | — | 3.45 | — | 0.17 |
| <i>Mineral fiberboard, wet felled</i> | | | | | | |
| Core or roof insulation | 16 to 17 | 0.34 | — | 2.94 | — | — |
| Acoustical tile | 18.0 | 0.35 | — | 2.86 | — | 0.19 |
| Acoustical tile | 21.0 | 0.37 | — | 2.70 | — | — |
| <i>Mineral fiberboard, wet molded</i> | | | | | | |
| Acoustical tile | 23.0 | 0.42 | — | 2.38 | — | 0.14 |
| <i>Wood or cane fiberboard</i> | | | | | | |
| Acoustical tile, 0.5 in. | — | — | 0.80 | — | 1.25 | 0.31 |
| Acoustical tile, 0.75 in. | — | — | 0.53 | — | 1.89 | — |
| Interior finish (plank, tile) | 15.0 | 0.35 | — | 2.86 | — | 0.32 |
| Cement fiber slabs (shredded wood with Portland cement binder) | 25 to 27 | 0.50 to 0.53 | — | 2.0 to 1.89 | — | — |
| Cement fiber slabs (shredded wood with magnesia oxysulfide binder) | 22.0 | 0.57 | — | 1.75 | — | 0.31 |

Table 4C

| Description | Density, lb/ft ³ | Conductivity (K) | Conductance (C) | Resistance (R) | | Specific heat, Btu/lb/°F |
|--|--------------------------------|---------------------|--------------------|-------------------|------------------|--------------------------------|
| | | | | per inch (1/K) | overall (1/C) | |
| <i>Loose fill</i> | | | | | | |
| Cellulosic insulation (milled paper or wood pulp) | 2.3 to 3.2 | 0.27 to 0.32 | — | 3.70 to 3.13 | — | 0.33 |
| Perlite, expanded | 2.0 to 4.1 | 0.27 to 0.31 | — | 3.7 to 3.3 | — | 0.26 |
| | 4.1 to 7.4 | 0.31 to 0.36 | — | 3.3 to 2.8 | — | — |
| | 7.4 to 11.0 | 0.36 to 0.42 | — | 2.8 to 2.4 | — | — |
| Mineral fiber (rock, slag, or glass) | | | | | | |
| approx 3.75 to 5 in. | 0.6 to 2.0 | — | — | — | 11.0 | 0.17 |
| approx 6.5 to 8.75 in. | 0.6 to 2.0 | — | — | — | 19.0 | — |
| approx 7.5 to 10 in. | 0.6 to 2.0 | — | — | — | 22.0 | — |
| approx 10.25 to 13.75 in. | 0.6 to 2.0 | — | — | — | 30.0 | — |
| Mineral fiber (rock, slag, or glass) | | | | | | |
| approx 3.5 in. (closed sidewall application) | 2.0 to 3.5 | — | — | — | 12.0 to 14.0 | — |
| Vermiculite, exfoliated | 7.0 to 8.2 | 0.47 | — | 2.13 | — | 0.32 |
| | 4.0 to 6.0 | 0.44 | — | 2.27 | — | — |
| <i>Spray applied</i> | | | | | | |
| Polyurethane foam | 1.5 to 2.5 | 0.16 to 0.18 | — | 6.25 to 5.56 | — | — |
| Ureaformaldehyde foam | 0.7 to 1.6 | 0.22 to 0.28 | — | 4.55 to 3.57 | — | — |
| Cellulosic fiber | 3.5 to 6.0 | 0.29 to 0.34 | — | 3.45 to 2.94 | — | — |
| Glass fiber | 3.5 to 4.5 | 0.26 to 0.27 | — | 3.85 to 3.70 | — | — |
| <i>Reflective insulation</i> | | | | | | |
| Reflective material ($\epsilon < 0.5$) in center of $\frac{3}{4}$ -in. cavity forms two $\frac{3}{8}$ -in. vertical air spaces | — | — | 0.31 | — | 3.2 | — |
| ROOFING | | | | | | |
| Asbestos-cement shingles | 120 | — | 4.76 | — | 0.21 | 0.24 |
| Asphalt roll roofing | 70 | — | 6.50 | — | 0.15 | 0.36 |
| Asphalt shingles | 70 | — | 2.27 | — | 0.44 | 0.30 |
| Built-up roofing 0.375 in. | 70 | — | 3.00 | — | 0.33 | 0.35 |
| Slate 0.5 in. | — | — | 20.00 | — | 0.05 | 0.30 |
| Wood shingles, plain and plastic film faced | — | — | 1.06 | — | 0.94 | 0.31 |
| PLASTERING MATERIALS | | | | | | |
| Cement plaster, sand aggregate | 116 | 5.0 | — | 0.20 | — | 0.20 |
| Sand aggregate 0.375 in. | — | — | 13.3 | — | 0.08 | 0.20 |
| Sand aggregate 0.75 in. | — | — | 6.66 | — | 0.15 | 0.20 |
| Gypsum plaster | | | | | | |
| Lightweight aggregate 0.5 in. | 45 | — | 3.12 | — | 0.32 | — |
| Lightweight aggregate 0.625 in. | 45 | — | 2.67 | — | 0.39 | — |
| Lightweight aggregate on metal lath 0.75 in. | — | — | 2.13 | — | 0.47 | — |
| Perlite aggregate | 45 | 1.5 | — | 0.67 | — | 0.32 |
| Sand aggregate | 105 | 5.6 | — | 0.18 | — | 0.20 |
| Sand aggregate 0.5 in. | 105 | — | 11.10 | — | 0.09 | — |
| Sand aggregate 0.625 in. | 105 | — | 9.10 | — | 0.11 | — |
| Sand aggregate on metal lath 0.75 in. | — | — | 7.70 | — | 0.13 | — |
| Vermiculite aggregate | 45 | 1.7 | — | 0.59 | — | — |
| MASONRY MATERIALS | | | | | | |
| <i>Masonry units</i> | | | | | | |
| Brick, fired clay | 150 | 8.4 to 10.2 | — | 0.12 to 0.10 | — | — |
| | 140 | 7.4 to 9.0 | — | 0.14 to 0.11 | — | — |

Table 4D

| Description | Density, lb/ft ³ | Conductivity (K) | Conductance (C) | Resistance (R) | | Specific heat, Btu/lb°F |
|---|--------------------------------|---------------------|--------------------|-------------------|------------------|-------------------------------|
| | | | | per inch (1/K) | overall (1/C) | |
| Brick, fired clay (continued) | 130 | 6.4 to 7.8 | — | 0.16 to 0.12 | — | — |
| | 120 | 5.6 to 6.8 | — | 0.19 to 0.15 | — | 0.19 |
| | 110 | 4.9 to 5.9 | — | 0.20 to 0.17 | — | — |
| | 100 | 4.2 to 5.1 | — | 0.24 to 0.20 | — | — |
| | 90 | 3.6 to 4.3 | — | 0.29 to 0.24 | — | — |
| | 80 | 3.0 to 3.7 | — | 0.33 to 0.27 | — | — |
| | 70 | 2.5 to 3.1 | — | 0.40 to 0.33 | — | — |
| Clay tile, hollow | | | | | | |
| 1 cell deep 3 in. | — | — | 1.25 | — | 0.80 | 0.21 |
| 1 cell deep 4 in. | — | — | 0.90 | — | 1.11 | — |
| 2 cells deep 6 in. | — | — | 0.66 | — | 1.52 | — |
| 2 cells deep 8 in. | — | — | 0.54 | — | 1.85 | — |
| 2 cells deep 10 in. | — | — | 0.45 | — | 2.22 | — |
| 3 cells deep 12 in. | — | — | 0.40 | — | 2.50 | — |
| Concrete blocks | | | | | | |
| Limestone aggregate | | | | | | |
| • 8 in., 36 lb, 1.38 lb/ft ³ concrete, 2 cores | — | — | — | — | — | — |
| • Same with perlite filled cores | — | — | 0.48 | — | 2.1 | — |
| • 12 in., 55 lb, 1.38 lb/ft ³ concrete, 2 cores | — | — | — | — | — | — |
| • Same with perlite filled cores | — | — | 0.27 | — | 3.7 | — |
| Normal weight aggregate (sand and gravel) | | | | | | |
| • 8 in., 33 to 36 lb, 126 to 136 lb/ft ³ concrete, 2 or 3 cores | — | — | 0.90 to 1.03 | — | 1.11 to 0.97 | 0.22 |
| • Same with perlite filled cores | — | — | 0.50 | — | 2.0 | — |
| • Same with vermiculite filled cores | — | — | 0.52 to 0.73 | — | 1.92 to 1.37 | — |
| • 12 in., 50 lb, 125 lb/ft ³ concrete, 2 cores | — | — | 0.81 | — | 1.23 | 0.22 |
| Medium weight aggregate (combinations of normal weight and lightweight aggregate) | | | | | | |
| • 8 in., 26 to 29 lb, 97 to 112 lb/ft ³ concrete, 2 or 3 cores | — | — | 0.58 to 0.78 | — | 1.71 to 1.28 | — |
| • Same with perlite filled cores | — | — | 0.27 to 0.44 | — | 3.7 to 2.3 | — |
| • Same with vermiculite filled cores | — | — | 0.30 | — | 3.3 | — |
| • Same with molded EPS (beads) filled cores | — | — | 0.32 | — | 3.2 | — |
| • Same with molded EPS inserts in cores | — | — | 0.37 | — | 2.7 | — |
| Lightweight aggregate (expanded shale, clay, slate or slag, pumice) | | | | | | |
| • 6 in., 16 to 17 lb, 85 to 87 lb/ft ³ concrete, 2 or 3 cores | — | — | 0.52 to 0.61 | — | 1.93 to 1.65 | — |
| • Same with perlite filled cores | — | — | 0.24 | — | 4.2 | — |
| • Same with vermiculite filled cores | — | — | 0.33 | — | 3.0 | — |
| • 8 in., 19 to 22 lb, 72 to 86 lb/ft ³ concrete | — | — | 0.32 to 0.54 | — | 3.2 to 1.90 | 0.21 |
| • Same with perlite filled cores | — | — | 0.15 to 0.23 | — | 6.8 to 4.4 | — |
| • Same with vermiculite filled cores | — | — | 0.19 to 0.26 | — | 5.3 to 3.9 | — |
| • Same with molded EPS (beads) filled cores | — | — | 0.21 | — | 4.8 | — |
| • Same with UF foam filled cores | — | — | 0.22 | — | 4.5 | — |
| • Same with molded EPS inserts in cores | — | — | 0.29 | — | 3.5 | — |

Table 4E

| Description | Density, lb/ft ³ | Conductivity (K) | Conductance (C) | Resistance (R) | | Specific heat, Btu/lb°F |
|--|--------------------------------|---------------------|--------------------|-------------------|------------------|-------------------------------|
| | | | | per inch (1/K) | overall (1/C) | |
| Lightweight aggregate (expanded shale, clay, slate or slag, pumice) (continued) | | | | | | |
| • 12 in., 32 to 36 lb, 80 to 90 lb/ft ³ concrete, 2 or 3 cores | — | — | 0.38 to 0.44 | — | 2.6 to 2.3 | — |
| • Same with perlite filled cores | — | — | 0.11 to 0.16 | — | 9.2 to 6.3 | — |
| • Same with vermiculite filled cores | — | — | 0.17 | — | 5.8 | — |
| Stone, lime, or sand | 160 | 72 | — | 0.01 | — | — |
| Quartzitic and sandstone | 160 | 43 | — | 0.02 | — | — |
| | 140 | 24 | — | 0.04 | — | — |
| | 120 | 13 | — | 0.08 | — | 0.19 |
| Calclitic, dolomitic, limestone, marble, and granite | 160 | 30 | — | 0.03 | — | — |
| | 160 | 22 | — | 0.05 | — | — |
| | 140 | 16 | — | 0.06 | — | — |
| | 120 | 11 | — | 0.09 | — | 0.19 |
| | 100 | 8 | — | 0.13 | — | — |
| Gypsum partition tile | | | | | | |
| 3 by 12 by 30 in., solid | — | — | 0.79 | — | 1.26 | 0.19 |
| 3 by 12 by 30 in., 4 cells | — | — | 0.74 | — | 1.35 | — |
| 4 by 12 by 30 in., 3 cells | — | — | 0.60 | — | 1.67 | — |
| Concretes | | | | | | |
| Sand and gravel or stone aggregate concretes (concretes with more than 50% quartz or quartzite sand have conductivities in the higher end of the range) | 150 | 10.0 to 20.0 | — | 0.10 to 0.05 | — | — |
| | 140 | 9.0 to 18.0 | — | 0.11 to 0.06 | — | 0.19 to 0.24 |
| | 130 | 7.0 to 13.0 | — | 0.14 to 0.08 | — | — |
| Limestone concretes | 140 | 11.1 | — | 0.09 | — | — |
| | 120 | 7.9 | — | 0.13 | — | — |
| | 100 | 5.5 | — | 0.18 | — | — |
| Gypsum-fiber concrete (87.5% gypsum, 12.5% wood chips) | 51 | 1.66 | — | 0.60 | — | 0.21 |
| Cement/lime, mortar, and stucco | 120 | 9.7 | — | 0.10 | — | — |
| | 100 | 6.7 | — | 0.15 | — | — |
| | 80 | 4.5 | — | 0.22 | — | — |
| Lightweight aggregate concretes | | | | | | |
| Expanded shale, clay, or slate; expanded slags; cinders; pumice (with density up to 100 lb/ft ³); and scoria (sanded concretes have conductivities in the higher end of the range) | 120 | 6.4 to 9.1 | — | 0.16 to 0.11 | — | — |
| | 100 | 4.7 to 6.2 | — | 0.21 to 0.16 | — | 0.20 |
| | 80 | 3.3 to 4.1 | — | 0.30 to 0.24 | — | 0.20 |
| | 60 | 2.1 to 2.5 | — | 0.48 to 0.40 | — | — |
| | 40 | 1.3 | — | 0.78 | — | — |
| Perlite, vermiculite, and polystyrene beads | 50 | 1.8 to 1.9 | — | 0.55 to 0.53 | — | — |
| | 40 | 1.4 to 1.5 | — | 0.71 to 0.67 | — | 0.15 to 0.23 |
| | 30 | 1.1 | — | 0.91 | — | — |
| | 20 | 0.8 | — | 1.25 | — | — |
| Foam concretes | 120 | 5.4 | — | 0.19 | — | — |
| | 100 | 4.1 | — | 0.24 | — | — |
| | 80 | 3.0 | — | 0.33 | — | — |
| | 70 | 2.5 | — | 0.40 | — | — |

Table 4F

| Description | Density, lb/ft ³ | Conductivity (K) | Conductance (C) | Resistance (R) | | Specific heat, Btu/lb/°F |
|---|-----------------------------|------------------|-----------------|----------------|---------------|--------------------------|
| | | | | per inch (1/K) | overall (1/C) | |
| Foam concretes and cellular concretes | 60 | 2.1 | — | 0.48 | — | — |
| | 40 | 1.4 | — | 0.71 | — | — |
| | 20 | 0.8 | — | 1.25 | — | — |
| SIDING MATERIALS (on flat surface) | | | | | | |
| <i>Shingles</i> | | | | | | |
| Asbestos-cement | 120 | — | 4.75 | — | 0.21 | — |
| Wood, 16 in., 7.5-in. exposure | — | — | 1.15 | — | 0.87 | 0.31 |
| Wood, double, 16-in., 12-in. exposure | — | — | 0.84 | — | 1.19 | 0.28 |
| Wood plus insulated backer board, 0.312 in. | — | — | 0.71 | — | 1.40 | 0.31 |
| <i>Siding</i> | | | | | | |
| Asbestos-cement, 0.25 in., lapped | — | — | 4.76 | — | 0.21 | 0.24 |
| Asphalt roll siding | — | — | 6.50 | — | 0.15 | 0.35 |
| Asphalt insulating siding (0.5-in. bed) | — | — | 0.69 | — | 1.46 | 0.35 |
| Hardboard siding, 0.4375 in. | — | — | 1.49 | — | 0.67 | 0.28 |
| Wood, drop, 1 by 8 in. | — | — | 1.27 | — | 0.79 | 0.28 |
| Wood, bevel, 0.5 by 8 in., lapped | — | — | 1.23 | — | 0.81 | 0.28 |
| Wood, bevel, 0.75 by 10 in., lapped | — | — | 0.95 | — | 1.05 | 0.28 |
| Wood, plywood, 0.375 in., lapped | — | — | 1.69 | — | 0.59 | 0.29 |
| Aluminum, steel, or vinyl over sheathing | — | — | — | — | — | — |
| • Hollow-backed | — | — | 1.64 | — | 0.61 | 0.29 |
| • Insulating-board backed, nominal 0.375 in. | — | — | 0.65 | — | 1.82 | 0.32 |
| • Insulating-board backed, nominal 0.375 in., foil backed | — | — | 0.34 | — | 2.96 | — |
| Architectural (soda-lime float) glass | 158 | 8.9 | — | — | — | 0.21 |
| WOODS (12% moisture content) | | | | | | |
| <i>Hardwoods</i> | | | | | | |
| Oak | 41.2 to 46.8 | 1.12 to 1.25 | — | 0.89 to 0.80 | — | 0.39 |
| Birch | 42.6 to 45.4 | 1.16 to 1.22 | — | 0.87 to 0.82 | — | — |
| Maple | 39.8 to 44.0 | 1.09 to 1.19 | — | 0.92 to 0.84 | — | — |
| Ash | 38.4 to 41.9 | 1.06 to 1.14 | — | 0.94 to 0.88 | — | — |
| <i>Softwoods</i> | | | | | | |
| Southern pine | 35.6 to 41.2 | 1.00 to 1.12 | — | 1.00 to 0.89 | — | — |
| Douglas fir-larch | 33.5 to 36.3 | 0.95 to 1.01 | — | 1.06 to 0.99 | — | — |
| Southern cypress | 31.4 to 32.1 | 0.90 to 0.92 | — | 1.11 to 1.09 | — | — |
| Hemlock-fir, spruce-pine-fir | 24.5 to 31.4 | 0.74 to 0.90 | — | 1.35 to 1.11 | — | — |
| West Coast woods, cedars | 21.7 to 31.4 | 0.68 to 0.90 | — | 1.48 to 1.11 | — | — |
| California redwood | 24.5 to 29.0 | 0.74 to 0.82 | — | 1.35 to 1.22 | — | — |

Table 4G

Table 18
Rapid load selection for back bars
(Based on 2" glass fiber or equivalent insulation and 59°F. T.D.)

| Back Bar Length in feet | BTU/Hour Load Based on 16 Hour Compressor Operation |
|-------------------------|---|
| 6 Feet | 1,040 |
| 8 Feet | 1,416 |
| 10 Feet | 1,770 |
| 12 Feet | 2,120 |
| 15 Feet | 2,650 |
| 20 Feet | 3,640 |

Table 19
Refrigeration requirements for hardening ice cream

| Overrun, Percent | Hardening Load, BTU per Gal. Ice Cream |
|------------------|--|
| 80 | 532 |
| 70 | 500 |
| 80 | 470 |
| 90 | 447 |
| 100 | 425 |
| 110 | 405 |
| 120 | 386 |

Table 4H

Table 9
Heat loads of keg and bottled beer BTU/24 HR

| Type and Size of Container | Temperature Reduction of Beer Only, °F. | | | | | | | |
|--------------------------------|---|------|-------|------|------|------|------|------|
| | 60 | 50 | 40 | 30 | 20 | 15 | 10 | 5 |
| Wood | | | | | | | | |
| One keg | — | — | 12000 | 9000 | 6000 | 4500 | 3000 | 1500 |
| Half keg | — | — | 5800 | 4650 | 3100 | 2325 | 1550 | 775 |
| Quarter keg | — | — | 3200 | 2490 | 1600 | 1200 | 800 | 400 |
| Eight keg | — | — | 1640 | 1230 | 820 | 615 | 410 | 205 |
| Aluminum | | | | | | | | |
| Half keg | — | — | 5200 | 3950 | 2600 | 1950 | 1300 | 650 |
| Quarter keg | — | — | 2900 | 1920 | 1260 | 950 | 640 | 320 |
| Eight keg | — | — | 1490 | 1090 | 720 | 525 | 350 | 175 |
| Steel | | | | | | | | |
| Half keg | — | — | 4900 | 3680 | 2500 | 1850 | 1250 | 620 |
| Quarter keg | — | — | 2400 | 1820 | 1220 | 900 | 620 | 310 |
| Bottles oz. | | | | | | | | |
| 6 | 32 | 27 | 22 | 16 | 10.8 | 8.1 | 5.4 | 2.7 |
| 7 | 37 | 31 | 25 | 20 | 12.4 | 9.3 | 6.2 | 3.1 |
| 8 | 42 | 35 | 28 | 21 | 14.9 | 10.6 | 7.8 | 3.8 |
| 9 | 47 | 38 | 30 | 23 | 15.2 | 11.4 | 7.6 | 3.8 |
| 12 | 60 | 50 | 40 | 28 | 20 | 15 | 10 | 5.0 |
| Case of 24-12 oz. bottles/cans | 1620 | 1000 | 1280 | 960 | 640 | 480 | 320 | 160 |

Table 10
Carcass weights

| Carcass | Average Weight Lbs. | Specific Heat | Entering Carcass Temp. °F. | Final Carcass Temp. °F. |
|---------|---------------------|---------------|----------------------------|-------------------------|
| Cattle | 550 | .77 | 106 | 35 |
| Calves | 150 | .76 | 104 | 35 |
| Sheep | 45 | .76 | 101 | 33 |
| Hogs | 180 | .54 | 106 | 35 |

Table 11
Heat equivalent of electric motors

| Motor HP | BTU Per (HP) (HR) | | |
|------------|---|--|--|
| | Connected Load In Refr Space ¹ | Motor Losses Outside Refr Space ² | Connected Load Outside Refr Space ³ |
| 1/8 to 1/2 | 4,250 | 2,545 | 1,700 |
| 1/2 to 3 | 3,700 | 2,545 | 1,150 |
| 3 to 20 | 2,950 | 2,545 | 400 |

¹ For use when both useful output and motor losses are dissipated within refrigerated space; motors driving fans for forced circulation unit coolers.
² For use when motor losses are dissipated outside refrigerated space and useful work of motor is expended within refrigerated space; pump on a circulating brine or chilled water system, fan motor outside refrigerated space driving fan circulating air within refrigerated space.
³ For use when motor heat losses are dissipated within refrigerated space and useful work expended outside of refrigerated space; motor in refrigerated space driving pump or fan located outside of space.

Table 12
Heat equivalent of occupancy

| Cooler Temperature F | Heat Equivalent/Person BTU/24 Hrs. |
|----------------------|------------------------------------|
| 50 | 17,000 |
| 40 | 20,100 |
| 30 | 22,800 |
| 20 | 25,200 |
| 10 | 26,800 |
| 0 | 31,200 |
| -10 | 33,600 |

Table 13
General standards for insulation thickness in storage rooms

| Storage Temperature | | Desirable Insulation Thickness in Inches | |
|---------------------|--------------|--|----------|
| ° F. | ° C. | Styrofoam | Urethane |
| -50° to -25° | -45° to -32° | 8 | 6 |
| -25° to 0° | -32° to -18° | 6 | 4 |
| 0° to 25° | -18° to -4° | 4 | 4 |
| 25° to 40° | -4° to 5° | 4 | 3-4 |
| 40° and up | +5° and up | 2 | 2 |

Table 14
Heat gain due to operation of battery operated lift trucks

| Battery operated, load capacity, lb. | Heat Gain per hour of truck operation, BTU/hr.* | Approximate total weight of lift truck, lb. |
|--------------------------------------|---|---|
| 2,000 | 14,000 | 6,000 |
| 4,000 | 21,000 | 8,000 |
| 6,000 | 23,000 | 12,000 |
| 8,000 | 26,000 | 14,000 |

*Heat gain from lift trucks with internal combustion engines can be approximated by multiplying the engine horsepower by 2.545 by the number of hours of operation (BTU/24 hrs.)

Table 15
Specific heats of various liquids and solids

| Name | Specific Heat | |
|--------------------|---------------|------------|
| | BTU/Lb./° F. | Temp. ° F. |
| Liquids | | |
| Acetic Acid | 0.522 | 79-203 |
| Alcohol-Ethyl | 0.580 | 32-208 |
| Alcohol-Methyl | 0.610 | 59-68 |
| Calcium Chloride | | |
| Brine (20% by Wt.) | 0.744 | 66 |
| Carbon | | |
| Tetrachloride | 0.201 | 66 |
| Chloroform | 0.234 | 66 |
| Gasoline | 0.500 | 32-212 |
| Glycerine | 0.575 | 59-120 |
| Olive Oil | 0.471 | 44 |
| Toluene | 0.404 | 66 |
| Turpentine | 0.420 | 66 |
| Solids | | |
| Aluminum | 0.214 | — |
| Asphalt | 0.220 | — |
| Bakelite | 0.350 | — |
| Brickwork | 0.200 | — |
| Brass | 0.090 | — |
| Bronze | 0.104 | — |
| Concrete | 0.156 | — |
| Glass | 0.200 | — |
| Ice | 0.485 | -4 |
| Ice | 0.497 | 32 |
| Iron (cast) | 0.120 | — |
| Lead | 0.031 | — |
| Paper | 0.320 | — |
| Porcelain | 0.180 | — |
| Rubber Goods | 0.400 | — |
| Sand | 0.191 | — |
| Steel | 0.120 | — |
| Woods | | |
| Fir | 0.550 | — |
| Oak | 0.570 | — |
| Pine | 0.670 | — |

OUTDOOR DESIGN TEMPERATURES

In refrigeration and air conditioning applications, maximum load conditions generally occur during the “warmest weather. Nevertheless, it is neither economical nor practical to design equipment for the highest possible temperature that might occur in a given area. After all, the temperature may be at that record level for only a few hours over a period of several years. National Weather Service records spanning many years have been used to establish suitable outdoor design temperatures for specific geographical areas. The outdoor design temperature is a temperature that, according to past data, will not be exceeded more than a given percentage of the time during the summer season in that area. Table 5 at the end of this chapter lists typical summer design temperatures. Actual temperatures should equal or exceed those listed only during 1% of the hours of the four-month summer season.

Table5A

| Location | Dry bulb, °F | Wet bulb, °F | Location | Dry bulb, °F | Wet bulb, °F |
|------------------------------|-----------------|-----------------|-----------------------------|-----------------|-----------------|
| CANADA | | | NOVA SCOTIA | | |
| ALBERTA | | | Greenwood | 84 | 69 |
| Calgary | 83 | 60 | Halifax | 80 | 68 |
| Edmonton | 82 | 63 | Sable Island | 70 | 67 |
| Fort McMurray | 84 | 64 | Shearwater | 78 | 66 |
| Grande Prairie | 81 | 62 | Sydney | 81 | 68 |
| Medicine Hat | 90 | 63 | Truro | 79 | 69 |
| Red Deer | 82 | 62 | Yarmouth | 73 | 66 |
| Vermilion | 83 | 64 | ONTARIO | | |
| BRITISH COLUMBIA | | | Armstrong | 81 | 66 |
| Abbotsford | 85 | 67 | Earlton | 85 | 69 |
| Fort Nelson | 82 | 62 | London | 85 | 71 |
| Port Hardy | 68 | 59 | North Bay | 81 | 67 |
| Prince George | 81 | 60 | Ottawa | 86 | 70 |
| Vancouver | 76 | 65 | Sault Sainte Marie | 83 | 69 |
| Victoria | 79 | 63 | Thunder Bay | 84 | 68 |
| Williams Lake | 83 | 59 | Toronto | 87 | 71 |
| MANITOBA | | | Trenton | 84 | 71 |
| Brandon | 87 | 67 | Windsor | 89 | 73 |
| Churchill | 77 | 62 | PRINCE EDWARD ISLAND | | |
| Winnipeg | 87 | 68 | Charlottetown | 79 | 69 |
| NEW BRUNSWICK | | | QUEBEC | | |
| Chatham | 86 | 69 | Bagotville | 84 | 67 |
| Moncton | 83 | 68 | Montreal | 85 | 71 |
| Saint John | 78 | 65 | Quebec | 84 | 70 |
| NEWFOUNDLAND | | | Riviere du Loup | 79 | 68 |
| Battle Harbour | 65 | 58 | Roberval | 83 | 68 |
| Cartwright | 75 | 62 | Sherbrooke | 84 | 70 |
| Deer Lake | 81 | 66 | Val d'Or | 83 | 67 |
| Gander | 79 | 65 | SASKATCHEWAN | | |
| Saint John's | 76 | 65 | Moose Jaw | 90 | 64 |
| Stephenville | 74 | 64 | North Battleford | 86 | 64 |
| Webush Lake | 76 | 60 | Prince Albert | 84 | 65 |
| NORTHWEST TERRITORIES | | | Regina | 89 | 64 |
| Cape Parry | 58 | 53 | Saskatoon | 87 | 64 |
| Fort Smith | 82 | 63 | Yorkton | 86 | 65 |
| Norman Wells | 80 | 62 | YUKON | | |
| Yellowknife | 77 | 60 | Burwash | 73 | 57 |
| NUNAVUT | | | Whitehorse | 77 | 57 |
| Baker Lake | 69 | 57 | | | |
| Cambridge Bay | 60 | 53 | | | |
| Chesterfield | 66 | 54 | | | |
| Coral Harbour | 64 | 53 | | | |
| Hall Beach | 56 | 50 | | | |

Table 5B

| Location | Dry bulb, °F | Wet bulb, °F | Location | Dry bulb, °F | Wet bulb, °F |
|--------------------|--------------|--------------|----------------------------|--------------|--------------|
| ALABAMA | | | FLORIDA (continued) | | |
| Birmingham | 94 | 75 | Fort Myers | 94 | 77 |
| Mobile | 94 | 77 | Jacksonville | 94 | 77 |
| Montgomery | 95 | 76 | Key West | 90 | 79 |
| Tuscaloosa | 95 | 77 | Miami | 91 | 77 |
| ALASKA | | | Pensacola | 93 | 78 |
| Anchorage | 71 | 59 | Saint Petersburg | 94 | 80 |
| Fairbanks | 81 | 61 | Tampa | 92 | 77 |
| Juneau | 74 | 60 | West Palm Beach | 91 | 78 |
| Nome | 69 | 57 | GEORGIA | | |
| ARIZONA | | | Athens | 94 | 75 |
| Flagstaff | 85 | 56 | Atlanta | 93 | 75 |
| Phoenix | 110 | 70 | Fort Benning | 97 | 76 |
| Tucson | 104 | 65 | Macon | 96 | 76 |
| ARKANSAS | | | Marietta | 94 | 74 |
| Fayetteville | 95 | 75 | Savannah | 95 | 77 |
| Fort Smith | 99 | 76 | HAWAII | | |
| Little Rock | 97 | 77 | Honolulu | 89 | 73 |
| CALIFORNIA | | | IDAHO | | |
| Bakersfield | 104 | 70 | Boise | 96 | 63 |
| Fresno | 103 | 71 | ILLINOIS | | |
| Long Beach | 92 | 67 | Chicago | 91 | 74 |
| Los Angeles | 85 | 64 | Decatur | 94 | 76 |
| Sacramento | 100 | 69 | Moline | 93 | 76 |
| San Diego | 85 | 67 | Peoria | 92 | 76 |
| San Francisco | 83 | 63 | Rockford | 91 | 74 |
| San Jose | 93 | 67 | Springfield | 93 | 76 |
| Santa Barbara | 83 | 64 | INDIANA | | |
| COLORADO | | | Evansville | 94 | 77 |
| Colorado Springs | 90 | 58 | Fort Wayne | 90 | 74 |
| Denver | 93 | 60 | Indianapolis | 91 | 75 |
| Pueblo | 97 | 62 | Lafayette | 93 | 75 |
| CONNECTICUT | | | South Bend | 90 | 73 |
| Bridgeport | 86 | 73 | Terre Haute | 93 | 76 |
| Hartford | 91 | 73 | IOWA | | |
| DELAWARE | | | Cedar Rapids | 93 | 75 |
| Dover | 93 | 76 | Des Moines | 93 | 76 |
| Wilmington | 91 | 75 | Fort Dodge | 92 | 75 |
| D.C. | | | Mason City | 91 | 74 |
| Washington | 95 | 76 | Sioux City | 94 | 75 |
| FLORIDA | | | Waterloo | 91 | 75 |
| Cape Canaveral | 92 | 78 | KANSAS | | |
| Daytona Beach | 92 | 77 | Dodge City | 100 | 70 |
| Fort Lauderdale | 92 | 78 | Topeka | 96 | 75 |
| | | | Wichita | 100 | 73 |

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Table 5C

| Location | Dry bulb, °F | Wet bulb, °F | Location | Dry bulb, °F | Wet bulb, °F |
|------------------------|--------------|--------------|-----------------------|--------------|--------------|
| KENTUCKY | | | MONTANA | | |
| Bowling Green | 94 | 76 | Billings | 93 | 63 |
| Fort Knox | 94 | 76 | Bozeman | 91 | 61 |
| Lexington | 91 | 74 | Butte | 86 | 57 |
| Louisville | 93 | 76 | Helena | 90 | 60 |
| LOUISIANA | | | Missoula | 91 | 62 |
| Baton Rouge | 94 | 78 | NEBRASKA | | |
| Lafayette | 94 | 78 | Lincoln | 97 | 74 |
| Lake Charles | 93 | 78 | Omaha | 95 | 75 |
| New Orleans | 93 | 79 | NEVADA | | |
| Shreveport | 97 | 77 | Las Vegas | 108 | 66 |
| MAINE | | | Reno | 95 | 61 |
| Augusta | 87 | 71 | NEW HAMPSHIRE | | |
| Bangor | 87 | 71 | Concord | 90 | 71 |
| Brunswick | 87 | 71 | Lebanon | 88 | 71 |
| Portland | 86 | 71 | Mount Washington | 60 | 56 |
| MARYLAND | | | NEW JERSEY | | |
| Baltimore | 93 | 75 | Atlantic City | 91 | 74 |
| MASSACHUSETTS | | | Newark | 93 | 74 |
| Boston | 91 | 73 | Trenton | 93 | 75 |
| Worcester | 85 | 71 | NEW MEXICO | | |
| MICHIGAN | | | Albuquerque | 96 | 60 |
| Detroit | 90 | 73 | Carlsbad | 101 | 65 |
| Flint | 88 | 73 | Roswell | 98 | 65 |
| Grand Rapids | 89 | 73 | Santa Fe | 90 | 65 |
| Lansing | 89 | 73 | NEW YORK | | |
| Marquette | 86 | 69 | Albany | 90 | 71 |
| Saginaw | 90 | 74 | Buffalo | 86 | 70 |
| Traverse City | 89 | 71 | New York | 91 | 74 |
| MINNESOTA | | | Niagara Falls | 87 | 72 |
| Brainerd | 88 | 70 | Poughkeepsie | 92 | 75 |
| Duluth | 84 | 69 | Rochester | 89 | 73 |
| Hibbing | 85 | 70 | Syracuse | 88 | 72 |
| International Falls | 86 | 69 | White Plains | 89 | 74 |
| Minneapolis-Saint Paul | 91 | 73 | NORTH CAROLINA | | |
| Rochester | 88 | 72 | Asheville | 88 | 72 |
| Saint Cloud | 91 | 72 | Charlotte | 94 | 74 |
| MISSISSIPPI | | | Fort Bragg | 96 | 77 |
| Biloxi | 92 | 79 | Greensboro | 92 | 75 |
| Jackson | 95 | 77 | Raleigh/Durham | 93 | 76 |
| Tupelo | 96 | 76 | Wilmington | 93 | 79 |
| MISSOURI | | | Winston-Salem | 92 | 74 |
| Columbia | 95 | 75 | NORTH DAKOTA | | |
| Kansas City | 96 | 75 | Bismarck | 93 | 68 |
| Saint Louis | 95 | 76 | Fargo | 91 | 71 |

Table 5D

| Location | Dry bulb, °F | Wet bulb, °F | Location | Dry bulb, °F | Wet bulb, °F |
|-----------------------|--------------|--------------|--------------------------|--------------|--------------|
| OHIO | | | TEXAS (continued) | | |
| Akron | 88 | 72 | Corpus Christi | 95 | 78 |
| Cincinnati | 93 | 74 | Dallas | 100 | 74 |
| Cleveland | 89 | 73 | El Paso | 101 | 64 |
| Columbus | 90 | 74 | Fort Worth | 100 | 75 |
| Dayton | 90 | 74 | Galveston | 91 | 82 |
| Toledo | 90 | 73 | Houston | 96 | 77 |
| Youngstown | 88 | 72 | Laredo | 102 | 73 |
| OKLAHOMA | | | Lubbock | 97 | 67 |
| Oklahoma City | 98 | 74 | San Antonio | 98 | 73 |
| Tulsa | 100 | 76 | Waco | 101 | 75 |
| OREGON | | | Wichita Falls | 103 | 74 |
| Eugene | 91 | 67 | UTAH | | |
| Pendleton | 97 | 64 | Ogden | 93 | 61 |
| Portland | 90 | 67 | Salt Lake City | 96 | 62 |
| Salem | 92 | 67 | VERMONT | | |
| PENNSYLVANIA | | | Burlington | 87 | 71 |
| Allentown | 90 | 73 | Montpelier | 85 | 70 |
| Altoona | 89 | 72 | VIRGINIA | | |
| Erie | 85 | 72 | Hampton | 94 | 78 |
| Harrisburg | 92 | 74 | Lynchburg | 93 | 74 |
| Philadelphia | 92 | 75 | Newport News | 95 | 78 |
| Pittsburgh | 89 | 72 | Norfolk | 93 | 77 |
| Wilkes-Barre/Scranton | 88 | 71 | Quantico | 94 | 77 |
| RHODE ISLAND | | | Richmond | 94 | 76 |
| Providence | 89 | 73 | Roanoke | 92 | 73 |
| SOUTH CAROLINA | | | WASHINGTON | | |
| Charleston | 94 | 78 | Olympia | 87 | 67 |
| Greenville | 93 | 74 | Seattle | 85 | 65 |
| Myrtle Beach | 93 | 79 | Spokane | 92 | 62 |
| SOUTH DAKOTA | | | Takoma | 86 | 65 |
| Pierre | 99 | 70 | Walla Walla | 98 | 66 |
| Rapid City | 95 | 65 | Yakima | 95 | 65 |
| Sioux Falls | 94 | 73 | WEST VIRGINIA | | |
| TENNESSEE | | | Charleston | 91 | 73 |
| Chattanooga | 94 | 75 | WISCONSIN | | |
| Knoxville | 92 | 74 | Green Bay | 88 | 73 |
| Memphis | 96 | 78 | La Crosse | 91 | 74 |
| Nashville | 94 | 76 | Madison | 90 | 73 |
| TEXAS | | | Milwaukee | 89 | 74 |
| Abilene | 99 | 71 | Wausau | 88 | 71 |
| Amarillo | 96 | 67 | WYOMING | | |
| Austin | 98 | 74 | Casper | 92 | 59 |
| Beaumont/Port Arthur | 94 | 79 | Cheyenne | 87 | 58 |
| Brownsville | 95 | 78 | Cody | 91 | 59 |
| | | | Rock Springs | 86 | 54 |

MAKING ALLOWANCES FOR SOLAR HEAT RADIATION

Radiant heat from the sun contributes significantly to heat gain. The heat load is much greater if the walls of a refrigerated space are exposed to the sun's rays, either directly or indirectly. In the northern hemisphere, the sun's rays fall on east, south, and west walls. To allow for solar radiation in heat load calculations, simply increase the temperature differential by the applicable figure shown in Table 6 on the next page (or in a similar table). Note that the figures given in Table 6 are for the summer season, and are to be used for refrigeration load calculations only. They are not accurate for estimating air conditioning loads.

Table 6

| Type of surface | East wall | South wall | West wall | Flat roof |
|---|-----------|------------|-----------|-----------|
| Dark surfaces Slate roofing Tar roofing Black paints | 8 | 5 | 8 | 20 |
| Medium surfaces Unpainted wood Brick Red tile Dark cement Red, gray, green paint | 6 | 4 | 6 | 15 |
| Light surfaces White stone Light-colored cement White paint | 4 | 2 | 4 | 9 |
| <small>Figures are to be added to the normal temperature differentials for heat leakage calculations in order to compensate for sun effect. Not to be used for air conditioning design.</small> | | | | |

Table 6. Allowance for sun effect, in °F

MAKING QUICK HEAT LOAD CALCULATIONS

There may be times when you need to make a non-critical heat load calculation, either for basic cost- estimating purposes or for some other reason. Table 7 at the bottom of the next page will help you make a quick calculation of heat transmission through insulated walls. It lists the heat gain for various thick- nesses of common insulations. The values given in Table 7 are in Btu per degree Fahrenheit of temperature difference per square foot of surface area per 24 hours. Note that the "thickness of insulation" refers to the insulation itself, not the thickness of the overall wall.

For example, assume that you are asked to find the heat transfer over a 24-hr period through a 6-ft x 8-ft wall insulated with 4 in. of fiberglass. The wall's outside surface is exposed to an ambient temperature of 95°F. The temperature inside the refrigerated space is 0°F. Refer to Table 7 and calculate as follows:

$$Q = \text{heat transfer value} \times \text{area} \times \Delta T = 1.5 \times 48 \text{ ft}^2 \times 95^\circ\text{F} = 6,840 \text{ Btu}$$

Table 7

| Insulation | Thickness of Insulation, in. | | | | | | | | | | |
|--|------------------------------|------|------|-------|------|------|------|------|------|------|------|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| <i>K</i> -value approximately 0.17 Expanded polyurethane | 2.04 | 1.36 | 1.02 | 0.815 | 0.68 | 0.58 | 0.51 | 0.45 | 0.41 | 0.37 | 0.34 |
| <i>K</i> -value approximately 0.25 Glass fiber, cork, mineral wool fill and board, expanded polystyrene | 3.0 | 2.0 | 1.5 | 1.2 | 1.0 | 0.86 | 0.75 | 0.67 | 0.60 | 0.55 | 0.50 |

Table 7. Quick-estimate values for heat transmission through insulated walls (Btu per 1°F temperature difference per ft² of area per 24 hours)

AIR INFILTRATION

Outside air enters a refrigerator or other refrigerated space whenever a door is opened. Reducing the temperature of this outside air to the level inside the enclosure increases the refrigeration load. If the moisture content of the entering air is above that of the refrigerated space, the excess moisture will condense out of the air. The latent heat of condensation also adds to the overall heat load.

Because of the many variables involved, it is difficult to calculate the additional heat gain due to air infiltration. Traffic in and out of a refrigerated area usually varies with the area's size or volume. The number of doors is not important, but the number of times the doors are opened must be considered.

Table 8 lists estimated average air changes per 24 hours for refrigerated areas of various sizes. These figures assume that the storage temperature is above 32°F. "Average air changes" are due to door openings and infiltration. As noted previously, however, it is difficult to estimate these figures accurately. You may have to modify the values as shown if you find that the use of the area is very heavy or very light. Another method of calculating air infiltration into a refrigerated space is to determine the velocity of airflow through an open door. When the door to a refrigerated space is opened, the difference in density between the cold air inside and the warm air outside creates a pressure differential. This pressure differential causes cold air to flow out at the bottom of the doorway, and warm air to flow in at the top. Velocities vary from a maximum value at the top and bottom of the doorway to zero at the vertical center of the opening. The average velocity in either half of a 7-ft doorway, for example, is 100 ft/min when the temperature difference is 60°F. The velocity varies with the square root of the height of the doorway, and with the square root of the temperature difference.

Air change per 24 Hours for room above 32°F by average due to doors and infiltration

Table 8A

| Volume, ft ³ | Air changes Per 24 hours | Volume, ft ³ | Air changes Per 24 hours |
|----------------------------|-----------------------------|----------------------------|-----------------------------|
| 200 | 44.0 | 6,000 | 6.5 |
| 300 | 34.5 | 8,000 | 5.5 |
| 400 | 29.5 | 10,000 | 4.9 |
| 500 | 26.0 | 15,000 | 3.9 |
| 600 | 23.0 | 20,000 | 3.5 |
| 800 | 20.0 | 25,000 | 3.0 |
| 1,000 | 17.5 | 30,000 | 2.7 |
| 1,500 | 14.0 | 40,000 | 2.3 |
| 2,000 | 12.0 | 50,000 | 2.0 |
| 3,000 | 9.5 | 75,000 | 1.6 |
| 4,000 | 8.2 | 100,000 | 1.4 |
| 5,000 | 7.2 | | |

TABLE 8B

Air change per 24 Hours for room below 32°F by average due to doors and infiltration

| Volume CU. FT | Air Changes Per 24 Hrs. | Volume Cu. Ft | Air Changes Per 24 Hrs | Volume Cu. Ft | Air Changes Per 24 Hrs |
|------------------|-------------------------------|------------------|------------------------------|------------------|------------------------------|
| 200 | 33.5 | 2,000 | 9.3 | 25,000 | 2.3 |
| 250 | 29.0 | 3,000 | 7.4 | 30,000 | 2.1 |
| 300 | 26.2 | 4,000 | 6.3 | 40,000 | 1.8 |
| 400 | 22.5 | 5,000 | 5.6 | 50,000 | 1.6 |
| 500 | 20.0 | 6,000 | 5.0 | 75,000 | 1.3 |
| 600 | 18.0 | 8,000 | 4.3 | 100,00 | 1.1 |
| 800 | 15.3 | 10,000 | 3.8 | 150,000 | 1.0 |
| 1,000 | 13.5 | 15,000 | 3.0 | 200,000 | 0.9 |
| 1,500 | 11.0 | 20,000 | 2.6 | 300,000 | 0.85 |

Table 8. Average air changes per 24 hours due to door opening and infiltration, for storage room above 32°F

Note: For heavy usage, multiply the above values by 2.0, for undisturbed long periods of storage multiply the above values by 0.6.

Here is a sample calculation. Assume that you wish to estimate the rate of infiltration through a door 8 ft high and 4 ft wide. There is a 100°F temperature difference between the refrigerated space and the outside air. Use the 7-ft doorway and the 60°F temperature difference as reference figures, and find the velocity as follows:

$$\begin{aligned}
 \text{Velocity} &= 100 \text{ ft/min} \times (\sqrt{8} / \sqrt{7}) \times (\sqrt{100} / \sqrt{60}) = 100 \times (2.83 / 2.65) \times (10 / 7.75) \\
 &= 100 \times 1.07 \times 1.29 \\
 &= 138 \text{ ft/min}
 \end{aligned}$$

Now, using this value for velocity, you can calculate the estimated rate of infiltration in cubic feet per minute (cfm):

$138 \text{ ft/mIn} \times (.8\text{ft} \times 4\text{ft} / 2) = 2,208 \text{ cfm}$

For refrigerated spaces in which ventilation is provided by supply and/or exhaust fans, the ventilation load replaces the infiltration load (if the ventilation load is greater). You can calculate heat gain based on the ventilating air volume.

Table 9

Heat (BTU per cu. Ft) going into Storage room

| Temperature of Outside Air of box | | | | | | | | | | | | | | |
|-----------------------------------|--|-------------|-------------|---------------|-------------|----------------|------|------|------|------|------|------|------|------|
| Storage Room Temperature | Relative Humidity of Outside Air of the box% | | | | | | | | | | | | | |
| | 40°F (4.4°C) | 50°F (10°C) | 85°F (29°C) | 90°F (32.2°C) | 95°F (35°C) | 100°F (37.8°C) | 70 | 80 | 70 | 80 | 50 | 60 | 50 | 60 |
| 55 | 12.8 | | | | | | 1.12 | 1.34 | 1.41 | 1.66 | 1.72 | 2.01 | 2.06 | 2.44 |
| 50 | 10.0 | | | | | | 1.32 | 1.54 | 1.62 | 1.87 | 1.93 | 2.22 | 2.28 | 2.65 |
| 45 | 7.2 | | | | | | 1.50 | 1.73 | 1.80 | 2.06 | 2.12 | 2.42 | 2.47 | 2.85 |
| 40 | 4.4 | | | | | | 1.69 | 1.92 | 2.00 | 2.26 | 2.31 | 2.62 | 2.67 | 3.65 |
| 35 | 1.7 | | | 0.36 | 0.41 | 1.86 | 2.09 | 2.17 | 2.43 | 2.49 | 2.79 | 2.85 | 3.24 | |
| 30 | -1.1 | 0.24 | 0.29 | 0.58 | 0.66 | 2.00 | 2.24 | 2.26 | 2.53 | 2.64 | 2.94 | 2.95 | 3.35 | |
| 25 | -3.9 | 0.41 | 0.45 | 0.75 | 0.83 | 2.09 | 2.42 | 2.44 | 2.71 | 2.79 | 3.16 | 3.14 | 3.54 | |
| 20 | -6.7 | 0.56 | 0.61 | 0.91 | 0.99 | 2.27 | 2.61 | 2.62 | 2.90 | 2.97 | 3.35 | 3.33 | 3.73 | |
| 15 | -9.4 | 0.71 | 0.75 | 1.06 | 1.14 | 2.45 | 2.74 | 2.80 | 3.07 | 3.16 | 3.54 | 3.51 | 3.92 | |
| 10 | -12.2 | 0.85 | 0.89 | 1.19 | 1.27 | 2.57 | 2.87 | 2.93 | 3.20 | 3.29 | 3.66 | 3.64 | 4.04 | |
| 5 | -15.0 | 0.98 | 1.03 | 1.34 | 1.42 | 2.76 | 3.07 | 3.12 | 3.40 | 3.48 | 3.87 | 3.84 | 4.27 | |
| 0 | -17.0 | 1.12 | 1.17 | 1.48 | 1.56 | 2.92 | 3.23 | 3.28 | 3.56 | 3.64 | 4.03 | 4.01 | 4.43 | |
| -5 | -20.6 | 1.23 | 1.28 | 1.59 | 1.67 | 3.04 | 3.36 | 3.41 | 3.69 | 3.78 | 4.18 | 4.15 | 4.57 | |
| -10 | -23.3 | 1.35 | 1.41 | 1.73 | 1.81 | 3.19 | 3.49 | 3.56 | 3.85 | 3.93 | 4.33 | 4.31 | 4.74 | |
| -15 | -26.1 | 1.50 | 1.53 | 1.85 | 1.92 | 3.29 | 3.60 | 3.67 | 3.96 | 4.05 | 4.46 | 4.42 | 4.86 | |
| -20 | -28.9 | 1.63 | 1.68 | 2.01 | 2.00 | 3.49 | 3.72 | 3.88 | 4.18 | 4.27 | 4.69 | 4.66 | 5.10 | |
| -25 | -31.7 | 1.77 | 1.80 | 2.12 | 2.21 | 3.61 | 3.84 | 4.00 | 4.30 | 4.39 | 4.80 | 4.78 | 5.21 | |
| -30 | -34.4 | 1.90 | 1.95 | 2.29 | 2.38 | 3.86 | 4.05 | 4.21 | 4.51 | 4.56 | 5.00 | 4.90 | 5.44 | |

Once you know the rate of infiltration, you can calculate the heat load from the heat gain per cubic foot of infiltration. For conditions not covered by available data, you can find the infiltration heat load by determining the difference in enthalpy between the entering air and the air inside the refrigerated space. You can do this most easily by using a psychrometric chart.

PRODUCT LOAD

The second factor to be considered in estimating the total heat load is the product load. The term "product" covers a wide variety of materials and substances. The nature of the product can determine the design of the enclosure in which it will be kept chilled or frozen. For example, there is a wide difference between freezing and storing bakery products in an insulated cabinet and chilling water in a continuous, tubular water chiller. Even in air conditioning there is a "product"-two, in fact, since both the dry air and the water vapor mixed with it are cooled.

In order to estimate the product load accurately, you must know several things about the product. What kinds of foods will be kept in the cooler, and at what temperatures? Where is the product coming from, and how is it being transported? How much of the product is to be placed in the cooler, on average, per day or per week?

From this information, you can estimate the amount of heat that must be removed from the product. The object is to cool it from the temperature at which it enters the cooler to the temperature at which it will be stored (and then to keep that temperature constant).

Assume that the following amounts of meats, vegetables, fruits, milk, and other dairy products represent an average daily product load:

Meats.

It is estimated that approximately 300 lb of fresh meat and 85 lb of poultry are handled on an average day. These meats are obtained from a local packinghouse. They are delivered pre-chilled, but not down to 36°F. Delivery temperature depends on the time of arrival, but averages about 50°F, which then must be reduced about 15°F to reach an acceptable storage temperature.

When larger quantities of meat products are involved, you must calculate the heat load factor for each different kind of fresh meat separately. However, the limited capacity of the walk-in cooler used in this example makes this unnecessary. The meats can be grouped together as far as their specific heats are concerned.

Let us assume that most of the meat involved is beef. The specific heat of fresh beef at an above-freezing temperature, as shown in Table 2 at the end of this chapter, ranges from 0.70 to 0.84 Btu/lb/°F. If the beef is relatively lean; you can use 0.77, the midpoint of this range, for your calculations. Simple math then tells you that to cool 300 lb of fresh meat through 15°F will require 3,465 Btu of refrigeration per day ($300 \times 15 \times 0.77 = 3,465$).

The specific heat of fresh poultry is 0.79 Btu/lb/°F. Make the same kind of calculation as you did for the beef, and you find that 1,007 Btu of heat must be removed from the 85 lb of poultry per day ($85 \times 15 \times 0.79 = 1,007$).

Milk and dairy products

It is estimated that 25 gallons of milk are handled daily. A gallon weighs roughly 8 lb, so 25 gallons of milk would weigh approximately 200 lb. The specific heat of milk, again from Table 2, is 0.93 Btu/lb/°F. Assuming a similar 15°F temperature change, the heat load from this product comes to about 2,790 Btu per day ($200 \times 15 \times 0.93 = 2,790$).

Vegetables and fruits

Included in this category are cabbage, lettuce, string beans, peas, rhubarb, carrots, apples, peaches, pears, oranges, grapefruit, etc. About 100 lb of these items are handled daily. However, they are on display during regular business hours and are only in the storage cooler overnight. Since they represent a minimum load, and then only at a time when there is no traffic in or out of the cooler, they may be disregarded as part of the product load. (*Note: For larger applications, such as cold-storage warehouses, individual product loads can never be disregarded. When estimating the total heat load for such applications, you must make separate computations for each product, and for its respective temperature and specific heat.*)

From the preceding calculations, you can now find the total product load:

Fresh meats 3,465 Btu per day + Poultry 1,007 Btu per day Milk + 2,790 Btu per day

Total product load = 7,262 Btu per day

If the product to be stored in the refrigerated space is delivered pre-cooled, the product load is usually negligible, especially in small walk-in cooler installations. For large-volume applications, however, the product load may be substantial enough to require separate calculations for each product. This requires knowing the freezing point, specific heat, percent water, etc. of each product.

The *product load*, whether it is heavy or light, is defined as any heat gain resulting from the products that are being stored in the refrigerated space. The heat given off depends on the specific product and its storage temperature.

Product heat gain consists of some or all of:

- the heat released from products that were initially stored and/or transported at a higher temperature than that maintained in the refrigerated space
- the heat removed in the process of freezing or chilling the products
- The heat of respiration from chemical reactions that take place in products.

Note that the values resulting from the last item vary with the storage temperature.

CALCULATING SENSIBLE HEAT

Above-freezing temperatures

Most products are at a higher temperature than the storage temperature when they are first placed in the refrigerated space. Many food products have a high percentage of water content. Their reaction to a loss of heat is quite different above the freezing point than it is below the freezing point. Above the freezing point, the water continues to exist as liquid. Below the freezing point, it changes to ice.

The *specific heat* of a product is defined, as the amount of heat (Btu) required raising the temperature of 1 lb of the substance 1°F. Note that the specific heat of a product differs depending on whether the temperature is above freezing or below freezing. The freezing point, which in most cases is below 32°F, also varies among products.

The heat to be removed from a stored product to lower its temperature to a point above freezing can be calculated as follows:

$$Q = W \times C \times (T_1 - T_2)$$

where:

Q = the quantity of heat (Btu) to be removed

W = the weight of the product (lb)

C = the specific heat of the product above freezing

T1 = the initial temperature (OF)

T2 = the final temperature, at or above the freezing point (OF).

For example, assume that you want to calculate the heat that must be removed in order to cool 1,000 lb of veal from 42°F to 29°F. The highest freezing point of veal is 29° F. The specific heat, taken from Table 2 at the end of the previous chapter, is 0.76 Btu/lb/°F. Proceed as follows:

$$Q = 1,000 \text{ lb} \times 0.76 \times (42^\circ\text{F} - 29^\circ\text{F})$$

$$= 1,000 \times 0.76 \times 13 = 9,880$$

Btu Below-freezing temperatures

Once the water content of a product has been frozen, sensible cooling occurs again, just as it did when the product was above freezing. Now the ice in the product causes the specific heat to change. For example, the specific heat of veal *above* freezing is 0.76. Its specific heat *below* freezing is 0.41.

The heat to be removed from a stored product to lower its temperature to a point *below* freezing can be calculated as follows:

$$Q = W \times C1 \times (T1 - T 3)$$

where:

Q = the quantity of heat (Btu) to be removed

W = the weight of the product (lb)

C1 = the specific heat of the product below freezing

T1 = the freezing temperature (OF)

T 3 = the final temperature, below the freezing point (OF).

For example, to calculate the heat that must be removed from the same 1,000 lb of veal in order to cool it from its freezing point (29°F) to 0°F, you would proceed as follows:

$$Q = 1,000\text{lb} \times 0.41 \times (29^\circ\text{F} - 0^\circ\text{F})$$
$$= 1,000 \times 0.41 \times 29 = 11,890 \text{ Btu}$$

CALCULATING THE LATENT HEAT OF FREEZING

Most refrigerated food products contain a high percentage of water. When calculating the amount of heat that must be removed in order to freeze a product, you need to know its water content.

The *latent heat of freezing* (also called the *latent heat of fusion*) is defined as the amount of heat (Btu) that must be removed in order to change 1 lb of a liquid to 1 lb of solid at the same temperature. You can find a product's latent heat of freezing by multiplying the latent heat of water (144 Btu/lb) times the percentage of water in the product. It also shows the latent heat of fusion for veal to be 100 Btu/lb, but you could have arrived at approximately the same figure by calculating as follows:

$$0.70 \times 144 \text{ Btu/lb} = 100 \text{ Btu/lb}$$

To calculate the amount of heat that must be removed from a product in order to freeze it, then, simply proceed as follows:

$$Q = W \times hf$$

where:

Q = the quantity of heat (Btu) to be removed

W = the weight of the product (lb)

hf = the product's latent heat of fusion (Btu/lb).

Therefore, the latent heat of freezing 1,000lb of veal at 29°F is:

$$Q = W \times hf$$
$$= 1,000 \text{ lb} \times 100 \text{ Btu/lb} = 100,000 \text{ Btu}$$

CALCULATING THE TOTAL PRODUCT LOAD

The *total product load* is the sum of the individual calculations just completed. It includes the sensible heat above freezing, the latent heat of freezing, and the sensible heat below freezing. Using the previous calculations as an example, if 1,000 lb of veal is cooled from 42°F to 0°F, the total product load would be:

Sensible heat above freezing 9,880 Btu + Latent heat of freezing 100,000 Btu + Sensible heat below freezing 11,890 Btu = 121,770 Btu total.

Table 10A

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/ F° | Specific Heat Below Freezing BTU/Lb/ F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |
|-------------------------|------------------|---------------------|--------------------------|---------------------------|---|---|---------------------------------|---|
| Vegetables | | | | | | | | |
| Artichokes | | | | | | | | |
| Globe | 32° | 95 to 100 | 2 week | 29.8° | 0.93 | 0.48 | 122 | - |
| <i>Jerusalem</i> | 31° to 32° | 90 to 95 | 4 to 5 months | 27.5° | 0.87 | 0.54 | 112 | |
| <i>Asparagus</i> | 32° to 35° | 95 to 100 | 2 to 3 weeks | 30.9° | 0.94 | 0.48 | 134 | 25 |
| Beans | | | | | | | | |
| <i>Snap or Green</i> | 40° to 45° | 95 | 7 to 10 days | 30.7° | 0.91 | 0.47 | 128 | 14 |
| <i>Lima</i> | 34° to 40° | 95 | 3 to 5 day | 31.0° | 0.73 | 0.40 | 94 | |
| <i>Dried</i> | 50° | 70 | 6 to 8 months | | | | | |
| Beets | | | | | | | | |
| <i>Roots</i> | 32° | 95 to 100 | 4 to 6 months | 30.1° | 0.90 | 0.46 | 126 | 23 |
| <i>Bunch</i> | 32° | 98 to 100 | 10 to 14 days | | | | | |
| Broccoli | 33° | 95 | 10 to 14 days | 30.9 | 0.96 | 0.43 | | |
| Brussels sprouts | 32° | 95 to 100 | 3 to 5 weeks | 30.5 | 0.88 | 0.46 | 122 | |
| Cabbage, Late | 32° | 98 to 100 | 5 to 6 months | 30.4° | 0.94 | 0.47 | 132 | 17 |
| Carrots | | | | | | | | |
| <i>Topped-immature</i> | 32° | 98 to 100 | 4 to 6 weeks | 29.5° | 0.90 | 0.46 | 126 | 22 |
| <i>Topped-mature</i> | 32° | 98 to 100 | 7 to 9 months | 29.5° | 0.90 | 0.46 | 126 | 22 |
| Cauliflower | 32° | 95 to 98 | 3 to 4 weeks | 29.0° | 0.93 | 0.47 | 132 | 16 |
| Celeriac | 32° | 95 to 100 | 6 to 8 months | 30.3° | 0.91 | 0.46 | 126 | |
| Celery | 32° | 98 to 100 | 2 to 3 months | 31.1° | 0.95 | 0.48 | 135 | 30 |
| Collards | 32° | 95 to 100 | 10 to 14 days | 30.6° | 0.94 | 0.44 | 130 | |
| Corn, Sweet | 32° | 95 to 98 | 4 to 8 days | 30.9° | 0.79 | 0.42 | 106 | 16 |
| Cucumbers | 45° to 50° | 95 | 10 to 14 days | 31.1° | 0.97 | 0.49 | 137 | 20 |
| Eggplant | 45° to 50° | 90 to 95 | 7 to 10 days | 30.6° | 0.94 | 0.48 | 132 | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/ F° | Specific Heat Below Freezing BTU/Lb/ F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |

Table 10B

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|---------------------|------------------|---------------------|--------------------------|---------------------------|--|--|---------------------------------|--|
| Endive (Escarole) | 32° | 95 | 2 to 3 weeks | 31.9° | 0.94 | 0.48 | 132 | |
| Frozen Vegetables | -10° to 0° | | 6 to 12 months | | | | | |
| Garlic | 33° | 70 | 1 to 2 months | 30.6° | 0.76 | 0.52 | 84 | |
| Garlic, dry | 32° | 65 to 70 | 6 to 7 weeks | 30.5° | 0.69 | 0.40 | 89 | |
| Greens, leafy | 32° | 95 | 10 to 14 days | 30.0° | 0.91 | 0.48 | 136 | 32 |
| Ginger, root | 34° | 90 to 95 | 1 to 2 months | 29.0° | 0.90 | 0.46 | 117 | |
| Horseradish | 30° to 32° | 95 to 100 | 10 to 12 months | 28.7° | 0.78 | 0.42 | 104 | |
| Jicama | 55° to 65° | 65 to 70 | 1 to 2 months | | | | | |
| Kale | 32° | 95 | 3 to 4 months | 31.1° | 0.89 | 0.46 | 124 | |
| Kohlrabi | 32° | 95 | 2 to 4 weeks | 30.2° | 0.92 | 0.47 | 124 | |
| Leeks, green | 32° | 95 | 1 to 3 months | 30.7° | 0.88 | 0.46 | 126 | |
| Lettuce head | 34° | 95 to 100 | 2 to 3 weeks | 31.7° | 0.96 | 0.48 | 136 | 25 |
| Mushrooms | 32° | 90 | 3 to 4 days | 30.4° | 0.93 | 0.47 | 130 | |
| Okra | 45° to 50° | 90 to 95 | 7 to 10 days | 28.7° | 0.92 | 0.46 | 128 | |
| Onions | | | | | | | | |
| Green | 32° | 95 | 3 to 4 weeks | 30.4° | 0.91 | | | 22 |
| Dry, and onion sets | 32° | 65 to 70 | 1 to 8 months | 30.6° | 0.90 | 0.46 | 124 | |
| Parsley | 32° | 95 | 1 to 2 months | 30.0° | 0.88 | 0.45 | 122 | |
| Parsnips | 32° | 98 to 100 | 4 to 6 months | 30.4° | 0.84 | 0.44 | 112 | 36 |
| Peas | | | | | | | | |
| Green | 32° | 95 | 1 to 3 weeks | 30.9° | 0.79 | 0.42 | 106 | 23 |
| Dried | 50° | 70 | 6 to 8 months | | | | | |
| Peppers | | | | | | | | |
| Dried chili | 32° to 50° | 60 to 70 | 6 months | | 0.30 | 0.24 | 17 | |
| Sweet | 45° to 50° | 90 to 95 | 2 to 3 weeks | 30.7° | 0.94 | 0.47 | 132 | 41 |
| | | | | | | | | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

Table 10C

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/ F° | Specific Heat Below Freezing BTU/Lb/ F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |
|---------------------|------------------|---------------------|--------------------------|---------------------------|---|---|---------------------------------|---|
| Potatoes | | | | | | | | |
| <i>Early</i> | 38° to 40° | 90 to 95 | 4 to 5 months | 30.9° | 0.85 | 0.43 | 111 | |
| <i>Main crop</i> | 38° to 40° | 90 to 95 | 5 to 8 months | 30.9° | 0.82 | 0.44 | 116 | |
| <i>Spring</i> | 32° | 95 to 100 | 3 to 4 weeks | 30.7° | 0.95 | 0.48 | 134 | |
| <i>Winter</i> | 32 | 95 to 100 | 2 to 4 months | 30.2° | 0.95 | 0.48 | 134 | |
| Rhubarb | 32° | 95 | 2 to 4 weeks | 30.3° | 0.96 | 0.48 | 134 | |
| Rutabagas | 32° | 98 to 100 | 4 to 6 months | 30.1° | 0.91 | 0.47 | 127 | |
| Salsify | 32° | 98 to 100 | 2 to 4 months | 30.0° | 0.83 | 0.44 | 133 | |
| Seed, vegetable | 32° to 50° | 50 to 65 | 10 to 12 months | | 0.29 | 0.23 | 16 | |
| Spinach | 32° | 95 | 10 to 14 days | 31.5° | 0.94 | 0.48 | 132 | |
| Squash | - | - | - | - | - | - | - | - |
| <i>Acorn</i> | 45° to 50° | 70 to 75 | 5 to 8 weeks | 30.5° | | | | |
| <i>Summer</i> | 32° to 50° | 85 to 95 | 5 to 14 days | 31.1° | 0.95 | 0.48 | 135 | |
| <i>Winter</i> | 50° to 55° | 70 to 75 | 4 to 6 months | 30.3° | 0.91 | 0.48 | 127 | |
| Tamarillos | 37° to 40° | 85 to 95 | 10 weeks | | | | | |
| Tomatoes | - | - | - | - | - | - | - | - |
| <i>Mature green</i> | 55° to 70° | 85 to 90 | 1 to 3 weeks | 31.0° | 0.95 | 0.48 | 134 | 25 |
| <i>Firm, ripe</i> | 45° to 50° | 85 to 90 | 4 to 7 days | 31.1° | 0.94 | 0.48 | 134 | 21 |
| Turnips | - | - | - | - | - | - | - | - |
| <i>Roots</i> | 32° | 95 | 4 to 5 months | 30.1° | 0.93 | 0.47 | 130 | |
| <i>Greens</i> | 32° | 95 to 100 | 10 to 14 days | 30.6° | 0.92 | 0.48 | | |
| Watercress | 32° | 95 to 100 | 2 to 3 weeks | | | | | |
| Yams | 60° | 85 to 90 | 3 to 60 months | 28.5° | 0.79 | 0.40 | 105 | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/ F° | Specific Heat Below Freezing BTU/Lb/ F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |

Table 10D

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|-------------------------|------------------|---------------------|--------------------------|---------------------------|--|--|---------------------------------|--|
| Fruit and Melons | | | | | | | | |
| Apples | 30° to 40° | 90 | 3 to 8 months | 29.3 ° | 0.87 | 0.45 | 121 | 28 |
| Apples dried | 41° to 48° | 55 to 60 | 5 to 8 months | | | | | |
| Apricots | 31° to 32 ° | 90 | 1 to 2 weeks | 30.1 ° | 0.88 | 0.46 | 122 | 30 |
| Avocados | 45° to 55° | 85 to 90 | 2 to 4 weeks | 31.5° | 0.72 | 0.40 | 94 | 19 |
| Bananas | 55° to 65° | 85 to 95 | | 30.6° | 0.80 | 0.42 | 108 | |
| Blackberries | 31° to 32° | 95 | 3 days | 30.5° | 0.88 | 0.46 | 122 | 19 |
| Blueberries | 31° to 32° | 90 to 95 | 2 weeks | 29.7° | 0.86 | 0.45 | 118 | 19 |
| Cantaloupes | 36° to 40° | 95 | 5 to 15 days | 29.8° | 0.94 | 0.46 | 129 | |
| Casaba melons | 45° to 50° | 85 to 95 | 4 to 6 weeks | | | | | |
| Cherries | - | - | - | - | - | - | - | - |
| <i>Sour</i> | 31° to 32° | 90 to 95 | 3 to 7 days | 29.0° | 0.87 | 0.49 | 124 | 18 |
| <i>Sweet</i> | 30° to 31° | 90 to 95 | 2 to 3 weeks | 28.8° | 0.89 | 0.51 | 116 | |
| Coconuts | 32° to 35° | 80 to 85 | 1 to 2 months | 30.4° | 0.58 | 0.34 | 67 | |
| Cranberries | 36° to 40° | 90 to 95 | 2 to 4 months | 30.4° | 0.90 | 0.46 | 124 | 22 |
| Crenshaw melons | 45° to 50° | 75 to 80 | 2 to 4 weeks | | | | | |
| Currants | 31° to 32° | 90 to 95 | 10 to 14 days | 30.2° | 0.88 | 0.45 | 120 | |
| Dates, cured | 0° to 32° | 75 or less | 6 to 12 months | 3.7° | 0.36 | 0.26 | 29 | 24 |
| Dewberries | 31° to 32° | 90 to 95 | 3 days | 27.0° | 0.88 | | | |
| Elderberries | 31° to 32° | 90 to 95 | 1 to 2 weeks | | | | | |
| Figs | - | - | - | - | - | - | - | - |
| <i>Dried</i> | 32° to 40° | 50 to 60 | 9 to 12 months | | 0.36 | 0.27 | 34 | 45 |
| <i>Fresh</i> | 31° to 32° | 85 to 90 | 7 to 10 days | 27.6° | 0.82 | 0.43 | 112 | 21 |
| | | | | | | | | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

Table 10E

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|--------------------------|------------------|---------------------|--------------------------|---------------------------|--|--|---------------------------------|--|
| Frozen fruits | -12° to 0° | 90 to 95 | 18 to 24 months | | | | | |
| Grapefruit | 50° to 60° | 85 to 90 | 4 to 6 weeks | 30.0° | 0.91 | 0.46 | 126 | 30 |
| Grapes | - | - | - | - | - | - | - | - |
| <i>American type</i> | 31° to 32° | 85 to 90 | 2 to 8 weeks | 29.7° | 0.86 | 0.44 | 116 | 29 |
| <i>European type</i> | 30° to 31° | 90 to 95 | 3 to 6 months | 28.1° | 0.86 | 0.44 | 116 | 29 |
| <i>Vinifera</i> | 30° to 31° | 90 to 95 | 3 to 6 months | | | | | |
| Guavas | 45° to 50° | 90 | 2 to 3 weeks | | 0.86 | | | |
| Honeydew melons | 41° to 50° | 90 to 95 | 2 to 3 weeks | 30.4° | 0.94 | 0.44 | 129 | |
| Kiwifruit | 31° to 32° | 90 to 95 | 3 to 5 months | | | | | |
| Lemons | 32° to 58° | 85 to 90 | 1 to 6 months | 29.4° | 0.91 | 0.46 | 127 | 33 |
| Limes | 45° to 48° | 85 to 90 | 6 to 8 weeks | 29.1° | 0.89 | 0.46 | 122 | 32 |
| Loganberries | 31° to 32° | 90 to 95 | 2 to 3 days | | | | | |
| Loquats | 32° | 90 | 3 weeks | | | | | |
| Lychees | 35° | 90 to 95 | 3 to 5 weeks | | | | | |
| Mangoes | 55° | 85 to 90 | 2 to 3 weeks | 30.3° | 0.85 | 0.44 | 117 | |
| Melons, Casaba | 45° to 48° | 75 to 80 | 2 to 4 weeks | 30.0° | 0.95 | 0.45 | 132 | |
| Nectarines | 31° to 32° | 90 | 2 to 4 weeks | 30.4° | 0.90 | 0.49 | 119 | |
| Olives, fresh | 45° to 50° | 85 to 90 | 4 to 6 weeks | 29.4° | 0.80 | 0.42 | 108 | |
| Oranges Juice | 32° to 35° | | 3 to 6 weeks | 30.6° | 0.91 | 0.47 | 128 | |
| <i>Oranges CA and AZ</i> | 38° to 40° | 85 to 90 | 3 to 6 weeks | 30.6° | 0.90 | 0.46 | 124 | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

Table 10F

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |
|--------------------------|------------------|---------------------|--------------------------|---------------------------|--|--|---------------------------------|---|
| <i>Oranges FL and TX</i> | 32° to 34° | 85 to 90 | 8 to 12 weeks | 28.6° | 0.91 | 0.46 | 126 | |
| Papayas | 45° | 85 to 90 | 1 to 3 weeks | 30.4° | 0.82 | 0.47 | 130 | |
| Peaches | 31° to 32° | 90 | 2 to 4 weeks | 30.3° | 0.90 | 0.46 | 124 | 33 |
| Peaches dried | 32° to 41° | 55 to 60 | 5 to 8 months | | 0.61 | 0.83 | 46 | |
| Pears | 29° to 31° | 90 to 95 | 2 to 7 months | 29.2° | 0.86 | 0.45 | 118 | 47 |
| Persian melons | 45° to 50° | 90 to 95 | 2 weeks | | 0.81 | 0.43 | 112 | |
| Persimmons | 30° | 90 | 3 to 4 months | 28.1° | 0.84 | 0.43 | 112 | |
| Pineapples, ripe | 45° | 85 to 90 | 2 to 4 weeks | 30.0° | 0.88 | 0.45 | 122 | 25 |
| Plums | 31° to 32° | 90 to 95 | 2 to 4 weeks | 30.5° | 0.88 | 0.45 | 118 | 22 |
| Pomegranates | 32° | 90 | 2 to 4 weeks | 26.6° | 0.87 | 0.48 | 112 | |
| Prunes | - | - | - | - | - | - | - | - |
| <i>Fresh</i> | 31° to 32° | 90 to 95 | 2 to 4 weeks | 30.5° | 0.84 | 0.34 | 112 | |
| <i>Dried</i> | 32° to 41° | 55 to 60 | 5 to 8 months | | | | | |
| Quinces | 31° to 32° | 90 | 2 to 3 months | 28.4° | 0.88 | 0.45 | 122 | |
| Raisins | 40° | 60 to 70 | 9 to 12 months | | 0.47 | 0.32 | 43 | 45 |
| Raspberries, black | 31° to 32° | 90 to 95 | 2 to 3 days | 30.0° | 0.84 | 0.44 | 122 | |
| Raspberries, red | 31° to 32° | 90 to 95 | 2 to 3 days | 30.9° | 0.87 | 0.45 | 121 | |
| Strawberries | 31° to 32° | 90 to 95 | 5 to 7 days | 30.6° | 0.92 | 0.42 | 129 | 40 |
| Tangerines | 32° to 38° | 85 to 90 | 2 to 4 weeks | 30.1° | 0.90 | 0.46 | 125 | |
| Watermelons | 40° to 50° | 80 to 90 | 2 to 3 weeks | 31.3° | 0.97 | 0.48 | 132 | 27 |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |

Table 10G

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|--------------------|------------------|---------------------|--------------------------|---------------------------|--|--|---------------------------------|--|
| Haddock, Cod Perch | 30° to 35° | 90 to 95 | 12days | 28° | 0.82 | 0.43 | 112 | 35 |
| Hake, Whiting | 32° to 34° | 95 to 100 | 10 days | 28° | 0.86 | 0.45 | 118 | |
| Halibut | 31° to 34° | 95 to 100 | 18 days | 28.0° | 0.75 | 0.45 | 110 | |
| Herring | - | - | - | - | - | - | - | - |
| <i>Kippered</i> | 32° to 36° | 80 to 90 | 10 days | 28.0° | 0.76 | 0.41 | 100 | |
| <i>Smoked</i> | 40° to 50° | 50 to 60 | 6 to 8 months | | 0.70 | 0.39 | 92 | |
| Tuna | 30° to 35° | 90 to 95 | 15 days | 28° | 0.76 | 0.41 | 100 | 35 |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/ F° | Specific Heat Below Freezing BTU/Lb/ F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |
|-----------------------------|------------------|---------------------|--------------------------|---------------------------|---|---|---------------------------------|---|
| Mackerel | 32° to 34° | 95 to 100 | 6 to 8 days | 28.0° | 0.66 | 0.37 | 82 | |
| Salmon | 40° to 50° | 50 to 60 | 15 days | 28° | 0.71 | 0.39 | 92 | |
| Scallop meat | 32° to 34° | 95 to 100 | 12 days | 28° | 0.84 | 0.44 | 115 | |
| Shrimp | 31° to 34° | 95 to 100 | 12 to 14 days | 28° | 0.86 | 0.45 | 119 | 35 |
| Lobster American | 41° to 50° | In sea water | indefinitely | 28° | 0.87 | 0.51 | 113 | |
| Oysters, Clams | | | | | | | | |
| <i>(meat and liquid)</i> | 32° to 36° | 100 | 5 to 8 days | 28° | 0.90 | 0.46 | 125 | |
| Oyster in shell | 41° to 50° | 95 to 100 | 5 days | | | | | |
| Frozen shellfish | -30° to -4° | 90 to 95 | 3 to 8 months | | | 0.46 | 110 | |
| Beef | | | | | | | | |
| Beef, Aging | 34° | 85 to 90 | 45 days | 29° | 0.75 | 0.40 | 110 | |
| Beef, fresh, average | 32° to 34° | 88 to 92 | 1 to 6 weeks | 28° to 29° | 0.70 to 0.84 | 0.38 to 0.43 | 89 to 110 | |
| Beef carcass | | | | | | | | |
| <i>Choice 60% lean</i> | 32° to 39° | 85 to 90 | 1 to 3 weeks | 28.5° | 0.84 | 0.43 | 110 | |
| <i>Prime 54% lean</i> | 32° to 34° | 85 | 1 to 3 weeks | 29° | 0.70 | 0.38 | 89 | |
| <i>Sirloin cut (choice)</i> | 32° to 34° | 85 | 1 to 3 weeks | 28° | 0.75 | 0.40 | 100 | |
| <i>Round cut (choice)</i> | 32° to 34° | 85 | 1 to 3 weeks | 28° | 0.75 | 0.40 | 100 | |
| <i>Dried, chipped</i> | 50° to 59° | 15 | 6 to 8 weeks | 28° | 0.87 | 0.51 | 110 | |
| Liver | 32° | 90 | 5 days | 28.9° | 0.83 | 0.52 | 99 | |
| Veal, lean | 28° to 34° | 85 to 95 | 3 weeks | 27° | 0.85 | 0.45 | 89 | |
| Beef, frozen | -10° to 0° | 90 to 95 | 6 to 12 months | | | 0.41 | 100 | |
| Pork | | | | | | | | |
| <i>Fresh, average</i> | 32° to 43° | 85 to 90 | 3 to 7 days | 28° to 29° | 0.46 to 0.55 | 0.30 to 0.33 | 46 to 63 | |
| <i>Carcass, 47% lean</i> | 32° to 34° | 85 to 90 | 3 to 5 days | 28° | 0.74 | 0.75 | 65 | |
| <i>Bellies, 35% lean</i> | 32° to 34° | 85 | 3 to 5 days | 28° | 0.67 | 0.0.81 | 65 | |
| <i>Backfat, 100% fat</i> | 32° to 34° | 85 | 7 to 12 days | 28° to 29° | 0.58 to 0.63 | 0.34 to 0.36 | 67 to 77 | 37 |
| <i>Shoulder, 67% lean</i> | 32° to 34° | 85 to 90 | 3 to 5 days | 28° | 0.60 | 0.35 | 65 | |
| Pork frozen | -10° to 0° | 90 to 95 | 4 to 8 months | | | | | |
| <i>Ham</i> | | | | | | | | |
| <i>74% lean</i> | 32° to 34° | 80 to 85 | 3 to 5 days | 28° | 0.56 | 0.33 | 60 | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/ F° | Specific Heat Below Freezing BTU/Lb/ F | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |

Table 10H

Table 10I

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|----------------------------|------------------|---------------------|--------------------------|---------------------------|--|---------------------------------------|---------------------------------|--|
| <i>cured</i> | 60° to 65° | 50 to 60 | 0 to 2 years | 28° | 0.52 to 0.56 | 0.32 to 0.33 | 57 to 64 | |
| <i>Country cure</i> | 50° to 59° | 65 to 70 | 3 to 5 months | 29° | 0.54 | 0.33 | 60 | |
| <i>Frozen</i> | -10° to 0° | 90 to 95 | 6 to 8 months | 29° | 0.54 | 0.33 | 60 | |
| Bacon | | | | | | | | |
| <i>Medium fat class</i> | 37° to 41° | 80 to 85 | 2 to 3 weeks | 29° | 0.40 | 0.26 | 38 | |
| <i>Curd, farm style</i> | 61° to 64° | 85 | 4 to 6 months | 29° | 0.30 to 0.43 | 0.24 to 0.29 | 18 to 41 | 57 |
| <i>Cured, packer style</i> | 34° to 39° | 85 | 2 to 6 weeks | 29° | 0.40 | 0.26 | 38 | |
| <i>Frozen</i> | -10° to 0° | 90 to 95 | 2 to 4 months | 29° | 0.40 | 0.26 | 38 | |
| Sausage | | | | | | | | |
| <i>Links or bulk</i> | 32° to 34° | 85 | 1 to 7 days | 29° | 0.75 | 0.59 | 39 | |
| <i>Country, smoked</i> | 32° | 85 | 1 to 3 weeks | 28° | 0.75 | 0.59 | 39 | |
| <i>Braunschweiger</i> | 32° | 85 | 1 to 3 weeks | 29° | 0.72 | 0.57 | 69 | |
| <i>Frankfurter</i> | 32° | 85 | 1 to 3 weeks | 28° | 0.75 | 0.55 | 77 | |
| <i>Italian</i> | 32° | 85 | 1 to 3 weeks | 29° | 0.74 | 0.57 | 74 | |
| <i>Polish</i> | 32° | 85 | 1 to 3 weeks | 29° | 0.75 | 0.56 | 77 | |
| <i>Pork</i> | 32° | 85 | 1 to 3 weeks | 29° | 0.70 | 0.58 | 64 | |
| <i>Smoked links</i> | 32° | 85 | 2 to 3 months | 28° | 0.67 | 0.59 | 56 | |
| Frankfurters | | | | | | | | |
| <i>Average</i> | 32° | 85 | 1 to 3 weeks | 28° | 0.43 | 0.26 | 40 | |
| <i>Polish style</i> | 32° | 85 | 1 to 3 weeks | 28° | 0.43 | 0.26 | 40 | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

Table 10J

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|------------------------|------------------|---------------------|--------------------------|---------------------------|--|--|---------------------------------|--|
| Meat (Lamb) | | | | | | | | |
| Fresh, average | 32° to 34° | 85 to 90 | 5 to 12 days | 28° to 29° | 0.68 to 0.76 | 0.38 to 0.51 | 86 to 100 | |
| Choice, lean | 32° | 85 | 5 to 12 days | 29° | 0.74 | 0.40 | 95 | |
| Fresh, average | 28° to 32° | 95 to 100 | 1 to 3 weeks | 28° to 29° | 0.46 to 0.55 | 0.30 to 0.33 | 46 to 63 | |
| Chicken all classes | 28° to 32° | 95 to 100 | 1 to 4 weeks | 28 | 1.04 | 0.79 | 95 | |
| Turkey, all classes | 28° to 32° | 95 to 100 | 1 to 4 weeks | 28 | 0.84 | 0.54 | 101 | |
| Turkey breast roll | -4° to -1° | | 6 to 12 months | 28 | 0.83 | 0.53 | 101 | |
| Turkey frankfurters | 0° to 15° | | 6 to 16 months | 29° | | | | |
| Duck | 28° to 32° | 95 to 100 | 1 to 4 weeks | 26° | 0.73 | 0.59 | 70 | |
| Poultry, frozen | -10° to 0° | 90 to 95 | 12 months | | | | | |
| Meat Misc. | | | | | | | | |
| Rabbits, fresh | -10° to 0° | 90 to 95 | 6 to 10 months | 28 | 0.50 | 0.35 | 89 | |
| Dairy Products | | | | | | | | |
| Butter | 40° | 75 to 85 | 1 months | -4° to 31° | 0.50 | 0.25 | 23 | |
| Butter, frozen | -10° | 70 to 85 | 12 to 20 months | | | | | |
| Cheese, Cheddar | | | | | | | | |
| <i>Long storage</i> | 32° to 34° | 65 to 70 | 12 months | | 0.65 | 0.62 | | |
| <i>Short storage</i> | 40° | 65 to 70 | 6 months | | 0.65 | | | |
| <i>Processed</i> | 40° | 65 to 70 | 12 months | | 0.65 | | | |
| <i>Grated</i> | 40° | 65 to 70 | 12 months | | 0.65 | | | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

Table 10K

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|-------------------------------|------------------|---------------------|--------------------------|---------------------------|--|---------------------------------------|---------------------------------|--|
| <i>Camembert</i> | | | | | 0.74 | 0.80 | 74 | |
| <i>Cheddar</i> | | | | 8.8 ° | 0.66 | 0.73 | 53 | |
| <i>Cottage uncreamed</i> | | | | 29.8 ° | 0.89 | 0.48 | 114 | |
| <i>Cream</i> | | | | | 0.75 | 0.70 | 77 | |
| <i>Gouda</i> | | | | | 0.69 | 0.66 | 59 | |
| <i>Limburger</i> | | | | 18.7 ° | 0.72 | 0.67 | 70 | |
| <i>Mozzarella</i> | | | | | 0.75 | 0.59 | 78 | |
| <i>Parmesan, hard</i> | | | | | 0.62 | 0.70 | 42 | |
| <i>Processed American</i> | | | | 19.6 ° | 0.67 | 0.66 | 56 | |
| <i>Roquefort</i> | | | | 2.7 ° | 0.67 | 0.80 | 57 | |
| <i>Swiss</i> | | | | 14.0 ° | 0.66 | 0.69 | 53 | |
| Ice cream | | | | | | | | |
| <i>10% fat</i> | -20° to -15° | 90 to 95 | 3 to 23 months | 21.0° | 0.66 to 0.70 | 0.37 to 0.39 | 86 | 25 |
| <i>Premium</i> | -30° to -20 | 90 to 95 | 3 to 23 months | 22° | 0.70 | 0.39 | 86 | |
| <i>Chocolate</i> | -20 | 95 | 3 to 23 months | 21.9 | 0.74 | 0.66 | 80 | |
| <i>Strawberry</i> | -20 | 95 | 3 to 23 months | 21.9 | 0.76 | 0.65 | 86 | |
| <i>Vanilla</i> | -20 | 95 | 3 to 23 months | 21.9 | 0.77 | 0.65 | 88 | |
| Milk | | | | | | | | |
| <i>Fluid pasteurized</i> | 39° to 43° | | 7 days | | 0.93 | 0.43 | 124 | 64 |
| <i>Grade A (3.7% fat)</i> | 32° to 39° | | 7 to 14 days | 31° | 0.93 | 0.43 | 124 | 64 |
| <i>Raw</i> | 32° to 39° | | 2 days | | 0.93 | 0.43 | 124 | 64 |
| <i>Dried, Whole</i> | 70° | low | 6 to 9 months | | | | 3 | |
| <i>Skim, dried</i> | 70° | low | 16 months | | 0.43 | | 5 | |
| <i>Dried, nonfat</i> | 45° to 70° | Low | 16 months | | 0.44 | | | |
| <i>Evaporated</i> | 40° | | 24 months | 29.5° | 0.85 | 0.50 | 106 | |
| <i>Evaporated unsweetened</i> | 70° | | 12 months | | | | | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

Table 10L

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/ F° | Specific Heat Below Freezing BTU/Lb/ F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/ Cu FT |
|----------------------------|------------------|---------------------|--------------------------|---------------------------|---|---|---------------------------------|---|
| <i>Condensed sweetened</i> | 40° | | 15 months | | | | | |
| Whey, dried | 70° | low | 12months | | | | | |
| Cream | | | | | | | | |
| <i>Half and half</i> | | | | | | 0.89 | 0.52 | 116 |
| <i>Table</i> | | | | | 28.0 ° | 0.86 | 0.53 | 106 |
| <i>Heavy whipping</i> | | | | | | 0.78 | 0.55 | 83 |
| Shell, farm cooler | 50° to 55° | 70 to 75 | 2 to 3 weeks | 28° | 0.73 | 0.40 | 96 | 19 |
| Frozen | 0 or below | | 1 year + | 28° | 0.73 | 0.42 | 106 | 41 |
| <i>Whole</i> | 0° | | 1 year + | | | | | |
| <i>Yolk</i> | 0° | | 1 year + | | | | | |
| <i>White</i> | 0° | | 1 year + | | | | | |
| <i>Whole egg solids</i> | 35° to 40° | low | 6 to 12 months | | | | | |
| Yolk solids | 35° to 40° | low | 6 to 12 months | | | | | |
| Flake albumen solids | | Low | 1 year + | | | | | |
| Dry spray albumen solids | | low | 1 year + | | | | | |
| Candy | | | | | | | | |
| Milk chocolate | 0° to 34° | 40 | 6 to 12 months | | 0.44 | | 2 | |
| Peanut brittle | 0° to 34° | 40 | 1.5 to 6 months | | 0.42 | | 3 | |
| Fudge | 0° to 34° | 65 | 5 to 12 months | | 0.45 | | 15 | |
| Marshmallows | 0° to 34° | 65 | 3 to 9 months | | | | | |

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|----------------------------|------------------|---------------------|--------------------------|---------------------------|--|--|---------------------------------|--|
| Miscellaneous | - | - | - | - | - | - | - | |
| Alfalfa meal | 0° | 70 to 75 | 1 year + | | | | | |
| Beer | | | | | | | | |
| <i>Keg</i> | 35° to 40° | | 3 to 8 weeks | 28° | 0.92 | | 129 | |
| <i>Bottles and cans</i> | 33° to 38° | 65 or below | 3 to 6 months | 28° | 0.92 | | 129 | |
| Body Box | 34° | 93 | 7 days | 29° | 0.84 | 0.43 | 110 | |
| Bread | 0° | | 3 to 13 weeks | | | | | |
| Canned goods | 32° to 60° | 70 or lower | 1 year | | | | | |
| Cocoa | 32° to 34° | 50 to 70 | | | | | | |
| Coffee, green | 35° to 37° | 80 to 85 | 2 to 4 months | | 0.30 | 0.24 | 14 to 21 | |
| Fur and Fabrics | 34° to 40° | 45 to 55 | years | | | | | |
| Fur debugging | -10° to 0° | 50 to 55 | 2 weeks | | | | | |
| Honey | 38° to 50° | 50 to 60 | 1 year + | | 0.35 | 0.26 | 26 | |
| Hops | 28° to 32° | 50 to 60 | 6 months | | | | | |
| Lard (without Antioxidant) | 45 | 90 to 95 | 4 to 8 months | | | | | |
| Maple syrup | 75° to 80° | 60 to 65 | 1 year + | | 0.24 | 0.21 | 7 | |
| Nuts | 32° to 50° | 65 to 75 | 8 to 12 months | | 0.50 to 0.53 | 0.21 to 0.22 | 4 to 8 | 25 |
| Oil, vegetable salad | 70° | | 1 year + | | | | | |
| Oleomargarine | 35° | 60 to 70 | 1 year + | | | | | |
| Orange Juice | 30° to 35° | | 3 to 6 weeks | | 0.91 | 0.47 | 128 | |
| Popcorn, unpopped | 32° to 40° | 85 | 4 to 6 months | | 0.31 | 0.24 | 19 | |
| Yeast, baker's compressed | 31° to 32° | | 1 year + | | | | | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |
|-------------------|------------------|---------------------|--------------------------|---------------------------|--|--|---------------------------------|--|
| Tobacco | | | | | | | | |
| <i>Hogshead</i> | 50° to 65° | 50 to 65 | 1 year + | | | | | |
| <i>Bales</i> | 35° to 40° | 70 to 85 | 1 year + | | | | | |
| <i>Cigarettes</i> | 35° to 46° | 50 to 55 | 6 months | 25° | | | | |
| <i>Cigars</i> | 35° to 50° | 60 to 65 | 2 months | 25° | | | | |
| Horseradish | 30° to 32° | 95 to 100 | 10 to 12 months | 28.7° | 0.78 | 0.42 | 104 | |
| Commodity | Storage Temp. F° | Relative Humidity % | Approximate Storage Life | Highest Freezing point F° | Specific Heat above Freezing BTU/Lb/F° | Specific Heat Below Freezing BTU/Lb/F° | Latent Heat of Fusion BTU/Lb/F° | Product Loading Density Approx. Lb/Cu FT |

Flower

| Commodity | Storage Temperature F° | Relative Humidity % | Approximate Storage Life | Method of Holding | Highest Freezing Point °F |
|-----------------------|------------------------|---------------------|--------------------------|-------------------|---------------------------|
| Cut Flower | | | | | |
| Calla Lily | 40° | 90 to 95 | 1 week | Dry Pack | |
| Camellia | 45 ° | 90 to 95 | 3 to 6 days | Dry Pack | 30.6° |
| Carnation | 31° to 32° | 90 to 95 | 3 to 4 weeks | Dry Pack | 30.8° |
| Chrysanthemum | 31° to 32° | 90 to 95 | 3 to 4 weeks | Dry Pack | 30.5° |
| Daffodil (Narcissus) | 32° to 33° | 90 to 95 | 1 to 3 weeks | Dry Pack | 31.8° |
| Dahlia | 40° | 90 to 95 | 3 to 5 days | Dry Pack | |
| Gardenia | 32° to 34° | 90 to 95 | 2 weeks | Dry Pack | 31.0° |
| Gladiolus | 36° to 42° | 90 to 95 | 1 week | Dry Pack | 31.4° |
| Iris, tight buds | 31° to 32° | 90 to 95 | 2 weeks | Dry Pack | 30.6° |
| Lily, Easter | 32° to 35° | 90 to 95 | 2 to 3 weeks | Dry Pack | 31.1° |
| Lily, of the valley | 31° to 32° | 90 to 95 | 2 to 3 weeks | Dry Pack | |
| Orchid | 45° to 55° | 90 to 95 | 2 weeks | Water | 31.4° |
| Peony, tight buds | 32° to 35° | 90 to 95 | 4 to 6 weeks | Dry Pack | 30.1 |
| Rose tight buds | 32 | 90 to 95 | 2 weeks | Dry Pack | 31.2 |
| Snapdragon | 40° to 42° | 90 to 95 | 1 to 2 weeks | Dry Pack | 30.4 |
| Sweet Peas | 31 ° to 32 ° | 90 to 95 | 2 weeks | Dry Pack | 30.4 |
| Tulips | 31 ° to 32 ° | 90 to 95 | 2 to 3 weeks | Dry Pack | |
| Greens | | | | | |
| Asparagus (plumosus) | 35 ° to 40 ° | 90 to 95 | 2 to 3 weeks | Polylined cases | 26.0 |
| Fern, dagger and wood | 30 ° to 32 ° | 90 to 95 | 2 to 3 months | Dry Pack | 28.9 ° |
| | | | | | |

| Commodity | Storage Temperature F° | Relative Humidity % | Approximate Storage Life | Method of Holding | Highest Freezing Point °F |
|-------------------|------------------------|---------------------|--------------------------|-------------------|---------------------------|
| | | | | | |
| Fern, Leatherleaf | 43 ° | 90 to 95 | 1 to 2 months | Dry Pack | |
| Holly | 32 ° | 90 to 95 | 4 to 5 weeks | Dry Pack | 27.0 ° |
| Huckleberry | 32 ° | 90 to 95 | 1 to 4 weeks | Dry Pack | 26.7 ° |
| Laurel | 32 ° | 90 to 95 | 2 to 4 weeks | Dry Pack | 27.6 ° |
| Magnolia | 35 ° to 40 ° | 90 to 95 | 2 to 4 weeks | Dry Pack | 27.0 ° |
| Rhododendron | 32 ° | 90 to 95 | 2 to 4 weeks | Dry Pack | 27.6 ° |
| Commodity | Storage Temperature F° | Relative Humidity % | Approximate Storage Life | Method of Holding | Highest Freezing Point °F |

| Commodity | Storage Temperature F° | Relative Humidity % | Approximate Storage Life | Method of Holding | Highest Freezing Point °F |
|---------------------|------------------------|---------------------|--------------------------|--------------------|---------------------------|
| Salal | 32 ° | 90 to 95 | 2 to 3 weeks | Dry Pack | 26.8 ° |
| Bulbs | | | | | |
| Amaryllis | 38 ° to 45 ° | 70 to 75 | 5 months | Dry | 30.8 ° |
| Caladium | 70 ° | 70 to 75 | 2 to 4 months | | 29.7 ° |
| Crocus | 48 ° to 63 ° | | 2 to 3 months | | 29.7 ° |
| Dahlia | 40 ° to 48 ° | 70 to 75 | 5 months | Dry | 28.7 ° |
| Gladiolus | 45 ° to 50 ° | 70 to 75 | 5 to 8 months | Dry | 28.2 ° |
| Hyacinth | 63 ° to 68 ° | | 2 to 5 months | | 29.3 ° |
| Iris, Dutch Spanish | 68 ° to 77 ° | 70 to 75 | 4 months | Dry | 29.3 ° |
| Gloriosa | 50 ° to 63 ° | 70 to 75 | 3 to 4 months | Polyliner | |
| <i>Candidum</i> | 31 ° to 33 ° | 70 to 75 | 1 to 6 months | Polyliner and peat | |
| <i>croft</i> | 31 ° to 33 ° | 70 to 75 | 1 to 6 months | Polyliner and peat | |
| <i>Longiflorum</i> | 31 ° to 33 ° | 70 to 75 | 1 to 10 months | Polyliner and peat | 28.9 |
| | | | | | |
| Tuberose | 40 ° to 45 ° | 70 to 75 | 4 to 12 months | Dry | |
| | | | | | |
| Tulip | 63 ° | 70 to 75 | 2 to 6 months | Dry | |
| Commodity | Storage Temperature F° | Relative Humidity % | Approximate Storage Life | Method of Holding | Highest Freezing Point °F |

| Commodity | Storage Temperature F° | Relative Humidity % | Approximate Storage Life | Method of Holding | Highest Freezing Point °F |
|-----------------------|------------------------|---------------------|--------------------------|-------------------|---------------------------|
| Rose bushes | 31 ° to 36 ° | 85 to 95 | 4 to 5 months | Bare Rooted | |
| Strawberry plants | 30 ° to 32 ° | 80 to 85 | 8 to 10 months | Bare Rooted | 29.9 ° |
| Rooted cuttings | 31 ° to 36 ° | 85 to 95 | | Polywrap | |
| Herbaceous perennials | 27 ° to 35 ° | 80 to 85 | 3 to 8 months | | |
| Christmas trees | 22 ° to 32 ° | 80 to 85 | 6 to 7 weeks | | |
| Commodity | Storage Temperature F° | Relative Humidity % | Approximate Storage Life | Method of Holding | Highest Freezing Point °F |

This Table is for Product Load

Specific Heat

| Name | BTU/Lb./°F | Temperature °F |
|----------------------------|------------|----------------|
| Liquid | | |
| Acetic Acid | 0.522 | 79 – 203 |
| Alcohol- Ethyl | 0.680 | 32 – 208 |
| Alcohol-Methyl | 0.610 | 59 – 68 |
| Calcium Chloride Brine 20% | 0.744 | 68 |
| Carbon Tetrachloride | 0.201 | 68 |
| Chloroform | 0.234 | 68 |
| Gasoline | 0.500 | 32 – 212 |
| Glycerine | 0.575 | 59 – 120 |
| Olive Oil | 0.471 | 44 |
| Toluene | 0.404 | 68 |
| Turpentine | 0.420 | 68 |
| Solids | | |
| Aluminum | 0.214 | |
| Asphalt | 0.220 | |
| Bakelite | 0.350 | |
| Brickwork | 0.200 | |
| Brass | 0.090 | |
| Bronze | 0.104 | |
| Concrete | 0.156 | |
| Glass | 0.200 | |
| Ice | 0.465 | -4 |
| Ice | 0.487 | 32 |
| Iron (Cast) | 0.120 | |
| Lead | 0.031 | |
| Paper | 0.320 | |
| Porcelain | 0.180 | |
| Rubber Goods | 0.480 | |
| Sand | 0.191 | |
| Steel | 0.120 | |
| Woods | | |
| Fir | 0.650 | |
| Oak | 0.570 | |
| Pine | 0.670 | |

REFRIGERATION LOAD ESTIMATE FORM

Application _____ Room: Height _____ Width _____
 Room conditions _____ °F _____ RH Length _____ Volume _____
 Ambient conditions _____ °F _____ RH Insulation: Thickness _____
 Temperature difference (TD) _____ °F Type _____
 Product load _____
 Lights, motors _____
 Occupancy, miscellaneous _____

Heat transmission load

Side walls _____ L × _____ H × 2 = _____ area × _____ TD × _____ U-factor = _____
 End walls _____ W × _____ H × 2 = _____ area × _____ TD × _____ U-factor = _____
 Ceiling _____ L × _____ W = _____ area × _____ TD × _____ U-factor = _____
 Floor _____ L × _____ W = _____ area × _____ TD × _____ U-factor = _____
 Glass _____ area × _____ TD × _____ U-factor = _____
Subtotal = _____
× 24 hours = _____

Air infiltration

_____ ft³ volume × _____ air changes per 24 hours × usage factor × _____ Btu/ft³ = _____

Product load

Product temperature reduction

_____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____

Latent heat of freezing

_____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____

Heat of respiration

_____ lb × _____ Btu/24-hr heat of respiration = _____
 _____ lb × _____ Btu/24-hr heat of respiration = _____

Supplementary load

_____ watts × _____ hours × 3.41 Btu/h = _____
 _____ hp × _____ hours × _____ Btu/h = _____
 _____ people × _____ hours × _____ Btu/h = _____

Subtotal _____

_____ % safety factor _____

Total 24-hr refrigeration load _____

Required hourly compressor capacity based on 16-hr operation _____

REFRIGERATION LOAD ESTIMATE FORM

Application _____ Room: Height _____ Width _____
 Room conditions _____ °F _____ RH Length _____ Volume _____
 Ambient conditions _____ °F _____ RH Insulation: Thickness _____
 Temperature difference (TD) _____ °F Type _____
 Product load **Table 2** _____
 Lights, motors _____
 Occupancy, miscellaneous _____

Heat transmission load

Side walls _____ L × _____ H × 2 = _____ area × _____ TD × _____ U-factor = _____
 End walls _____ W × _____ H × 2 = _____ area × _____ TD × _____ U-factor = _____
 Ceiling _____ L × _____ W = _____ area × _____ TD × _____ U-factor = _____
 Floor _____ L × _____ W = _____ area × _____ TD × _____ U-factor = _____
 Glass **Table 4** _____ area × _____ TD × _____ U-factor = _____
Subtotal = _____
× 24 hours = _____

Air infiltration **Table 8** _____ ft³ volume × _____ air changes per 24 hours × usage factor × _____ Btu/ft³ = _____
Light Use 1.25 **Table 9**

Product load Table 10

Product temperature reduction

_____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____
 Latent heat of freezing
 _____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____
 Heat of respiration
 _____ lb × _____ Btu/24-hr heat of respiration = _____
 _____ lb × _____ Btu/24-hr heat of respiration = _____

Supplementary load

_____ watts × _____ hours × 3.41 Btuh = _____
Table 11 _____ hp × _____ hours × _____ Btuh = _____
 _____ people × _____ hours × _____ Btuh = _____

People 345 to 450 Btuh **Subtotal** _____
15% % safety factor _____
Total 24-hr refrigeration load _____
Required hourly compressor capacity based on 16-hr operation _____

MISCELLANEOUS HEAT LOAD

Heat introduced into the cooler from heat-producing devices such as lights, motors, etc., also must be considered when estimating the total heat load. Any electrical energy dissipated directly into the cooler is converted into heat, which must be included in your calculations.

One watt-hour of electrical energy is equivalent to 3.41 Btu of heat energy. This conversion ratio is accurate in dealing with any amount of electric power. Motor efficiency varies with the size of the motor-and the heat equivalent varies accordingly. Table 3 shows the heat load per horsepower for a variety of motor sizes. Although the values shown are useful approximations, the actual electric power input (in watts) is the only accurate measure for heat- estimating purposes.

Electric lights. Assume that the lighting in a cooler consists of two 60-W bulbs. They will add 409 Btuh (120×3.41) to the heat load. This is not much, true, but small loads can add up.

Electric motors. Electric motors may be used inside the refrigerated space to drive fans, pumps, or other equipment. They represent another example of miscellaneous heat load. The electrical energy that a motor consumes. is first converted to mechanical energy, but ultimately it is converted to heat.

Heat of motors
BTU Per (HP) per (HR)

| Motor HP | Connected load in Refrigeration space | Motor losses outside Refrigeration space | Connected load outside Refrigeration space |
|------------|---------------------------------------|--|--|
| 1/8 to 1/2 | 4,250 | 2,548 | 1,710 |
| 1/2 to 3 | 3,701 | 2,547 | 1.160 |
| 3 to 20 | 2,955 | 2545 | 405 |

Table 11

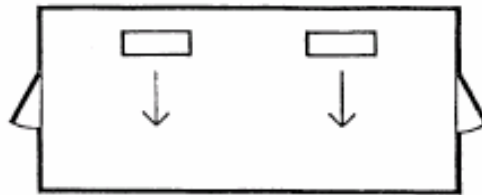
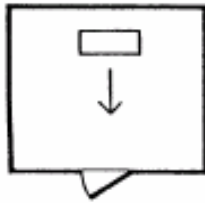
The power used by a motor driving the fan on a forced-draft evaporator is often overlooked. It should not be. Consider, for example, a small blower coil with a refrigerating capacity of approximately 5,000 Btuh. It incorporates a fan motor that consumes 225 W of power. While the fan is running (which is usually continuously), the motor is dissipating heat into the refrigerated space at the rate of 767 Btu per hour (225×3.41). So the refrigerating capacity of the evaporator is, in reality, 5,000 Btuh *minus* 767 Btuh, or 4,233 Btuh—a reduction of more than 15%.

Human occupancy. The people who live or work in a refrigerated space give off heat and moisture. The resulting refrigeration load will vary according to several conditions, including the duration of occupancy, the temperature of the refrigerated space, the type of work being done, and other factors 354 Btuh to 450 Btuh. These values are for extended occupancy periods. Stays of short duration, naturally, produce lower heat gains.

Heat of respiration. There is one other heat load factor to consider when an application involves the storage of certain products, such as bananas, oranges, lemons, limes, green onions, lettuce, pears, apples, etc. This factor is the heat that these products give up as chemical changes take place over a period of time. The rate at which this heat is given up is usually expressed in Btu per 100 lb of product per 24 hours.

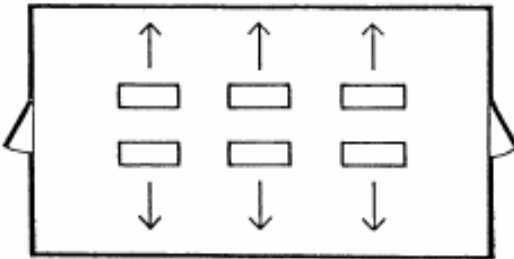
This chapter has demonstrated, through systematic explanation and calculation, the fundamentals of estimating the heat load. The application used as an example involved the maintenance of an above-freezing temperature in small, walk-in cooler and below-freezing temperature storage.

Unit Cooler Recommended Coil Replacement

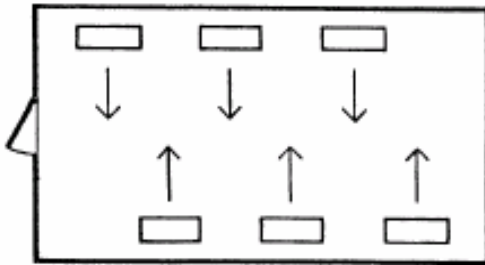


left
Large Cooler or Freezer

right
Large Cooler or Freezer



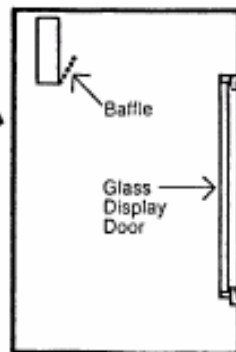
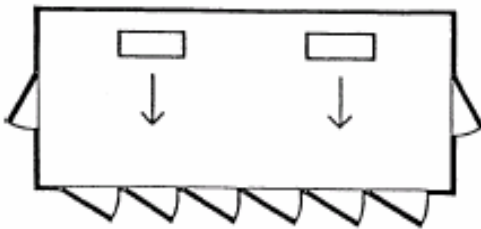
Large Cooler or Freezers where one wall will not accommodate all required evaporators or where air-throw distance must be considered.



Note: Always avoid placement of Unit Coolers directly above doors and door openings where low temperature is being maintained and wherever possible for normal temperature.

Allow sufficient space between rear of Unit Cooler and wall to permit free return of air. Refer to Unit manufacturers' catalog for proper space.

Always trap drain lines individually to prevent vapor migration. Traps on low temperature units must be outside of refrigerated enclosures.



left
Cooler or Freezer with Glass Display Doors

right
Elevation view of Glass Display Door Cooler or Freezer. Be sure Air Discharge Blows above, not directly at doors. Provide baffle if door extends above Blower level.

REFRIGERATION LOAD ESTIMATE FORM

Application _____ Room: Height _____ Width _____
 Room conditions _____ °F _____ RH Length _____ Volume _____
 Ambient conditions _____ °F _____ RH Insulation: Thickness _____
 Temperature difference (TD) _____ °F Type _____
 Product load _____
 Lights, motors _____
 Occupancy, miscellaneous _____

Heat transmission load

Side walls _____ L × _____ H × 2 = _____ area × _____ TD × _____ U-factor = _____
 End walls _____ W × _____ H × 2 = _____ area × _____ TD × _____ U-factor = _____
 Ceiling _____ L × _____ W = _____ area × _____ TD × _____ U-factor = _____
 Floor _____ L × _____ W = _____ area × _____ TD × _____ U-factor = _____
 Glass _____ area × _____ TD × _____ U-factor = _____
Subtotal = _____
× 24 hours = _____

Air infiltration

_____ ft³ volume × _____ air changes per 24 hours × usage factor × _____ Btu/ft³ = _____

Product load

Product temperature reduction

_____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____

Latent heat of freezing

_____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____

Heat of respiration

_____ lb × _____ Btu/24-hr heat of respiration = _____
 _____ lb × _____ Btu/24-hr heat of respiration = _____

Supplementary load

_____ watts × _____ hours × 3.41 Btu/h = _____
 _____ hp × _____ hours × _____ Btu/h = _____
 _____ people × _____ hours × _____ Btu/h = _____

Subtotal _____

_____ % safety factor _____

Total 24-hr refrigeration load _____

Required hourly compressor capacity based on 16-hr operation _____

REFRIGERATION LOAD ESTIMATE FORM

Application _____ Room: Height _____ Width _____
 Room conditions _____ °F _____ RH Length _____ Volume _____
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 Lights, motors _____
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 Glass _____ area × _____ TD × _____ U-factor = _____
Subtotal = _____
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Air infiltration

_____ ft³ volume × _____ air changes per 24 hours × usage factor × _____ Btu/ft³ = _____

Product load

Product temperature reduction

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Latent heat of freezing

_____ lb × _____ specific heat × _____ TD = _____
 _____ lb × _____ specific heat × _____ TD = _____

Heat of respiration

_____ lb × _____ Btu/24-hr heat of respiration = _____
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Supplementary load

_____ watts × _____ hours × 3.41 Btuh = _____
 _____ hp × _____ hours × _____ Btuh = _____
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Subtotal _____

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_____ lb × _____ Btu/24-hr heat of respiration = _____
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Latent heat of freezing

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Heat of respiration

_____ lb × _____ Btu/24-hr heat of respiration = _____
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Supplementary load

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Supplementary load

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Subtotal

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_____ lb × _____ Btu/24-hr heat of respiration = _____
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_____ watts × _____ hours × 3.41 Btuh = _____
 _____ hp × _____ hours × _____ Btuh = _____
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Subtotal _____

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