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Refrigeration Manual

Part 3 - The Refrigeration Load

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FOREWORD

The practice of refrigeration undoubtedly goes back as far as the history of mankind, but for thousands of years the only cooling mediums were water and ice. Today refrigeration in the home, in the supermarket, and in commercial and industrial usage is so closely woven into our everyday existence it is difficult to imagine life without it. But because of this rapid growth, countless people who must use and work with refrigeration equipment do not fully understand the basic fundamentals of refrigeration system operation.

This manual is designed to fill a need which exists for a concise, elementary text to aid servicemen, salesman, students, and others interested in refrigeration. It is intended to cover only the fundamentals of refrigeration theory and practice. Detailed information as to specific products is available from manufacturers of complete units and accessories. Used to supplement such literature—and to improve general knowledge of refrigeration—this manual should prove to be very helpful.

Part 3
THE REFRIGERATION LOAD

Section 12. HEAT TRANSMISSION

Section 13. AIR INFILTRATION

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Section 12
HEAT TRANSMISSION

The heat gain through walls, floors and ceilings will vary with the type of construction, the area exposed to a different temperature, the type of insulation, the thickness of insulation, and the temperature difference between the refrigerated space and the ambient air.

In catalog and technical literature pertaining to heat transfer, certain letter symbols are commonly used to denote the heat transfer factors, and a working knowledge of these symbols is frequently necessary to easily interpret catalog data.

TRANSMISSION HEAT LOAD — Q

The basic formula for heat transfer through some heat transfer barrier is:

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

- Q = Heat transfer, BTU/Hr
- U = Overall heat transfer coefficient BTU/(hour)(sq. ft.)(°F TD)
- A = Area in square feet
- TD = Temperature differential between sides of thermal barrier, for example, between outside design temperature and the refrigerated space temperature.

Q is the rate of heat flow, the quantity of heat flowing after all factors are considered.

THERMAL CONDUCTIVITY — k

Thermal conductivity, k, is defined as the rate of heat transfer that occurs through a material in units of BTU/(hr)(square foot of area)(°F TD) per inch of thickness. Different materials offer varying resistances to the flow of heat.

For example, the heat transfer in 24 hours through two square feet of material three inches in thickness having a thermal conductivity factor of .25 with an average temperature difference across the material of 70°F would be calculated as follows:

$$Q = \frac{.25(k) \times 2 \text{ sq. ft.} \times 24 \text{ hours} \times 70^\circ \text{ TD}}{3 \text{ inches thickness}} = 280 \text{ BTU}$$

Since the total heat transferred by conduction varies directly with time, area, and temperature difference, and varies inversely with the thickness of the material, it is readily apparent that in order to reduce heat transfer, the thermal conductivity factor should be as small as possible, and the material as thick as possible.

THERMAL RESISTIVITY — r

Thermal resistivity is defined as the reciprocal of thermal conductivity of 1/k. “r” is of importance because resistance values can be added numerically.

$$R \text{ total} = r_1 + r_2 + r_3$$

Where r_1, r_2, and r_3 are individual resistances. This makes the use of r convenient in calculating overall heat transfer coefficients.

CONDUCTANCE — C

Thermal conductance is similar to thermal conductivity, except that it is an overall heat transfer factor for a given thickness of material, as opposed to thermal conductivity, k, which is a factor per inch of thickness. The definition is similar, BTU/(hour)(square foot of area)(°F TD).

THERMAL RESISTANCE — R

Thermal resistance is the reciprocal of conductance, 1/C in the same way that thermal resistivity is the reciprocal of conductivity.

SURFACE FILM RESISTANCE

Heat transfer through any material is affected by the surface resistance to heat flow, and this is determined by the type of surface, rough or smooth; its position, vertical or horizontal; its reflective properties; and the rate of airflow over the surface. Surface film conductance, normally denoted by f_i for inside surfaces and f_o for outside surfaces is similar to conductance.

However, in refrigeration work with insulated walls, the conductivity is so low that the surface film conductance has little effect, and therefore, can be omitted from the calculation.

OVERALL COEFFICIENT OF HEAT TRANSFER — U

The overall coefficient of heat transfer, U, is defined as the rate of heat transfer through a material or compound structural member with parallel walls. The U factor, as it is commonly called, is the resulting heat transfer coefficient after giving effect to thermal conductivity, conductance, and surface film conductance, and is expressed in terms of BTU/(hour) (square foot of area)(°F TD). It is usually applied to compound structures such as walls, ceilings, and roofs.

The formula for calculating the U factor is complicated by the fact that the total resistance to heat flow through a substance of several layers is the sum of the resistance of the various layers. The resistance of heat flow is the reciprocal of the conductivity. Therefore, in order to calculate the overall heat transfer factor, it is necessary to first find the overall resistance to heat flow, and then find the reciprocal of the overall resistance to calculate the U factor.

The basic relation between the U factor and the various conductivity factors is as follows:

$$R\ \text{Total} = \frac{1}{C} + \frac{X1}{k1} + \frac{X2}{k2}$$

$$U = \frac{1}{R\ \text{Total}}$$

In the above equation, k_1, k_2, etc. are the thermal conductivities of the various materials used, C is the conductance if it applies rather than k_1, and X_1, X_2, etc. are the thicknesses of the material.

For example, to calculate the U factor of a wall composed of two inches of material having a k1 factor of .80, and two inches of insulation having a conductance of .16, the U value is found as follows:

$$R\ \text{Total} = \frac{1}{C} + \frac{X_1}{k_1}$$

$$= \frac{1}{.16} + \frac{2}{.80}$$

$$= 6.25 + 2.5 = 8.75$$

$$U = \frac{1}{R\ \text{Total}} = \frac{1}{8.75}$$

$$= .114\ \text{BTU/(hour)(sq. ft.)(°F TD)}$$

TRANSMISSION HEAT LOAD

Once the U factor is known, the heat gain by transmission through a given wall can be calculated by the basic heat transfer equation.

Assume a wall with a U factor of .114 as calculated in the previous example. Given an area of 90 square feet with an inside temperature of 0°F, an outside temperature of 80°F, the heat transmission would be:

$$\begin{aligned} Q &= U \times A \times TD \\ &= .114 \times 90\ \text{sq. ft} \times 80°TD \\ &= 812\ \text{BTU/hr} \end{aligned}$$

The entire heat gain into a given refrigerated space can be found in a similar manner by determining the U factor for each part of the structure surrounding the refrigerated space, and calculating as above.

VALUES OF THERMAL CONDUCTIVITY FOR BUILDING MATERIALS

Extensive testing has been done by many laboratories to determine accurate values for heat transfer through all common building and structural materials. Certain materials have a high resistance to the flow of heat (a low thermal conductivity) and are therefore used as insulation to decrease the heat transfer into the refrigerated space. There are many different types of insulation such as asbestos, glass fiber, cork, reflective metals, and the new foam materials. Most good insulating materials have a thermal conductivity (k) factor of approximately .25 or less, and rigid foam insulations have been developed with thermal conductivity (k) factors as low as .12 to .15.

Heat transmission coefficients for many commonly used building materials are shown in Table 4.

OUTDOOR DESIGN DATA

Extensive studies have been made of weather bureau records for many years to arrive at suitable outdoor design temperatures. For air conditioning or refrigeration applications, the maximum load occurs during the hottest weather.

However, it is neither economical or practical to design equipment for the hottest temperature which might ever occur, since the peak temperature might occur for only a few hours over the span of several years. Therefore, the design temperature normally is selected as a temperature that will not be exceeded more than a given percentage of the hours during the four month summer season. Table 5 lists summer design temperatures, which will be equaled or exceeded only during 1% of the hours during the four summer months.

(continued on p. 12-8)

Table 4

TYPICAL HEAT TRANSMISSION COEFFICIENTS
(Extracted from ASHRAE Handbook of Fundamentals, Reprinted by Permission)

Material	Density lb/cu.ft.	Conductivity k	Conductance C	Resistance (R) Per In.	Resistance (R) Overall
BUILDING BOARD					
Asbestos-Cement Board	120	4.0		.25	
Gypsum or Plaster, 1/2″	50		2.22		.45
Plywood	34	.80		1.25	
Wood Fiber, Hardboard	50	.73		1.37	
BUILDING PAPER					
Felt, Vapor-permeable			16.70		.06
Plastic Film, Vapor-seal					Neglibile
FLOORING MATERIALS					
Tile, Asphalt, Vinyl, Linoleum			20.0		.05
Wood Flooring, 3/4″			1.47		.68
INSULATING MATERIALS					
Fiber Glass Blanket	0.5	.32		3.12	
Expanded Urethane, R11	1.5	.16		6.25	
Expanded Polystyrene	1.8	.16		6.25	
Insulating Roof Deck, 2″			.18		5.56
Mineral Wool Loose Fill	2.0-5.0	.40		2.5	
Perlite, Expanded	5.0-8.0	.36		2.78	
Cellulose, Paper	3.0	.30		3.3	

Table 4 (Cont.)

TYPICAL HEAT TRANSMISSION COEFFICIENTS

Material	Density lb/cu.ft.	Conductivity k	Conductance C	Resistance (R) Per In.	Resistance (R) Overall
MASONRY MATERIALS					
Concrete, Sand & Gravel	140	9.0		.11	
Brick, Common	120	5.0		.20	
Brick, Face	130	9.0		.11	
Hollow Tile, 2 cell, 6"			.66		1.52
Concrete Block, Sand and Gravel, 8"			.90		1.11
Concrete Block, Cinder, 8"			.58		1.72
ROOFING					
Shingles, Asbestos-Cement	120		4.76		.21
Asphalt Roll Roofing	70		6.50		.15
Roofing, Built Up, 3/8"	70		3.0		.33
Shingles, Wood			1.06		.94
SIDING					
Plywood 3/8"			1.59		.59
WOODS					
Maple, Oak, Hardwood	45	1.10		.91	
Fir, Pine, Softwood	32	.80		1.25	
CONCRETE SLAB, 6"					
Uninsulated			.21		

Table 5

SUMMER OUTDOOR DESIGN DATA

(Design dry bulb and wet bulb temperature represents temperature equalled or exceeded during 1% of hours during the four summer months.)

(Extracted from 1981 ASHRAE Handbook of Fundamentals, Reprinted by Permission)

Location	Dry Bulb °F.	Wet Bulb °F.
ALABAMA		
Birmingham	96	74
Mobile	95	77
ALASKA		
Fairbanks	82	62
Juneau	74	60
ARIZONA		
Phoenix	109	71
Tucson	104	66
ARKANSAS		
Fort Smith	101	75
Little Rock	99	76
CALIFORNIA		
Bakersfield	104	70
Blythe	112	71
Los Angeles	93	70
San Francisco	82	64
Sacramento	101	70
COLORADO		
Denver	93	59
CONNECTICUT		
Hartford	91	74
DELAWARE		
Wilmington	92	74
D.C.		
Washington	93	75
FLORIDA		
Jacksonville	96	77
Miami	91	77
Tampa	92	77

Location	Dry Bulb °F.	Wet Bulb °F.
GEORGIA		
Atlanta	94	74
Savannah	96	77
HAWAII		
Honolulu	87	73
IDAHO		
Boise	96	65
ILLINOIS		
Chicago	94	74
Springfield	94	75
INDIANA		
Fort Wayne	92	73
Indianapolis	92	74
IOWA		
Des Moines	94	75
Sioux City	95	74
KANSAS		
Dodge City	100	69
Wichita	101	72
KENTUCKY		
Lexington	93	73
Louisville	95	74
LOUISIANA		
New Orleans	93	78
Shreveport	99	77
MAINE		
Portland	87	72
MARYLAND		
Baltimore	94	75

Table 5 (cont.)

SUMMER OUTDOOR DESIGN DATA

(Design dry bulb and wet bulb temperature represents temperature equalled or exceeded during 1% of hours during the four summer months.)

(Extracted from 1981 ASHRAE Handbook of Fundamentals, Reprinted by Permission)

Location	Dry Bulb °F.	Wet Bulb °F.
MASSACHUSETTS		
Boston	91	73
Worcester	87	71
MICHIGAN		
Detroit	91	73
Grand Rapids	91	72
MINNESOTA		
Duluth	85	70
Minneapolis	92	75
MISSISSIPPI		
Biloxi	94	79
Jackson	97	76
MISSOURI		
Kansas City	99	75
St. Louis	97	75
MONTANA		
Billings	94	64
Helena	91	60
NEBRASKA		
Omaha	94	76
NEVADA		
Las Vegas	108	66
Reno	95	61
NEW HAMPSHIRE		
Concord	90	72
NEW JERSEY		
Newark	94	74
Trenton	91	75

Location	Dry Bulb °F.	Wet Bulb °F.
NEW MEXICO		
Albuquerque	96	61
Santa Fe	90	61
NEW YORK		
Albany	91	73
Buffalo	88	71
New York	92	74
NORTH CAROLINA		
Charlotte	95	74
NORTH DAKOTA		
Bismark	95	68
OHIO		
Cincinnati	92	73
Cleveland	91	73
OKLAHOMA		
Tulsa	101	74
OREGON		
Pendleton	97	65
Portland	90	68
PENNSYLVANIA		
Philadelphia	93	75
Pittsburgh	89	72
RHODE ISLAND		
Providence	89	73
SOUTH CAROLINA		
Charleston	94	78
SOUTH DAKOTA		
Sioux Falls	94	73

Table 5 (cont.)

SUMMER OUTDOOR DESIGN DATA

(Design dry bulb and wet bulb temperature represents temperature equalled or exceeded during 1% of hours during the four summer months.)

(Extracted from 1981 ASHRAE Handbook of Fundamentals, Reprinted by Permission)

Location	Dry Bulb °F.	Wet Bulb °F.
TENNESSEE		
Memphis	98	77
Nashville	97	75
TEXAS		
Dallas	102	75
El Paso	100	64
Galveston	90	79
Houston	97	77
UTAH		
Salt Lake City	97	62
VERMONT		
Burlington	88	72
VIRGINIA		
Richmond	95	76
Roanoke	93	72
WASHINGTON		
Seattle	84	68
Spokane	93	64
Yakima	96	65
WEST VIRGINIA		
Charleston	92	74
WISCONSIN		
Milwaukee	90	74
WYOMING		
Cheyenne	89	58

Location	Dry Bulb °F.	Wet Bulb °F.
CANADA		
ALBERTA		
Calgary	84	63
BRITISH COLUMBIA		
Vancouver	79	67
MANITOBA		
Winnipeg	89	73
NEW BRUNSWICK		
St. John	80	67
NEWFOUNDLAND		
Gander	82	66
NOVA SCOTIA		
Halifax	79	66
ONTARIO		
Toronto	90	73
QUEBEC		
Montreal	86	71
SASKATCHEWAN		
Regina	91	69
YUKON		
Whitehorse	80	59

ALLOWANCE FOR RADIATION FROM THE SUN

The primary radiation factor involved in the refrigeration load is heat gain from the sun's rays. If the walls of the refrigerated space are exposed to the sun, additional heat will be added to the heat load. For ease in calculation, an allowance can be made for the sun load in refrigeration calculations by increasing the temperature differential by the factors listed in Table 6.

This table is usable for refrigeration loads only, and is not accurate for air conditioning estimates.

RECOMMENDED INSULATION THICKNESS

As the desired storage temperature decreases, the refrigeration load increases, and as the evaporating temperature decreases, the compressor efficiency decreases. Therefore, from a practical and economic standpoint, the insulation thickness must be increased as the storage temperature decreases.

Table 7 lists recommended insulation thickness from the 1981 ASHRAE Handbook of Fundamentals. The recommendations are based on expanded polyurethane which has a conductivity factor of .16. If other insulations are used, the recommended thickness should be adjusted base on relative k factors.

TABLE 6

ALLOWANCE FOR SUN EFFECT

(Fahrenheit degrees to be added to the normal temperature difference for heat leakage calculations to compensate for sun effect — not to be used for air conditioning design)

Type of Surface	East wall	South wall	West wall	Flat roof
Dark colored surfaces, such as Slate roofing, Tar roofing, Black paints	8	5	8	20
Medium colored surfaces, such as Unpainted wood, Brick, Red tile, Dark cement, Red, gray or green paint	6	4	6	15
Light colored surfaces, such as White stone, Light colored cement, White paint	4	2	4	9

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QUICK CALCULATION TABLE FOR WALK-IN COOLERS

As an aid in the quick calculation of heat transmission through insulated walls, Table 7A lists the approximate heat gain in BTU per 1°F. temperature difference per square foot of surface per 24 hours for various thicknesses of commonly used insulations. The thickness of insulation referred to is the actual thickness of insulation, and not the overall wall thickness.

For example, to find the heat transfer for 24 hours through a 6' x 8' wall insulated with 4 inches of glass fiber when the outside is exposed to 95°F ambient temperature, and the box temperature is 0°F., calculate as follows:

1.9 factor x 48 sq. ft. x 95°TD = 8664 BTU

Table 7

RECOMMENDED MINIMUM INSULATION THICKNESS

Based on k factor of .16

Storage Temperature	Insulation Thickness, Inches	
	Northern U.S.	Southern U.S.
50 to 60°F	1	2
40 to 50°F	2	2
25 to 40°F	2	3
15 to 25°F	3	3
0 to 15°F	3	4
−15 to 0°F	4	4
−40 to −15°F	5	5

Table 7A

QUICK ESTIMATE FACTORS For HEAT TRANSMISSION THROUGH INSULATED WALLS

BTU per 1°F. TD per sq. ft. per 24 hours

Insulation	Inches of Insulation										
	2	3	4	5	6	7	8	9	10	11	12
k factor approx. .16 Expanded Polyurethane, Expanded Polystyrene	1.92	1.28	.96	.77	.64	.55	.48	.43	.38	.35	.32
k factor approx. .32 Glass fiber, Mineral Wool fill and board.	3.8	2.6	1.9	1.5	1.3	1.1	.96	.86	.76	.70	.64

SECTION 13
AIR INFILTRATION

Any outside air entering the refrigerated space must be reduced to the storage temperature, thus increasing the refrigeration load. In addition, if the moisture content of the entering air is above that of the refrigerated space, the excess moisture will condense out of the air, and the latent heat of condensation will add to the refrigeration load.

Because of the many variables involved, it is difficult to calculate the additional heat gain due to air infiltration. Various means of estimating this portion of the refrigeration load have been developed based primarily on experience, but all of these estimating methods are subject to the possibility of sizable error, and specific applications may vary widely in the actual heat gain encountered.

AIR CHANGE ESTIMATING METHOD

The traffic in and out of a refrigerator usually varies with its size or volume. Therefore the number of times doors are opened will be related to the volume rather than the number of doors.

Table 8 lists estimated average air changes per 24 hours for various sized refrigerators due to door openings and infiltration for a refrigerated storage room. Note that these values are subject to major modification if it is definitely determined that the usage of the storage room is either heavy or light.

AIR VELOCITY ESTIMATING METHOD

Another means of computing infiltration into a refrigerated space is by means of the velocity of airflow through an open door. When the door of a refrigerated storage space is opened, the difference in density between cold and warm air will create a pressure differential causing cold air to flow out the bottom of the doorway and warm air to flow in the top. Velocities will vary from maximum at the top and bottom to zero in the center.

The estimated average velocity in either half of the door is 100 feet per minute for a doorway seven feet high at 60°F. TD. The velocity will vary as the square root of the height of the doorway and as the square root of the temperature difference.

For example the rate of infiltration through a door 8 feet high and 4 feet wide, with a 100°F. TD between the storage room and the ambient can be estimated as follows:

$$\text{Velocity} = 100 \text{ FPM} \times \frac{\sqrt{8}}{\sqrt{7}} \times \frac{\sqrt{100}}{\sqrt{60}}$$

$$= 100 \times \frac{2.83}{2.65} \times \frac{10}{7.74}$$

$$= 138 \text{ FPM}$$

Estimated rate of Infiltration

$$138 \text{ FPM} \times \frac{8 \text{ ft.} \times 4 \text{ ft.}}{2} = 2210 \text{ cu. ft per min.}$$

Infiltration velocities for various door heights and TDs are plotted in Figure 67.

If the average time the door is opened each hour can be determined, the average hourly infiltration can be calculated, and the heat gain can be determined as before.

Table 8

AVERAGE AIR CHANGES PER 24 HR. FOR STORAGE ROOMS DUE TO DOOR OPENINGS AND INFILTRATION

Volume cu. ft.	Air Changes per 24 hr.		Volume cu. ft.	Air Changes per 24 hr.	
	Above 32 F	Below 32 F		Above 32 F	Below 32 F
200	44.0	33.5	6,000	6.5	5.0
300	34.5	26.2	8,000	5.5	4.3
400	29.5	22.5	10,000	4.9	3.8
500	26.0	20.0	15,000	3.9	3.0
600	23.0	18.0	20,000	3.5	2.6
800	20.0	15.3	25,000	3.0	2.3
1,000	17.5	13.5	30,000	2.7	2.1
1,500	14.0	11.0	40,000	2.3	1.8
2,000	12.0	9.3	50,000	2.0	1.6
3,000	9.5	7.4	75,000	1.6	1.3
4,000	8.2	6.3	100,000	1.4	1.1
5,000	7.2	5.6			

Note: For heavy usage multiply the above values by 2.
For long storage multiply the above values by 0.6.

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VENTILATING AIR

If positive ventilation is provided for a space by means of supply or exhaust fans, the ventilation load will replace the infiltration load (if greater) and the heat gain may be calculated on the basis of the ventilating air volume.

INFILTRATION HEAT LOAD

Once the rate of infiltration has been determined, the heat load can then be calculated from the heat gain per cubic foot of infiltration as given in Table 9. For accurate calculations at conditions not covered by Table 9, the heat load can be determined by the difference in enthalpy between entering air and the storage room air conditions. This is most easily accomplished by use of the psychrometric chart, which will be discussed in detail in a subsequent section.

Table 9

HEAT REMOVED IN COOLING AIR TO STORAGE ROOM CONDITIONS
(BTU per cu. ft.)

Storage room temp F	Temperature of Outside Air, F							
	85		90		95		100	
	Relative Humidity, Percent							
	50	60	50	60	50	60	50	60
65	0.45	0.64	0.68	0.91	0.93	1.20	1.21	1.51
60	0.66	0.85	0.89	1.12	1.14	1.41	1.42	1.71
55	0.85	1.04	1.08	1.31	1.33	1.60	1.61	1.91
50	1.03	1.22	1.26	1.49	1.51	1.78	1.79	2.09
45	1.19	1.39	1.43	1.66	1.68	1.94	1.95	2.25
40	1.35	1.55	1.59	1.81	1.83	2.10	2.11	2.41
35	1.50	1.70	1.74	1.96	1.99	2.25	2.26	2.56
30	1.64	1.84	1.88	2.10	2.13	2.39	2.40	2.70

Storage room temp F	Temperature of Outside Air, F							
	40		50		90		100	
	Relative Humidity, Percent							
	70	80	70	80	50	60	50	60
25	0.39	0.43	0.69	0.75	2.02	2.24	2.54	2.84
20	0.52	0.56	0.82	0.89	2.15	2.38	2.68	2.97
15	0.65	0.69	0.95	1.01	2.28	2.50	2.80	3.10
10	0.77	0.82	1.08	1.14	2.40	2.63	2.93	3.22
5	0.89	0.94	1.20	1.26	2.52	2.75	3.05	3.34
0	1.01	1.05	1.31	1.38	2.64	2.86	3.16	3.46
−5	1.13	1.17	1.43	1.49	2.76	2.98	3.28	3.58
−10	1.24	1.29	1.55	1.61	2.88	3.10	3.40	3.70
−15	1.36	1.41	1.67	1.73	2.99	3.22	3.52	3.81
−20	1.48	1.52	1.78	1.85	3.11	3.34	3.64	3.93
−25	1.60	1.64	1.90	1.97	3.23	3.45	3.75	4.05
−30	1.72	1.76	2.03	2.09	3.35	3.58	3.88	4.17

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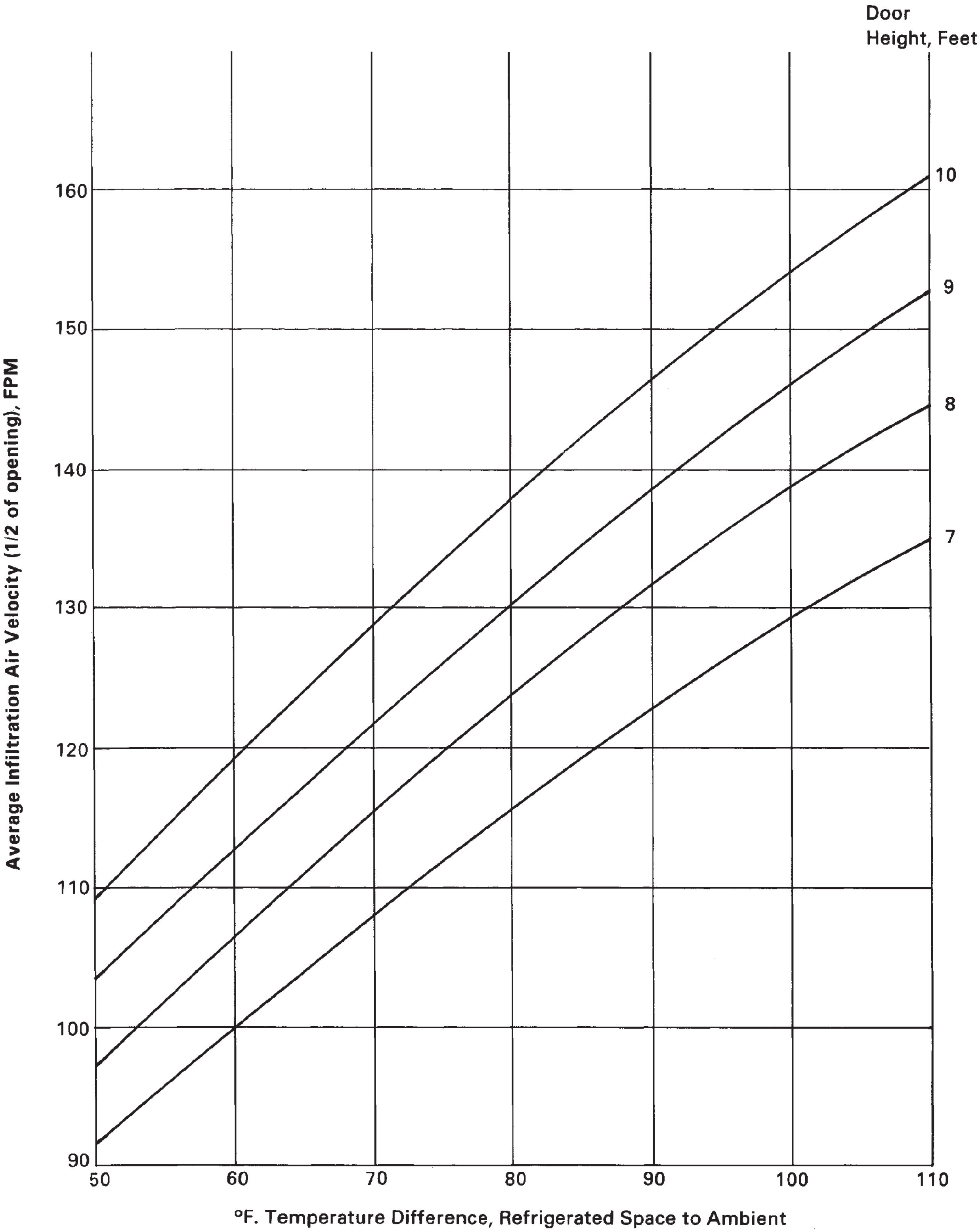

INFILTRATION AIR VELOCITY THROUGH OPEN DOORS

Figure 67

SECTION 14
PRODUCT LOAD

The product load is composed of any heat gain occurring due to the product in the refrigerated space. The load may arise from a product placed in the refrigerator at a temperature higher than the storage temperature, from a chilling or freezing process, or from the heat of respiration of perishable products. The total product load is the sum of the various types of product load which may apply to the particular application.

TABLES OF SPECIFIC PRODUCT DATA

The following tables list data on specific products that is essential in calculating the refrigeration product load. Table 10 covers food products, Table 11 solids, and Table 12 liquids.

HEAT OF RESPIRATION

Fruits and vegetables, even though they have been removed from the vine or tree on which they grew, are still living organisms. Their life processes continue for some time after being harvested, and as a result they give off heat. Certain other food products also undergo continuing chemical reactions which produce heat. Meats and fish have no further life processes and do not generate any heat.

The amount of heat given off is dependent on the specific product and its storage temperature. Table 10 lists various food products with pertinent storage data. Note that the heat of respiration varies with the storage temperature.

(continued on p. 14-7)

Table 10

FOOD PRODUCTS DATA

Product	Average Freezing Point F	Percent Water	SP ht, Btu/ (lb) (F deg)		Latent Heat of Fusion Btu/lb	Heat of Respiration Btu per (24 hr) (ton) at Temp. Indicated	
			Above Freezing	Below Freezing		°F	BTU
VEGETABLES							
Artichokes	29.1	83.7	0.87	0.45	120	40	10,140
Asparagus	29.8	93	0.94	0.48	134	40	11,700-23,100
Beans, string	29.7	88.9	0.91	0.47	128	40	9700-11400
Beans, Lima	30.1	66.5	0.73	0.40	94	40	4300-6100
Beans, dried		12.5	0.30	0.24	18		
Beets	31.1	87.6	0.90	0.46	126	32	2700
						40	4100
Broccoli	29.2	89.9	0.92	0.47	130	40	11,000-17,000
Brussels sprouts	31	84.9	0.88	0.46	122	40	6600-11,000
Cabbage	31.2	92.4	0.94	0.47	132	40	1700
Carrots	29.6	88.2	0.90	0.46	126	32	2100
						40	3500
Cauliflower	30.1	91.7	0.93	0.47	132	40	4500
Celery	29.7	93.7	0.95	0.48	135	32	1600
						40	2400
Corn (green)	28.9	75.5	0.79	0.42	106	32	7200-11,300
						40	10,600-13,200
Corn (dried)		10.5	0.28	0.23	15		
Cucumbers	30.5	96.1	0.97	0.49	137		
Eggplant	30.4	92.7	0.94	0.48	132		
Endive (escarole)	30.9	93.3	0.94	0.48	132		
Horseradish	26.4	73.4	0.78	0.42	104		
Kale	30.7	86.6	0.89	0.46	124		
Kohlrabi	30	90	0.92	0.47	128		
Lettuce	31.2	94.8	0.96	0.48	136	32	2300
						40	2700
Mushrooms	30.2	91.1	0.93	0.47	130	32	6200
						50	22,000
Olives	28.5	75.2	0.80	0.42	108		
Onions	30.1	87.5	0.90	0.46	124	32	700-1100
						40	1800

Table 10 (cont.)

FOOD PRODUCTS DATA

Product	Average Freezing Point F	Percent Water	SP ht, Btu/(lb) (F deg)		Latent Heat of Fusion Btu/lb	Heat of Respiration Btu per (24 hr) (ton) at Temp. Indicated	
			Above Freezing	Below Freezing		°F	BTU
Parsnips	28.9	78.6	0.84	0.46	112		
Peas (green)	30	74.3	0.79	0.42	106	40	13,200-16,000
Peas (dried)		9.5	0.28	0.22	14		
Peppers (sweet)	30.1	92.4	0.94	0.47	132	40	4700
Potatoes (white)	28.9	77.8	0.82	0.43	111	40	1300-1800
Potatoes (sweet)	28.5	68.5	0.75	0.40	97	40	1710
Pumpkin	30.1	90.5	0.92	0.47	130		
Radishes	30.1	93.6	0.95	0.48	134		
Rhubarb	28.4	94.9	0.96	0.48	134		
Sauerkraut	26	89	0.92	0.47	129		
Spinach	30.3	92.7	0.94	0.48	132	40	8000
Squash	30.1	90.5	0.92	0.47	130		
Tomatoes (green)	30.4	94.7	0.95	0.48	134	60	6230
Tomatoes (ripening)	30.4	94.1	0.95	0.48	134	40	1260
Turnips	30.5	90.9	0.93	0.47	130	32	1900
						40	2200
Vegetables (mixed)	30	90	0.90	0.45	130		
MEATS AND FISH							
Bacon		20	0.50	0.30	29		
Beef (dried)		5-15	0.22-0.34	0.19-0.26	7-22		
Beef (fresh-lean)	29	68	0.77	0.40	100		
Beef (fresh-fat)	28		0.60	0.35	79		
Brined meats			0.75				
Cod fish (fresh)	28		0.90	0.49	119		
Cut meats	29	65	0.72	0.40	95		
Fish (frozen)	28	70	0.76	0.41	101		
Fish (iced)		70	0.76	0.41	101		
Fish (dried)			0.56	0.34	65		
Hams and loins	27	60	0.68	0.38	86.5		
Lamb	29	58	0.67	0.30	83.5		
Livers	29	65.5	0.72	0.40	93.3		
Oyster (shell)	27	80.4	0.83	0.44	116		
Oysters (tub)	27	87	0.90	0.46	125		
Pork (fresh)	28	60	0.68	0.38	86.5		
Pork (smoked)		57	0.60	0.32			
Poultry (fresh)	27	74	0.79	0.37	106		
Poultry (frozen)	27	74	0.79	0.37	106		
Sausage (casings)			0.60				
Sausage (drying)	26	65.5	0.89	0.56	93		
Sausage (franks)	29	60	0.86	0.56	86		
Sausage (fresh)	26	65	0.89	0.56	93		
Sausage (smoked)	25	60	0.86	0.56	86		
Scallops	28	80.3	0.89	0.48	116		
Shrimp	28	70.8	0.83	0.45	119		
Veal	29	63	0.71	0.39	91		
MISCELLANEOUS							
Beer	28	92	1.0				
Bread		32-37	0.70	0.34	46-53		
Bread (dough)		58	0.75				
Butter	30-0	15	0.64	0.34	15		
Candy			0.93				
Caviar (tub)	20	55				40	3820
Cheese (American)	17	60	0.64	0.36	79	40	4680
Cheese (Camembert)	18	60	0.70	0.40	86	40	4920
Cheese (Limburger)	19	55	0.70	0.40	86	40	4920
Cheese (Roquefort)	3	55	0.65	0.32	79	45	4000
Cheese (Swiss)	15	55	0.64	0.36	79	40	4660
Chocolate (coating)	95-85	55	0.30	0.55	40		
Cream (40%)	28	73	0.85	0.40	90		
Eggs (crated)	27		0.76	0.40	100		
Eggs (frozen)	27			0.41	100		
Flour		13.5	0.38	0.28			
Flowers (cut)	32					480/sq. ft. Floor Area	
Furs—Woolens				0.40			

Table 10 (cont.)
FOOD PRODUCTS DATA

Product	Average Freezing Point F	Percent Water	SP ht, Btu/(lb)(F deg) Above Freezing	SP ht, Btu/(lb)(F deg) Below Freezing	Latent Heat of Fusion Btu/lb	Heat of Respiration Btu per (24 hr)(ton) at Temp. Indicated °F	BTU
Honey		18	0.35	0.26	26	40	1420
Hops						35	1500
Ice cream	27-0	58-66	0.78	0.45	96		
Lard			0.52				
Malt						50	1500
Maple sugar		5	0.24	0.21	7	45	1420
Maple syrup		36	0.49	0.31	52	45	1420
Milk	31	87.5	0.93	0.49	124		
Nuts (dried)		3-10	0.21-0.29	0.19-0.24	4.3-14	35	1000
Oleomargarine		15.5	0.32	0.25	22		
Tobacco and cigars	25						
Yeast		70.9	0.77	0.41	102		
FRUITS							
Apples	28.4	84.1	0.86	0.45	121	32	830
						40	1435
Apricots	28.1	85.4	0.88	0.46	122		
Avocadoes	27.2	94	0.91	0.49	136	60	13,200-39,700
Bananas	28	74.8	0.80	0.42	108	68	8400-9200
Blackberries	28.9	85.3	0.88	0.46	122		
Blueberries	28.6	82.3	0.86	0.45	118	32	1300-2200
Cantaloupes	29	92.7	0.94	0.48	132	40	2000
						60	8500
Cherries	26	83	0.87	0.45	120		
Cranberries	27.3	87.4	0.90	0.46	124		
Currants	30.2	84.7	0.88	0.45	120		
Dates (dry)	—4.1	20	0.36	0.26	29		
Dates (fresh)	27.1	78	0.82	0.43	112		
Figs (fresh)	27.1	78	0.82	0.43	112		
Figs (dried)		24	0.39	0.27	34		
Gooseberries	28.9	88.3	0.90	0.46	126		
Grapefruit	28.4	88.8	0.91	0.46	126	32	460
						40	1070
Grapes	26.3	81.7	0.86	0.44	116	35	830
Honey Dew Melon	20	92.6	0.94	0.48	132	40	1000
Lemons	28.1	89.3	0.92	0.46	127	40	810
						60	2970
Limes	29	86	0.89	0.46	122	40	810
						60	2970
Mangoes	32	93	0.90	0.46	134		
Nectarines	29	82.9	0.90	0.49	119		
Oranges	28	87.2	0.90	0.46	124	32	795
						40	1400
Peaches	29.4	86.9	0.90	0.46	124	32	1110
						40	1735
Pears	28.5	83.5	0.86	0.45	118	32	770
Persimmons	28.3	78.2	0.84	0.43	112		
Pineapples	29.4	85.3	0.88	0.45	123		
Plums	28	85.7	0.88	0.45	122		
Pomegranates	28	77	0.87	0.48	112		
Prunes (fresh)	28	85.7	0.88	0.45	123		
Quinces	28.1	85.3	0.88	0.45	122		
Raspberries	30.1	82	0.85	0.45	122	40	6800-8500
						60	18,100-22,300
Strawberries	29.9	90	0.92	0.47	129		
Tangerines	28.0	87.3	0.93	0.51	126	32	3265
						40	5865
Watermelons	29.2	92.1	0.97	0.48	132		

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Table 11

PROPERTIES OF SOLIDS

Name or Description	Specific Heat		Specific Gravity	Thermal Conductivity*	
	Btu per (lb) (F deg)	Temp F		Temp F	k
Aluminum	0.226	100	2.55-2.80	32	122.0
Aluminum bronze			7.7		
Alundum	0.186	212			
Abestos	0.25	0.47-0.58	2.1-2.8	32	0.09
Asphalt	0.3-0.4				
Ashes	0.20		0.64-0.72	32	0.041
Bakelite	0.3-0.4				
Brickwork	0.2		1.85-2.00	70	0.33-0.92
Brass, red	0.08991	32	8.4-8.7	32	59.5
Brass, yellow	0.08831	32	8.4-8.7	32	49.4
Bismuth tin	0.040			64	37.6
Bell metal	0.086	59-208.4			
Bronze	0.104		7.4-8.8		
Cadmium	0.0548		8.65	64	53.7
Carbon (gas retort)	0.204				
Cardboard					0.1-0.2
Cellulose	0.32				
Cement, Portland clinker	0.186		1.5-2.4		0.017
Charcoal (wood)	0.242		0.28-0.57	172	0.051
Chrome brick	0.17				
Clay	0.224		1.28		
Coal	0.26-0.37		0.65-1.8		
Coal tars	0.35	104			
Coal tar oils	0.34	59-194			
Coke	0.265	69.8-752	1.0-1.4	32	0.106
Concrete (stone)	0.156	70-213	1.5-2.4		0.5-0.75
Copper (cast rolled)			8.8-8.9	32	224.0
Cryolite	0.253	60.8-131			
Chalk	0:215		1.8-2.8		0.48
Cork (granulated rolled)	0.485		0.22-0.26	24	0.028
Cotton (flax, hemp)			1.47-1.50	32	0.033
Cotton (wool)					0.01
Diamond	0.147				
Earth (dry and packed)			1.5 (loose)	32	0.035
				100	0.039
Felt				86	0.022
Fireclay brick	0.198	212			
Fluorspar	0.21	86			
Glass (crown)	0.16-0.2		2.4-2.7		0.333-0.5
(flint)	0.117		3.2-4.7		
(pyrex)	0.20				
(silicate)	0.188-0.2	32-212			
(wool)	0.157				
(common)			2.40-2.80		
Graphite (powder)	0.165	78.8-168.8		104	0.106
Graphite	0.20	68-212	2.4-2.7		1.0-2.32
Gypsum	0.259	60.8-114.8	2.3-2.8	68	0.25
German silver	0.0946	32-212	8.58		
Garnet	0.1758	60.8-212			
Gold	0.0308		19.25-19.2	64	169.0
Ice	0.350	−112	0.88-0.92	32	1.28 (water)
Ice	0.434	−40		14	1.35
Ice	0.465	−4		−4	1.41
Ice	0.487	32		−22	1.471
Ice				−40	1.538
India rubber (para)	0.481	−148			
Iron (gray cast)	0.101		7.03-7.13	129	27.6

Table 11 (cont.)
PROPERTIES OF SOLIDS

Name or Description	Specific Heat Btu per (lb) (F deg)	Specific Heat Temp F	Specific Gravity	Thermal Conductivity* Temp F	Thermal Conductivity* k
Iron (cast pig)			7.2		
Iron (wrought)			7.6-7.9	64	34.9
Lead	0.030		11.34	64	20.1
Limestone	0.217	59-212	2.1-2.8		0.3-0.75
Litharge	0.055				
Leather			0.86-1.02		0.092
Linen					0.05
Marble	0.21	64.4	2.4-2.8		1.2-1.7
Manganese			7.42		
Magnesia	0.234	212			0.04
Magnesite brick	0.222	212			0.9-2.5
Monel metal	0.127	68-2372	8.97		
Mica	0.10	68			0.44
Nickel	0.103		8.9	64	34.4
Nickel steel	0.109				
Paper	0.324		0.70-1.15		0.075
Paraffin	0.6939	32-68	0.87-0.91	86	0.145
Platinum (cast)			21.5	64	40.2
Porcelain	0.22			329	0.945
Pyrites (copper)	0.131	66.2-122			
Pyrites (iron)	0.136	59-208.4			
Plaster (rough lime)					0.25-0.05
Sawdust			0.21	68	0.042
Rock salt	0.219	55.4-113			
Rubber (goods)	0.48		1.0-2.0	100	0.92
Saltpeter			1.07		
Sand	0.191		1.4-1.9	68	0.188
Silica	0.316				
Steel (cold drawn)	0.12		7.83	32	28.0
Stone	0.2				
Silver (cast)			10.4-10.6	64	244.0
Snow (fresh fallen)			0.125		
Tin (cast)	0.053		7.2-7.5	64	37.6
Tungsten	0.034		19.22		
Tar (bituminous)			1.20		
Wood (oak)	0.570		0.65-0.84		0.085-0.125
most woods vary between	0.45-0.65				
Ash			0.55-0.71		
Fir	0.65		0.40	86	0.094
Elm			0.56		
Hickory			0.74-0.80		
Mahogany			0.56-0.85		
Maple			0.53-0.68	86	0.092
Pine	0.67		0.43-0.67	86	0.065-0.085
Spruce			0.45		
Walnut			0.59		
Wool			1.32	86	0.022
Zinc (cast)			7.1	32	63.0

*Note: k = BTU per (hr.) (sq. ft.) (F deg per ft).
Specific Gravity = Ratio of density (pounds per cubic foot) to that of water (62.4 pounds per cubic foot)

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Table 12
PROPERTIES OF LIQUIDS

Name or Description	Boiling Point F	Enthalpy of Vaporization Btu/lb	Specific Heat		Viscosity		Freezing Point F	Enthalpy of Fusion Btu/lb	Specific Gravity or Density (d)		Thermal Conductivity*	
			Btu per (lb) (F deg)	Temp. F	Centipoises	Temp. F			Temp. F	lb/cu ft d	k	Temp. F
Acetaldehyde	69.44	244.8			0.275	32	−190.3					
Acetic acid	245.3	173.0	0.522	78.8-203	1.040	86	62.00	77.7			0.099	68
Acetone	132.98	223.0	0.506	32			203	42.1	68	49.4 (d)	0.102	77-86
Allyl alcohol	206.6	293.0	0.665	69.8-204.8	1.168	86	−200.2				0.104	77-86
Amyl alcohol	280.22	216.0					−109.3	48.0			0.094	86
Ammonia			1.099	32				94.5			0.29	5-86
Alcohol-ethyl	172.94	366.9	0.548	0	1.2	68	−174.28	45.6			0.789	
Alcohol-methyl	148.46	472.0	0.601	64	0.596	68	−142.6	39.6			0.796	
Aniline	63.2	198.0	0.514	60	4.467	68	+ 20.77	48.6	32	64.5 (d)		
Benzol			0.340	50	0.567	86		55.0				
Benzene	176.18	167.0						54.6	32	56.1 (d)	0.092	86
Bromine	137.84	86.4	0.107	13-45	0.911	86		29.15	32			
Butyl-alcohol	243.86	254.0	0.687	20-115			−129.64	54.0			0.097	86
Butyric acid	326.3	205.0	0.515	20-100	1.304	86	+ 22.01	54.2				
Calcium chloride brine			0.764	5					5	1.14		
			0.787	68					68	1.14	30% 0.32	86
			0.695	+4					+4	1.20	15% 0.34	86
			0.725	68					68	1.20		
			0.651	−4					−4	1.26		
			0.676	68					68	1.26		
Carbolic acid	359.96		0.561	57.2-78.8				52.2	59	60.2 (d)		
Carbon disulfide	115.27	151.3	0.240	68	0.352	86	−169.24		32	80.6 (d)	0.093	86
Carbon tetrachloride	169.16	83.5	0.201	68	0.848	86	− 9.04	74.8			0.107	32
Chloroform	142.16	106.0	0.226	59	0.519	86	− 82.3			1.50	0.080	86
Copper sulfate			0.848	58								
			0.951	57								
			0.975	59								
Diphenylamine	575.6		0.464	125			127.36					
Decane	345.2	108.2	0.500	0-50	0.77	72.14	− 22	86.4			0.085	86
Dow Corning 500	211.1											
	305.6											
	377.6											
	446.0											
Ethyl ether	94.08	159.0	0.529	32	0.223	86	−176.8	41.4		0.736	0.08	86
Ethyl acetate	170.78	183.5 (32 F)	0.475	68			−118.84	51.1			0.101	68
Ethyl alcohol	172.94	367.0	0.548	32				44.8			0.105	68
Ethyl bromide	101.12	108.0	0.215	59-68	0.368	86	−182.2					
Ethyl chloride	53.96	166.5	0.367	32			−217.66					
Ethyl iodide	161.78	81.3	0.161	68	0.540	86	−163.3				0.064	104
Ethylene bromide	269.06	83.0	0.173	68	1.475	86	50.108					
Ethylene chloride	182.66	139.0	0.299	68	0.736	86	− 31					
Ethylene glycol	386.6	344.0									0.153	32
Formic acid	213.44	216.0	0.525	68-212	1.46	86	47.12	104.4				
Glycerine	554		0.575	59-120	830.0	68.54	64.58	85.6				
Glycerol	555.08				207.0	68	64.4	85.5			0.164	68
Gasoline	158-194		0.5	32-212						0.73		
Heptane	209.12	137.1	0.490	68	0.375	86	−131.08	60.6			0.081	86
Hexane	755.6	142.5	0.600	68	0.296	86	−139	65.0			0.080	86
Isobutyl alcohol	224.42	248.0										
Kerosine			0.5	32-212						0.78-0.82	0.086	68
Linseed oil					33.1	86				0.925		
Methyl acetate	134.78	176.5	0.468	59			−144.49					
Methyl iodide	108.14	82.6			0.460	86	− 86.98					
Naphthalene	424.4	136.0	0.396	185			176.396	64.0				
Nitrobenzole			0.350	58								
Nitric acid	186.8						− 43.6	17.15		91%—1.50		
Nitrobenzene	411.62	142.2	0.350	57.2			42.53	40.5			0.095	86
Nonane	302		0.503	32-122	0.62	72.14	− 64.66				0.084	86
Oils												
Castor			0.434		451.0	86			59	60.5 (d)	0.104	68
Citron			0.438	42								
Olive			0.471	44	54.0	86			59	0.906	0.097	68
Sesame			0.387									
Rapeseed					42.2	100.04			59	57.0 (d)		
Soybean					40.6	86			194	0.919		
Sperm					42.0	60.08			77	55.0 (d)		

Table 12 (cont.)

PROPERTIES OF LIQUIDS

Name or Description	Boiling Point F	Enthalpy of Vaporization Btu/lb	Specific Heat		Viscosity		Freezing Point F	Enthalpy of Fusion Btu/lb	Specific Gravity or Density (d)		Thermal Conductivity*	
			Btu per (lb) (F deg)	Temp. F	Centipoises	Temp. F			Temp. F	lb/cu ft d	k	Temp. F
Octane	256.28	127.5	0.587	68-253.4	0.483	86	−70.42				0.083	86
Petroleum			0.511	70-135						0.87		
Pentane	96.8				0.220	86	−201.82		32	40.6 (d)		
Propionic acid	285.98	177.8	0.560	68-278.6	0.960	86	−5.44					
Propyl alcohol	207.5	295.2	0.57	68	1.779	86	−194.98			2.04		
Potassium hydroxide												
+30 parts H_2O			0.876	64								
+100 parts H_2O			0.975	64								
Sea water			0.980							1.004		
			0.938							1.024		
			0.903							1.046		
Sulfuric acid 100%	626	219.6	0.344	68			50.882	43.2		87%—1.80	0.21	86
Sodium chloride brine												
+10 parts H_2O			0.791	64						25%—0.33		86
+200 parts H_2O			0.978	64						13%—0.34		86
Sodium hydroxide			0.942	64								
+100 parts H_2O			0.983	64								
Toluol	231.8	154.8	0.364	50								
			0.534	185								
Toluene	230.54	155.7	0.440	53.6-210.2	0.525	86	−139					
Turpentine	320	123.4	0.411	32	1.272	86				0.864	0.074	59
Water	212	969.7	1.000	60.8	0.8007	86	32	143.05	39.2	1.00	0.330	32
									39.2	62.4 (d)	0.356	86
Xylene	287.6	149.2	0.411	86			−16.78				0.090	68
Zinc sulfate												
+50 parts H_2O			0.842	68-125								
+200 parts H_2O			0.952	125								

*Note: k = BTU per (hr.) (sq. ft.) (F deg. per ft.)
Density = Pounds per cubic foot
Specific Gravity = Ratio of density to that of water (62.4 pounds per cubic foot)

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SENSIBLE HEAT ABOVE FREEZING

Most products are at a higher temperature than the storage temperature when placed in a refrigerator. Since many foods have a high percentage of water content, their reaction to a loss of heat is quite different above and below the freezing point. Above the freezing point, the water exists in liquid form, while below the freezing point, the water has changed its state to ice.

As mentioned previously, the specific heat of a product is defined as the BTUs required to raise the temperature of one pound of the substance 1°F. The specific heats of various commodities are listed in Tables 10, 11, and 12. Note that in Table 10 the specific heat of the product above freezing is different than the specific heat below freezing, and the freezing point (listed in the first column) varies, but in practically all cases is below 32°F.

The heat to be removed from a product to reduce its temperature above freezing may be calculated as follows:

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

Q = BTU to be removed
W = Weight of the product in pounds
c = Specific heat above freezing
T_1 = Initial temperature, °F.
T_2 = Initial temperature, °F. (freezing or above)

For example, the heat to be removed in order to cool 1,000 pounds of veal (whose freezing point is 29°F.) from 42°F. to 29°F. can be calculated as follows:

$$\begin{aligned} Q &= W \times c \times (T_1 - T_2) \\ &= 1000 \text{ pounds} \times .71 \text{ specific heat} \times (42-29) \\ &= 1000 \times .71 \times 13 \\ &= 9{,}230 \text{ BTU} \end{aligned}$$

LATENT HEAT OF FREEZING

The latent heat of fusion or freezing for liquids other than water is given in Table 12. Substances such as metals which contain no water do not have a freezing point, and no latent heat of fusion is involved in lowering their temperature.

Most food products, however, have a high percentage of water content. In order to calculate the heat removal required to freeze the product, only the water need be considered. The water content percentage for various food products is given in Table 10, Column 2.

Since the latent heat of fusion or freezing of water is 144 BTU/lb., the latent heat of fusion for the product can be calculated by multiplying 144 BTU/lb. by the percentage of water content, and for ease in calculations this figure is given in Column 5 of Table 10. To illustrate, veal has a water percentage of 63%, and the latent heat of fusion listed in Column 5 for veal is 91 BTU/lb.

$$63\% \times 144 \text{ BTU/lb.} = 91 \text{ BTU/lb.}$$

The heat to be removed from a product for the latent heat of freezing may be calculated as follows:

$$Q = W \times h_{if}$$

Q = BTU to be removed
W = Weight of product in pounds
h_{if} = latent heat of fusion, BTU/lb.

The latent heat of freezing of 1000 pounds of veal at 29°F. is:

$$\begin{aligned} Q &= W \times h_{if} \\ &= 1000 \text{ lbs.} \times 91 \text{ BTU/lb.} \\ &= 91{,}000 \text{ BTU} \end{aligned}$$

SENSIBLE HEAT BELOW FREEZING

Once the water content of a product has been frozen, sensible cooling again can occur in the same manner as that above freezing, with the exception that the ice in the product causes the specific heat to change. Note in Table 10 the specific heat of veal above freezing is .71, while the specific heat below freezing is .39,

The heat to be removed from a product to reduce its temperature below freezing may be calculated as follow:

$$Q = W \times c_i \times (T_f - T_3)$$

Q = BTU to be removed
W = Weight of product in pounds
c_i = Specific heat below freezing
T_f = Freezing temperature
T_3 = Final temperature

For example, the heat to be removed in order to cool 1,000 pounds of veal from 29°F. to 0°F. can be calculated as follows:

$$\begin{aligned} Q &= W \times c_i \times (T_f - T_3) \\ &= 1{,}000 \text{ lbs.} \times .39 \text{ specific heat} \times (29-0) \\ &= 1{,}000 \times .39 \times 29 \\ &= 11{,}310 \text{ BTU} \end{aligned}$$

TOTAL PRODUCT LOAD

The total product load is the sum of the individual calculations for the sensible heat above freezing, the latent heat of freezing, and the sensible heat below freezing.

From the foregoing example, if 1,000 pounds of veal is to be cooled from 42°F. to 0°F., the total would be:

Sensible Heat above Freezing	9,230	BTU
Latent Heat of Freezing	91,000	BTU
Sensible Heat Below Freezing	11,310	BTU
Total Product Load	111,540	BTU

If several different commodities or crates, baskets, etc. are to be considered, then a separate calculation must be made for each item for an accurate estimate of the product load.

STORAGE DATA

Most commodities have conditions of temperature and relative humidity at which their quality is best preserved and their storage life is a maximum. Recommended storage conditions for various perishable products are listed in Table 13 and recommended storage conditions for cut flowers and nursery stock are listed in Table 14.

Data on various types of storage containers is listed in Table 15.

Table 13

STORAGE REQUIREMENTS AND PROPERTIES OF PERISHABLE PRODUCTS

Commodity	Storage Temp. F	Relative Humidity %	Approximate Storage Life
Apples	30-32	85-90	2- 6 months
Apricots	31-32	85-90	1- 2 weeks
Artichokes (Globe)	31-32	90-95	1- 2 weeks
Jerusalem	31-32	90-95	2- 5 months
Asparagus	32	90-95	2- 3 weeks
Avocados	45-55	85-90	4 weeks
Bananas	—	85-95	—
Beans (Green or snap)	45	85-90	8-10 days
Lima	32-40	85-90	10-15 days
Beer, barrelled	35-40		3-10 weeks
Beets			
Bunch	32	90-95	10-14 days
Topped	32	90-95	1- 3 months
Blackberries	31 32	85-90	7 days
Blueberries	31 32	85-90	3- 6 weeks
Bread	0		several weeks
Broccoli, sprouting	32	90-95	7-10 days
Brussels sprouts	32	90-95	3- 4 weeks
Cabbage, late	32	90-95	3- 4 months
Candy	0-34	40-65	—
Carrots			
Prepackaged	32	80-90	3- 4 weeks
Topped	32	90-95	4- 5 months
Cauliflower	32	90-95	2- 3 weeks
Celeriac	32	90-95	3- 4 months
Celery	31-32	90-95	2- 4 months
Cherries	31-32	85-90	10-14 days
Coconuts	32-35	80-85	1- 2 months
Coffee (green)	35-37	80-85	2- 4 months
Corn, sweet	31-32	85-90	4- 8 days
Cranberries	36-40	85-90	1- 4 months
Cucumbers	45-50	90-95	10-14 days
Currants	32	80-85	10-14 days
Dairy products			
Cheese	30-45	65-70	
Butter	32-40	80-85	2 months
Butter	0 to —10	80-85	1 year
Cream (sweetened)	—15	—	several months
Ice cream	—15	—	several months
Milk, fluid whole			
Pasteurized Grade A	33	—	7 days
Condensed, sweetened	40	—	several months
Evaporated	Room Temp	—	1 year, plus
Milk, dried			
Whole milk	45-55	low	few months
Non-fat	45-55	low	several months
Dewberries	31-32	85-90	7-10 days
Dried fruits	32	50-60	9-12 months
Eggplant	45-50	85-90	10 days
Eggs			
Shell	29-31	80-85	6- 9 months
Shell, farm cooler	50-55	70-75	
Frozen, whole	0 or below	—	1 year, plus
Frozen, yolk	0 or below	—	1 year, plus
Frozen, white	0 or below	—	1 year, plus
Whole egg solids	35-40	low	6-12 months
Yolk solids	35-40	low	6-12 months
Flake albumen solids	Room Temp	low	1 year, plus
Dried spray albumen solids	Room Temp	low	1 year, plus
Endive (escarole)	32	90-95	2- 3 weeks
Figs			
Dried	32-40	50-60	9-12 months
Fresh	28-32	85-90	5- 7 days
Fish			
Fresh	33-35	90-95	5-15 days
Frozen	—10-0	90-95	8-10 months
Smoked	40-50	50-60	6- 8 months
Brine salted		90-95	10-12 months
Mild cured	28-35	75-90	4- 8 months
Shellfish			
Fresh	33	90-95	3- 7 days
Frozen	0 to —20	90-95	3- 8 months
Frozen-pack fruits	—10-0	—	6-12 months
Frozen-pack vegetables	—10-0	—	6-12 months
Furs and Fabrics	34-40	45-55	several years
Garlic, dry	32	70-75	6- 8 months
Gooseberries	31-32	80-85	3- 4 weeks
Grapefruit	50	85-90	4- 8 weeks
Grapes			
American type	31-32	85-90	3- 8 weeks
European type	30-31	85-90	3- 6 months
Honey	—	—	1 year, plus
Hops	29-32	50-60	several months
Horseradish	32	90-95	10-12 weeks
Kale	32	90-95	2- 3 weeks
Kohlrabi	32	90-95	2- 4 weeks
Lard (without antioxidant)	45	90-95	4- 8 months
Lard (without antioxidant)	0	90-95	12-14 months
Leeks, green	32	90-95	1- 3 months
Lemons	32 or 50-58	85-90	1- 4 months
Lettuce	32	90-95	3- 4 weeks
Limes	48-50	85-90	6- 8 weeks
Logan blackberries	31-32	85-90	5- 7 days
Meat			
Bacon—Frozen	—10-0	90-95	4- 6 months
Cured (Farm style)	60-65	85	4- 6 months
Cured (Packer style)	34-40	85	2- 6 weeks
Beef—Fresh	32-34	88-92	1- 6 weeks
Frozen	—10-0	90-95	9-12 months
Fat backs	34-36	85-90	0- 3 months
Hams and shoulders—Fresh	32-34	85-90	7-12 days
Frozen	—10-0	90-95	6- 8 months
Cured	60-65	50-60	0- 3 years
Lamb—Fresh	32-34	85-90	5-12 days
Frozen	—10-0	90-95	8-10 months
Livers—Frozen	—10-0	90-95	3- 4 months
Pork—Fresh	32-34	85-90	3- 7 days
Frozen	—10-0	90-95	4- 6 months
Smoked Sausage	40-45	85-90	6 months
Sausage Casings	40-45	85-90	
Veal	32-34	90-95	5-10 days
Mangoes	50	85-90	2- 3 weeks
Melons, Cantaloupe	32-40	85-90	5-15 days
Persian	45-50	85-90	1- 2 weeks
Honeydew and Honey Ball	45-50	85-90	2- 4 weeks
Casaba	45-50	85-90	4- 6 weeks
Watermelons	36-40	85-90	2- 3 weeks

Table 13 (cont.)

STORAGE REQUIREMENTS AND PROPERTIES OF PERISHABLE PRODUCTS

Commodity	Storage Temp. F	Relative Humidity %	Approximate Storage Life
Mushrooms	32-35	85-90	3- 5 days
Mushroom spawn			
Manure spawn	34	75-80	8 months
Grain spawn	32-40	75-80	2 weeks
Nursery stock	32-35	85-90	3- 6 months
Nuts	32-50	65-75	8-12 months
Oil (vegetable salad)	35	—	1 year
Okra	50	85-95	7-10 days
Oleomargarine	35	60-70	1 year
Olives, fresh	45-50	85-90	4- 6 weeks
Onions and onion sets	32	70-75	6- 8 months
Oranges	32-34	85-90	8-12 weeks
Orange juice, chilled	30-35		3- 6 weeks
Papayas	45	85-90	2- 3 weeks
Parsnips	32	90-95	2- 6 months
Peaches and nectarines	31-32	85-90	2- 4 weeks
Pears	29-31	85-90	—
Peas, green	32	85-90	1- 2 weeks
Peppers, Sweet	45-50	85-90	8-10 days
Peppers, Chili (dry)	32-40	65-75	6- 9 months
Persimmons	30	85-90	2 months
Pineapples			
Mature green	50-60	85-90	3- 4 weeks
Ripe	40-45	85-90	2- 4 weeks
Plums, including fresh prunes	31-32	80-85	3- 4 weeks
Pomegranates	34-35	85-90	2- 4 months
Popcorn, unpopped	32-40	85	—
Potatoes			
Early crop	50-55	85-90	—
Late crop	38-50	85-90	—

Commodity	Storage Temp. F	Relative Humidity %	Approximate Storage Life
Poultry			
Fresh	32	85-90	1 week
Frozen, eviscerated	—20-0	90-95	9-10 months
Pumpkins	50-55	70-75	2- 6 months
Quinces	31--32	85-90	2- 3 months
Radishes—Spring, bunched or prepackaged	32	90-95	10 days
Winter	32	90-95	2- 4 months
Rabbits			
Fresh	32-34	90-95	1- 5 days
Frozen	—10-0	90-95	0- 6 months
Raspberries			
Black	31-32	85-90	7 days
Red	31-32	85-90	7 days
Frozen (red or black)	—10-0		1 year
Rhubarb	32	90-95	2- 3 weeks
Rutabagas	32	90-95	2- 4 months
Salsify	32	90-95	2- 4 months
Spinach	32	90-95	10-14 days
Squash			
Acorn	45-50	75-85	5- 8 weeks
Summer	32-40	85-95	10-14 days
Winter	50-55	70-75	4- 6 months
Strawberries			
Fresh	31-32	85-90	7-10 days
Frozen	—10-0	—	1 year
Sweet Potatoes	55-60	90-95	4- 6 months
Tangerines	31-38	90-95	3- 4 weeks
Tomatoes			
Mature green	57-70	85-90	2- 4 weeks
Firm ripe	45-50	85-90	2- 7 days
Turnips, roots	32	90-95	4- 5 months
Vegetable seed	32-50	50-65	—
Yeast, compressed baker's	31-32	—	—

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Table 14
STORAGE CONDITIONS FOR CUT FLOWERS AND NURSERY STOCK

Commodity	Storage Temperature, F	Relative Humidity, %	Approximate Storage Life	Method of Holding	Highest Freezing Point, F
CUT FLOWERS:					
Calla lilly	40	80-85	1 week	Dry pack	—
Camellia	45	80-85	3-6 days	Dry pack	30.6
Carnation	31	80-85	1 month	Dry pack	30.8
Chrysanthemum	31	80-85	2-5 weeks	Dry pack	30.5
Daffodil	31	80-85	1-2 weeks	Dry pack	—
Gardenia	31	80-85	2-3 weeks	Dry pack	31.0
Gladiolus	35	80-85	1 week	Dry pack	31.4
Iris, tight buds	31	80-85	2 weeks	Dry pack	30.6
Lily Easter	31	80-85	2 weeks	Dry pack	31.1
Lily-of-the-Valley	31	80-85	2-3 weeks	Dry pack	—
Orchid	45-55	80-85	2-3 days	Water	31.4
Peony, tight buds	31	80-85	6 weeks	Dry pack	30.1
Rose, tight buds	31	80-85	2 weeks	Dry pack	31.2
Sweet peas	31	80-85	2 weeks	Dry pack	30.4
Tulips	31	80-85	6-8 weeks	Dry pack	—
GREENS:					
Fern, dagger and wood	31	85-90	4-5 months	Dry pack	28.9
Holly	31	85-90	1-4 weeks	Dry pack	27.0
Huckleberry	31	85-90	1-4 weeks	Dry pack	26.7
Laurel	31	85-90	1-4 weeks	Dry pack	27.6
Magnolia	31	85-90	1-4 weeks	Dry pack	27.0
Rhododendron	31	85-90	1-4 weeks	Dry pack	27.6
Salal	31	85-90	1-4 weeks	Dry pack	26.8
BULBS:					
Amaryllis	70-75	75-80	5 months	Dry	30.8
Dahlia	40-45	75-80	5 months	Dry	28.7
Gladiolus	40-45	75-80	8 months	Dry	28.2
Iris, Dutch, Spanish	75-80	75-80	4 months	Dry	—
Lily					
Candidum	31	75-80	3 months	Poly liner & peat	—
Croft	31	75-80	2 months	Poly liner & peat	—
Longiflorum	31	75-80	3 months	Poly liner & peat	28.9
Speciosum	31	75-80	3 months	Poly liner & peat	—
Peony	40-45	75-80	5 months	Dry	—
Tuberose	40-45	75-80	4 months	Dry	—
Tulip	40-45	75-80	1-2 months	Dry	27.6
NURSERY STOCK:					
Trees and Shrubs	32-35	80-85	4-5 months		—
Rose bushes	32-35	85-95	4-5 months	Bare rooted with poly liner	—
Strawberry Plants	30-32	80-85	4-10 months	Bare rooted with poly liner	29.9
Rooted Cuttings	33-40	85-95	—	Poly wrap	—
Herbaceous Perennials	27-28 or 33-35	80-85	—		—

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Table 15

SPACE, WEIGHT, AND DENSITY DATA FOR COMMODITIES STORED IN REFRIGERATED WAREHOUSES

Commodity	Type of Package	Outside Dimensions of Package, In.	Avg. Gross Wt. of Pkg., Lb.	Avg. Net Wt. of Mdse., Lb.	Avg. Gross Wt. Density, Lb. per Cu. Ft.	Avg. Net Wt. Density, Lb. per Cu. Ft.
Apples	Wood Box					
	Northwestern	19½ X 11 X 12 3/16	50	42	33.1	27.8
	Fiber Tray Carton	20½ X 12½ X 13¼	46¾	43	23.8	21.9
	Fiber Master Carton	22½ X 12½ X 13	44¾	41	21.2	19.4
	Fiber Bulk Carton	19 X 12½ X 13	44¾	41	25.0	22.9
	Pallet Box	47 X 47 X 30	1030	900	26.9	23.5
Beef						
Boneless	Fiber Carton	28 X 18 X 6	146	140	83.4	80.0
Fores	Loose	—	—	—	—	22.2
Hinds	Loose	—	—	—	—	22.2
Celery	Wirebound Crates	20¼ X 16 X 9¾	60	55	32.8	30.0
	Fiber Carton	16 X 11 X 10	36	32	35.4	31.4
Cheese	Hoops	16 X 16 X 13	84	78	43.6	40.5
	Wood, Export	17 X 17 X 14	87	76	37.1	32.5
Cheese, Swiss	Wheels	32½ X 32½ X 7	—	171	—	40.0
Chili Peppers	Bags	45 X 21 X 26	234	229	16.5	16.1
Citrus Fruits						
Oranges	Box	12⅛ X 13¼ X 26¼	77	69	31.5	28.3
	Bruce Box	13 X 11 X 26¼	88	83	40.5	38.2
	Pallet, 40 Cartons	40 X 48 X 58½	1690	1480	26.0	22.8
California Oranges	Fiber Carton	16⅜ X 10 1/16 X 10½	40	37	38.0	35.2
Florida Oranges	Fiber Carton	19¼ X 12¼ X 8	45	37	41.3	33.9
Lemons	Fiber Carton	16⅜ X 10 1/16 X 10½	40	37	40.0	37.0
Grapefruit	Fiber Carton	19¼ X 12¼ X 8	40	38	36.7	34.9
Coconut, Shredded	Bags	38 X 18½ X 8	101	100	31.0	30.7
Cranberries	Fiber Carton	15¾ X 11¼ X 10½	26	24	24.1	22.2
Cream	Tins	12 X 12 X 14	52¾	50	45.2	42.9
Dried Fruit	Wood Box	15½ X 10 X 6½	26½	25	45.4	42.9
Dates	Fiber Carton	14 X 14 X 11	32	30	25.7	24.0
Raisins, prunes, figs, peaches	Fiber Carton	15 X 11 X 7	32	30	47.9	44.9
Eggs, Shell	Wood Cases	26 X 12 X 13	55	45	23.4	19.1
Eggs, Frozen	Cans	10 X 10 X 12½	32	30	44.2	41.5
Frozen Fishery Products						
Blocks	4/13½ lb. Carton	20¾ X 12⅛ X 6¾	56	54	57.0	55.0
	4/16½ lb. Carton	19¾ X 10¾ X 11¼	68	66	49.2	47.8
Fillets	12/16 oz. Carton	12¾ X 8⅝ X 3 13/16	13.5	12	55.8	49.6
	10/5 lb. Carton	14½ X 10 X 14	52.25	50	44.6	42.7
	5/10 lb. Carton	14½ X 10 X 14	52.2	50	44.5	42.7
Fish Sticks	12/8 oz. Carton	11 X 8⅜ X 3⅞	6.9	6	33.6	29.3
	24/8 oz. Carton	16 7/16 X 8 5/16 X 4⅝	13.8	12	37.8	32.9
Panned Fish	None, Glazed	Wooden Boxes	—	—	—	35.0
Portions	2, 3, 5, and 6 lb. Carton	Custom Packing	—	—	—	29-33
Round Ground Fish	None, Glazed	Stacked Loose	—	—	—	33-35
Round Halibut	None, Glazed	Wooden Box, Loose	—	—	—	30-35
		Stacked Loose	—	—	—	38.0
Round Salmon	None, Glazed	Stacked Loose	—	—	—	33-35
Shrimp	2½ and 5 lb. Cartons	Custom Packing	—	—	—	35.0
Steaks	1, 5, or 10 lb. Packages	Custom Packing	—	—	—	50-60
Frozen Fruits, Juices & Vegetables						
Asparagus	24/12 oz. Carton	13½ X 11¾ X 8¼	21	18	27.7	23.8
Beans, Green	36/10 oz. Carton	12½ X 11 X 8	25½	22½	40.1	35.3
Blueberries	24/12 oz. Carton	12 X 11½ X 8	20	18	31.3	28.2
Broccoli	24/10 oz. Carton	12½ X 11½ X 8½	18½	15	26.2	21.2
Citrus Concentrates	Fiber Carton 48/6 oz.	13 X 8¾ X 7½	27	26	54.7	52.7
Peaches	24/1 lb. Carton	13½ X 11¼ X 7½	27	24	41.0	36.4

Table 15 (cont.)

SPACE, WEIGHT, AND DENSITY DATA FOR COMMODITIES STORED IN REFRIGERATED WAREHOUSES

Commodity	Type of Package	Outside Dimensions of Package, In.	Avg. Gross Wt. of Pkg., Lb.	Avg. Net Wt. of Mdse., Lb.	Avg. Gross Wt. Density, Lb. per Cu. Ft.	Avg. Net Wt. Density, Lb. per Cu. Ft.
Peas	6/5 lb. Carton	17 X 11 X 9½	32	30	31.1	28.2
	48/12 oz. Carton	21½ X 8½ X 12½	38	36	28.7	27.2
Potatoes, Fr. Fries	12/16 oz. Carton	—	—	—	—	28.6
	24/9 oz. Carton	—	—	—	—	24.0
Spinach	24/14 oz. Carton	12½ X 11 X 8½	24	21	35.5	31.0
Strawberries	30 lb. Can	12½ X 10 X 10	32	30	44.2	41.5
	24/1 lb. Carton	13 X 11 X 8	28	24	42.3	36.2
	450 lb. Barrel	35 X 25 X 25	—	450	—	35.5
Grapes, California	Wood Lug Box	6½ X 15 X 18	31	28	32.4	29.2
Lamb, Boneless	Fiber Box	20 X 15 X 5	57	53	65.7	61.0
Lard (2/28 lb.)	Wood Export Box	18 X 13¼ X 7¾	64	56	59.8	52.5
Lettuce, head	Fiber Carton	20½ X 13½ X 9½	37½	35	24.7	—
	Fiber Carton	21½ X 14¼ X 10½	45-55	42-52	26.9	25.2
	Pallet, 30 Cartons	42 X 50 X 66	1350	1170	16.8	14.6
Milk, Condensed	Barrels	35 X 25½ X 25½	670	600	50.9	45.6
Nuts						
Almonds, in Shell	Sacks	24 X 15 X 33	91½	90	13.3	13.1
Almonds, Shelled	Cases	6¾ X 23½ X 11	32	28	31.7	27.7
English Walnuts, in Shell	Sacks	25 X 11 X 31	103	100	20.9	20.3
English Walnuts, Shelled	Fiber Carton	14 X 14 X 10	27	25	23.8	22.0
Peanuts, Shelled	Burlap Bag	35 X 10 X 15	127	125	39.2	38.6
Pecans, in Shell	Burlap Bag	35 X 22 X 12	126½	125	23.7	23.4
Pecans, Shelled	Fiber Carton	13 X 13 X 11	32	30	29.8	27.9
Peaches	¾ Bushel Baskets	16⅞ top dia.	41	38	43.9	40.7
	½ Bushel Baskets	14½ top dia.	28	25	45.0	40.2
	Wirebound Crate	19 X 11¾ X 11⅛	42	38	29.2	26.4
	Wood Lug Box	18⅛ X 11½ X 5¾	26	23	38.0	33.1
Pears	Wood Box	8½ X 11½ X 18	52	48	51.0	47.1
Pears, place pack	Fiber Carton	18½ X 12 X 10	52	46	40.5	35.6
Pork						
Bundle Bellies	Bundles	23½ X 10½ X 7	57	57	57.0	57.0
Loins (Regular)	Wood Box	28 X 10 X 10	60	54	37.0	33.3
Loins (Boneless)	Fiber Box	20 X 15 X 5	57	52	65.7	59.9
Potatoes	Sack	33 X 17½ X 11	101	100	27.5	27.2
Poultry, Fresh (Eviscerated)						
Fryers, Whole, 24-30 to Pkg.	Wirebound Crate	24 X 10 X 7	65	60	27.5	25.4
Fryer Parts	Wirebound Crate	17¾ X 10 X 12½	54	50	42.1	38.9
Poultry, Frozen (Eviscerated)						
Ducks, 6 to Pkg.	Fiber Carton	22 X 16 X 4	32½	31	39.9	38.0
Fowl, 6 to Pkg.	Fiber Carton	20¾ X 18 X 5½	33½	31	28.2	26.1
Fryers, cut up, 12 to Pkg.	Fiber Carton	17¼ X 15¾ X 4¼	30½	28	45.4	41.7
Roaster, 8 to Pkg.	Fiber Carton	20¾ X 18 X 5½	32½	30	27.3	25.2
Turkeys,						
3-6 lb., 6 to Pkg.	Fiber Carton	21 X 17 X 6½	30	27	22.5	20.1
6-10 lb., 6 to Pkg.	Fiber Carton	26 X 21½ X 7	52½	48	23.3	21.2
10-13 lb., 4 to Pkg.	Fiber Carton	26½ X 16 X 7½	50	46	27.2	25.0
13-16 lb., 4 to Pkg.	Fiber Carton	29 X 18½ X 9	67½	62	24.2	22.2
16-20 lb., 2 to Pkg.	Fiber Carton	17 X 16 X 9	39	36	27.7	25.4
20-24 lb., 2 to Pkg.	Fiber Carton	19 X 16½ X 9½	47½	44	27.6	25.5
Tomatoes						
Florida	Fiber Carton	19 X 10⅞ X 10¾	43	40	33.3	31.0
	Wirebound Crate	18¾ X 11 15/16 X 11 15/16	64	60	41.3	38.7
California	Wood Lug Box	17½ X 14 X 7¾	34	30	30.9	27.3
Texas	Wood Lug Box	17½ X 14 X 6⅝	34	30	36.2	31.9
Veal (Boneless)	Fiber Carton	20 X 15 X 5	57	53	65.7	61.0

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SECTION 15
SUPPLEMENTARY LOAD

In addition to the heat transmitted into the refrigerated space through the walls, air infiltration, and product load, any heat gain from other sources must be included in the total cooling load estimate.

ELECTRIC LIGHTS AND HEATERS

Any electric energy directly dissipated in the refrigerated space such as lights, heaters, etc. is converted to heat and must be included in the heat load. One watt hour equals 3.41 BTU, and this conversion ratio is accurate for any amount of electric power.

ELECTRIC MOTORS

Since energy cannot be destroyed, and can only be changed to a different form, any electrical energy transmitted to motors inside a refrigerated space must undergo a transformation. Any motor losses due to friction and inefficiency are immediately changed to heat energy. That portion of the electrical energy converted into useful work, for example in driving a fan or pump, exists only briefly as mechanical energy, is transferred to the fluid medium in the form of increased velocity, and as the fluid loses its velocity due to friction, eventually becomes entirely converted into heat energy.

A common misunderstanding is the belief that no heat is transmitted into the refrigerated space if an electric motor is located outside the space, and a fan inside the space is driven by means of a shaft. All of the electrical energy converted to mechanical energy actually becomes a part of the load in the refrigerated space.

Because the motor efficiency varies with size, the heat load per horsepower as shown in Table 16 has different values for varying size motors. While the values in the table represent useful approximations, the actual electric power input in watts is the only accurate measure of the energy input.

HUMAN HEAT LOAD

People give off heat and moisture, and the resulting refrigeration load will vary depending on the duration of occupancy of the refrigerated space, temperature, type of work, and other factors. Table 17 lists the average head load due to occupancy, but stays of short duration, the heat gain will be somewhat higher.

TOTAL SUPPLEMENTARY LOAD

The total supplementary load is the sum of the individual factors contributing to it. For example, the total supplementary load in a refrigerated storeroom maintained at 0°F. in which there are 300 watts of electric lights, a 3 HP motor driving a fan, and 2 people working continuously would be as follows:

300 Watts x 3.41 BTU/hr.	1,023 BTU/hr.
3 HP motor x 2,950 BTU/hr.	8,850 BTU/hr.
2 people x 1300 BTU/hr.	2,600 BTU/hr.
Total Supplementary Load	12,473 BTU/hr.

Table 16
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.

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Table 17
HEAT EQUIVALENT OF OCCUPANCY

Cooler Temperature F	Heat Equivalent/Person Btu/hr.
50	720
40	840
30	950
20	1,050
10	1,200
0	1,300
−10	1,400

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SECTION 16
EQUIPMENT SELECTION

Once the refrigeration load is determined, together with the required evaporating temperature and the expected condensing temperature, a compressor can be intelligently selected for a given application.

For refrigerated fixtures or prefabricated coolers and cold storage boxes to be produced in quantity, the load is normally determined by test. If the load must be estimated, the expected load should be calculated by determining the heat gain due to each of the factors contributing to the total load. Many short methods of estimating are commonly used for small refrigerated walk-in storage boxes with varying degrees of accuracy. A great deal of judgment must be used in the application of any method.

HOURLY LOAD

Refrigeration equipment is designed to function continuously, and normally the compressor operating time is determined by the requirements of the defrost system. The load is calculated on a 24 hour basis, and the required hourly compressor capacity is determined by dividing the 24 hour load by the desired hours of compressor operation during the 24 hour period. A reasonable safety factor must be provided to enable the unit to recover rapidly after a temperature rise, and to allow for loading heavier than the original estimate.

When the refrigerant evaporating temperature will not be below 30°F., frost will not accumulate on the evaporator, and no defrost period is necessary. It is general practice to choose the compressor for such applications on the basis of 18 to 20 hour operation.

For applications with storage temperatures of 35°F. or higher, and refrigerant temperatures low enough to cause frosting, it is common practice to defrost by stopping the compressor and allowing the return air to melt the ice from the coil. Compressors for such applications should be selected for 16 to 18 hour operation.

On low temperature applications, some positive means of defrost must be provided. With normal defrost periods, 18 hour compressor operation is usually acceptable, although some systems are designed for continuous operation except during the defrost period.

An additional 5% to 10% safety factor is often added to load calculations as a conservative measure to be sure the equipment will not be undersized. If data concerning the refrigeration load is very uncertain, this may be desirable, but in general the fact that the compressor is sized on the basis of 16 to 18 hour operation in itself provides a sizable safety factor. The load should be calculated on the basis of the peak demand at design conditions, and normally the design conditions are selected on the basis that they will occur no more that 1% of the hours during the summer months. If the load calculations are made reasonably accurately, and the equipment sized properly, an additional safety factor may actually result in the equipment being oversized during light load conditions, and can result in operating difficulties.

SAMPLE LOAD CALCULATION

The most accurate means of estimating a refrigeration load is by considering each factor separately. The following example will illustrate a typical selection procedure, although the load has been chosen to demonstrate the calculations required and does not represent a normal loading.

Walk-in cooler with 4 inches of glass fiber insulation, located in the shade.

Outside Dimensions, Height 8 ft., Width 10 ft.,
Length 40 ft., inside volume 3,000 cu. ft.

Floor area (outside dimensions) 400 sq. ft. on insulated slab in contact with ground.

Ambient temperature 100°F., 50% relative humidity

Ground temperature 55°F.

Refrigerator temperature 40°F.

1/2 HP fan motor running continuously

Two 100 watt lights, in use 12 hours per day.

Occupancy, 2 men for 2 hours per day.

In storage: 500 pounds of bacon at 50°F.
1000 pounds of string beans

Entering product:
500 pounds of bacon at 50°F.
15,000 pounds of beer at 80°F.
To be reduced to storage temperature in 24 hours.

Heavy door usage.

(A) HEAT TRANSMISSION LOAD

Sidewalls:

40' x 8' x 2 = 640 Ft^2 x 60°TD x 1.9 (Table 7A)	= 72,960	BTU
10' x 8' x 2 = 160 Ft^2 x 60°TD x 1.9	= 18,240	
Ceiling: 40' x 10' = 400 Ft^2 x 60°TD x 1.9	= 45,600	
Floor: 40' x 10' = 400 Ft^2 x 15°TD x 1.9	= 11,400	
Total 24 hour transmission load	=148,200	

(B) AIR INFILTRATION

3000 Ft^3 x 9.5 air changes (Table 8) x 2 usage factor x 2.11 factor (Table 9)	120,270	BTU

(C) PRODUCT LOAD

500 lbs. bacon x .50 sp. ht. (Table 10) x 10°TD	= 2,500	BTU
15,000 lbs. beer x 1.0 sp. ht. (Table 10) x 40°TD	= 600,000	BTU
500 lbs. lettuce x 2700 BTU/24 Hr/Ton (Table 10)	= 675	BTU
1,000 lbs. beans x 9700 BTU/24 Hr/Ton (Table 10)	= 4,850	BTU
Total 24 hour Product Load	608,025	BTU

(D) SUPPLEMENTARY LOAD

200 Watts x 12 hours x 3.41 BTU/Hr	8,184	BTU
1/2 H.P. x 4250 BTU/Hr-Hr (Table 16) x 24	51,000	BTU
2 People x 2 Hrs/Day x 840 BTU/Hr (Table 17)	3,360	BTU
Total 24 hour Supplementary Load	62,544	BTU

(E) REQUIRED COMPRESSOR CAPACITY

24 Hour Load:

Heat Transmission	148,200	BTU
Air Infiltration	120,270	
Product	608,025	
Supplementary	62,544	
Total 24 Hour Load	939,039	BTU

Required compressor capacity:

Based on 16 hour operation	58,690	BTU/Hr.

RELATIVE HUMIDITY AND EVAPORATOR TD

Relative humidity in a storage space is affected by many variables, such as system running time, moisture infiltration, condition and amount of product surface exposed, air motion, outside air conditions, type of system control, etc. Perishable products differ in their requirements for an optimum relative humidity for storage, and recommended storage conditions for various products are shown in Tables 13 and 14. Normally satisfactory control of relative humidity in a given application can be achieved by selecting the compressor and evaporator for the proper operating temperature difference or TD between the desired room temperature and the refrigerant evaporating temperature.

The following general recommendations have proven to be satisfactory in most normal applications:

Temperature Range	Desired Relative Humidity	TD (Refrigerant to Air)
25°F. to 45°F.	90%	8°F. to 12°F.
25°F. to 45°F.	85%	10°F. to 14°F.
25°F. to 45°F.	80%	12°F. to 16°F.
25°F. to 45°F.	75%	16°F. to 22°F.
10°F. and below	—	15°F. or less

COMPRESSOR SELECTION

In order to select a suitable compressor for a given application, not only the required compressor capacity must be known, but also the desired evaporating and condensing temperatures.

Assuming a desired relative humidity of 80%, a 14° TD might be used, which in a 40°F. storage room result in evaporating temperature of 26°F. To provide some safety factor for line losses, the compressor should be selected for the desired capacity at 2°F. to 3°F. below the desired evaporating temperature.

The condensing temperature depends on the type of condensing medium to be used, air or water, the design ambient temperature or water temperature, and the capacity of the condenser selected. Air cooled condensers are commonly selected to operate on temperature differences (TD) from 10°F. to 30°F. the lower TD normally being used for low temperature applications, and higher TDs for high temperature applications where the compression ratio is less critical. For the purposes of this example, a design TD of 20°F. has been selected, and in 100°F. ambient temperatures, this would result in a condensing temperature of 120°F.

COMPONENT BALANCING

Commercially available components seldom will exactly match the design requirements of a given system, and since system design is normally based on estimated peak loads, the system may often have to operate at conditions other than design conditions. More than one combination of components may meet the performance requirements, the efficiency of the system normally being dependent on the point at which the system reaches stabilized conditions or balances under operating conditions.

The capacities of each of the three major system components, the compressor, the condenser, and the evaporator, are each variable but interrelated. The compressor capacity varies with the evaporating and condensing temperatures. For illustration purposes an air cooled condenser will be considered, and for a given condenser with constant air flow, its capacity will vary with the temperature difference between the condensing temperature and the ambient temperature.

The factors involved in the variation in evaporator capacity are quite complex when both sensible heat transfer and condensation are involved. For component balancing purposes, the capacity of an evaporator where both latent and sensible heat transfer are involved (a wet coil) may be calculated as being proportional to the total heat content of the entering air, and this in turn is proportional to the wet bulb temperature. For wet coil conditions, evaporator capacities are normally available from coil manufacturers with ratings based on the wet bulb temperature of the air entering the coil. For conditions in which no condensation occurs (a dry coil) the evaporator capacity can be accurately estimated on the basis of the dry bulb temperature of the air entering the coil.

Some manufacturers of commercial and low temperature coils publish only ratings based on the temperature difference between entering dry bulb temperature and the evaporating refrigerant temperature. Although frost accumulation involving latent heat will occur, unless the latent load is unusually large, the dry bulb ratings may be used without appreciable error.

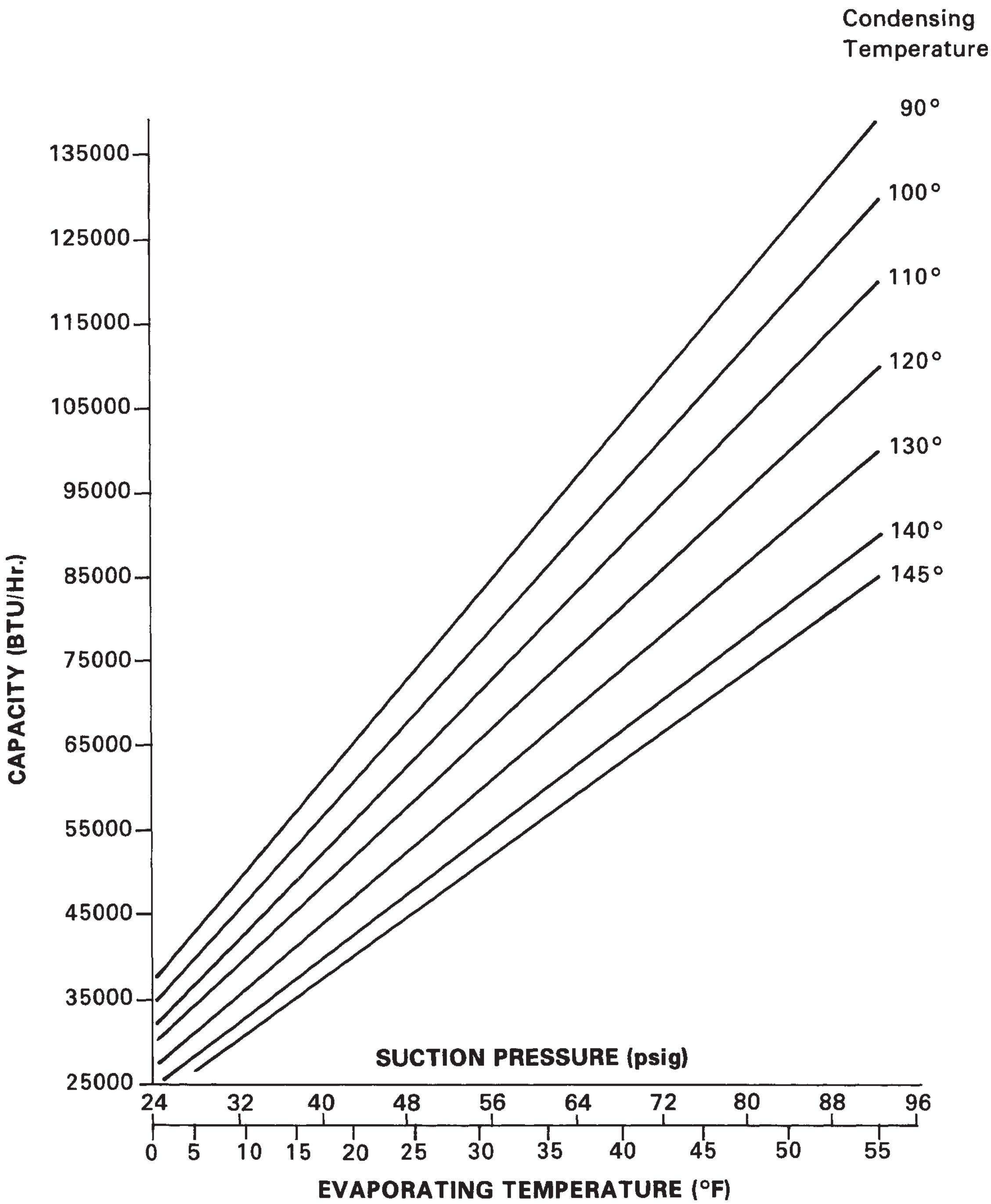
Because of the many variables involved, the calculation of system balance points is extremely complicated. A simple, accurate, and convenient method of forecasting system performance from readily available manufacturer's catalog data is the graphical construction of a component balancing chart. The following example illustrates the use of such a chart in checking the possible balance points of a system when selecting equipment. To illustrate the procedure, tentative selections of a compressor, condenser, and evaporator have been made for the sample load previously calculated.

Figure 69 shows the compressor capacity curves as published by Emerson Climate Technologies, Inc. on the Copeland® brand compressor specification sheet. It should be noted that Copeland® brand compressor capacity curves for Copelametic® compressors are based on 65°F. return suction gas. In order to realize the full compressor capacity, the suction gas must be raised to this temperature in a heat exchanger. If the suction gas returns to the compressor at a lower temperature, or if the increase in suction gas temperature occurs due to heat transfer into the suction line outside the refrigerated space, the effective compressor capacity will be somewhat lower. In the example, the desired capacity was 58,690 BTU/hr. at 24°F. evaporating temperature and 120°F.condensing temperature, and this compressor was the closest choice available, having a capacity of 57,000 BTU/hr. at the design conditions.

Figure 70 shows the same compressor curves, with the condenser capacity curves for the tentative condenser selection superimposed. From the condenser manufacturer's data, condenser capacity in terms of compressor capacity at varying evaporating temperatures are plotted, and the condenser capacity curves can then be drawn. Note that the net condensing capacity decreases at lower evaporating temperatures due to the increased heat of compression.

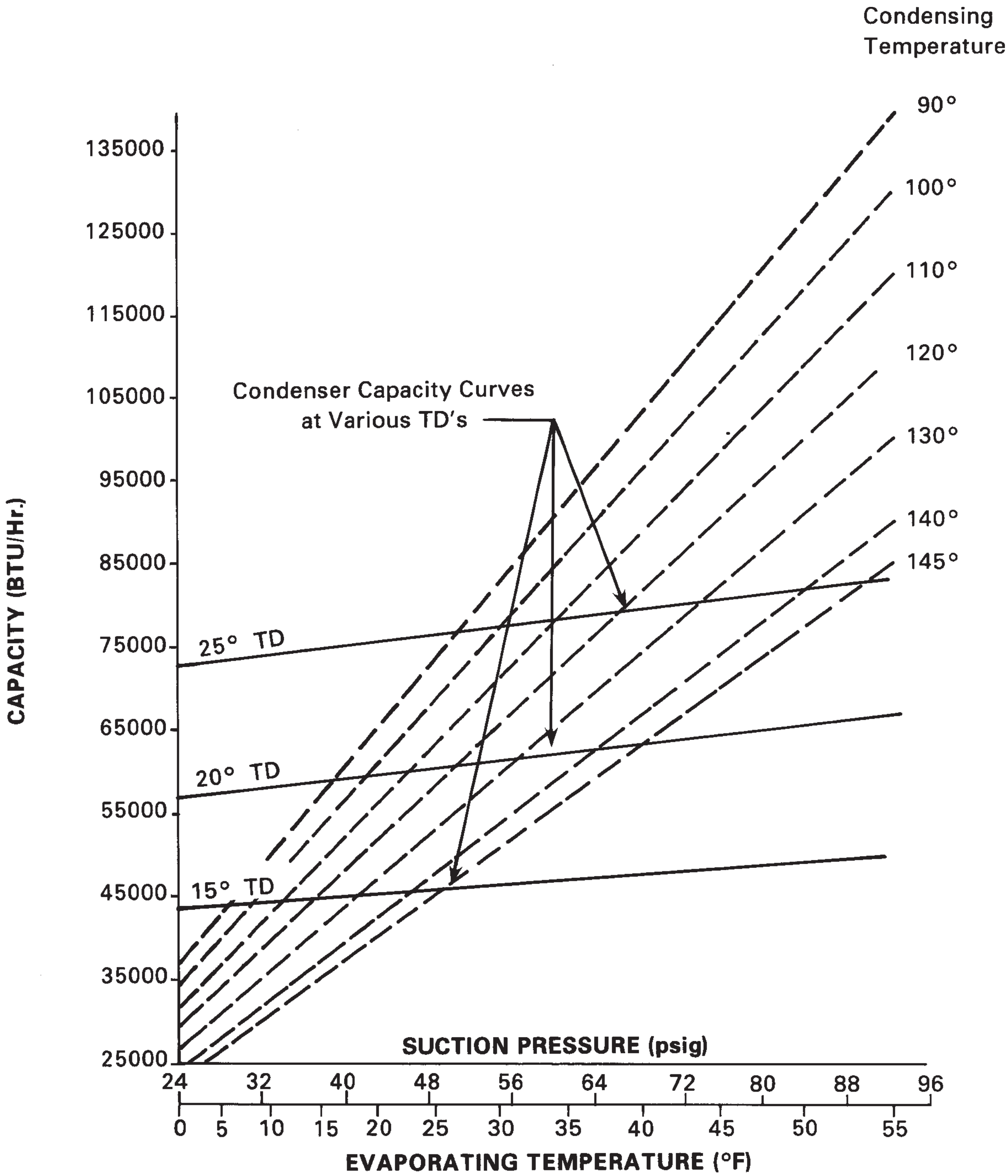
It is now possible to construct balance lines for the compressor and condenser at various ambient temperatures as shown in Figure 71. For an ambient temperature of 100°F., point A would represent the balance point if the compressor were operating at a suction pressure equivalent to a 28°F. evaporating temperature and 120°F. condensing temperature. At this point the capacity of the condenser would exactly match that of the compressor at a 20° TD (condensing temperature minus ambient temperature). The balance point is determined by the intersection of the 20°F. TD condenser capacity curve with the compressor capacity curve for

(continued on p. 16-9)



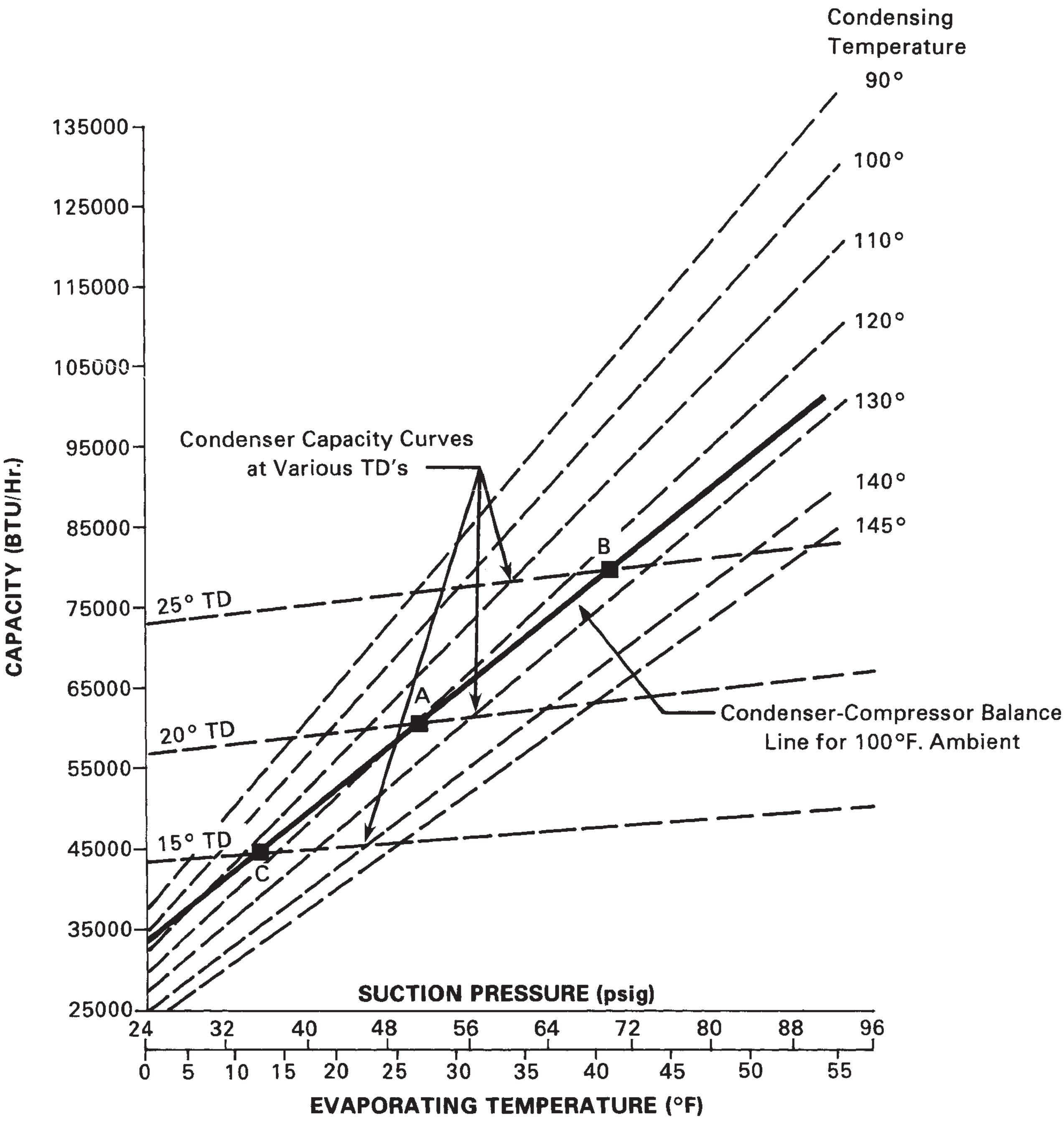
COMPRESSOR CAPACITY CURVES AT VARIOUS CONDENSING TEMPERATURES

Figure 69



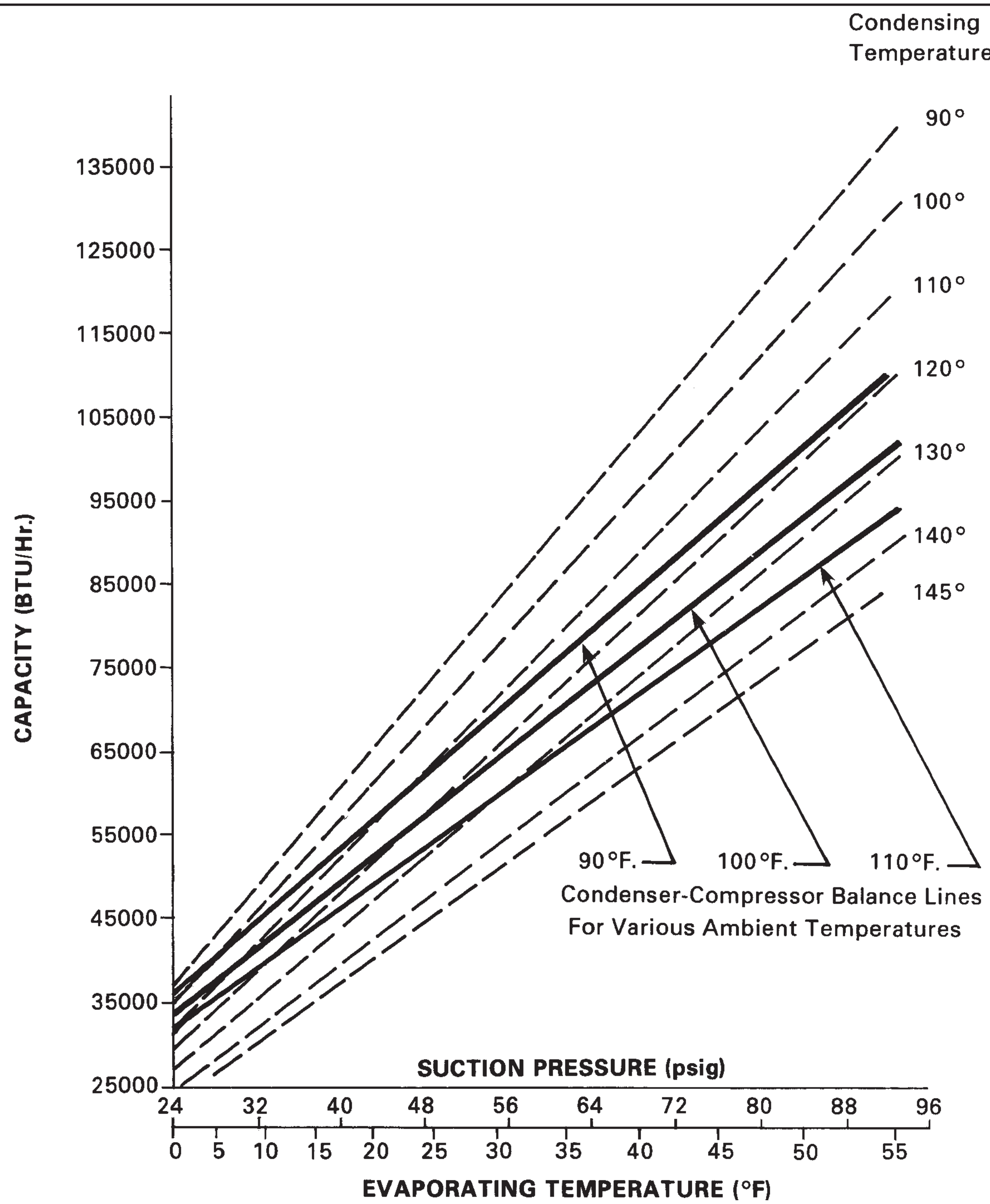
CONDENSER CAPACITY CURVES SUPERIMPOSED
ON COMPRESSOR CAPACITY CURVES

Figure 70



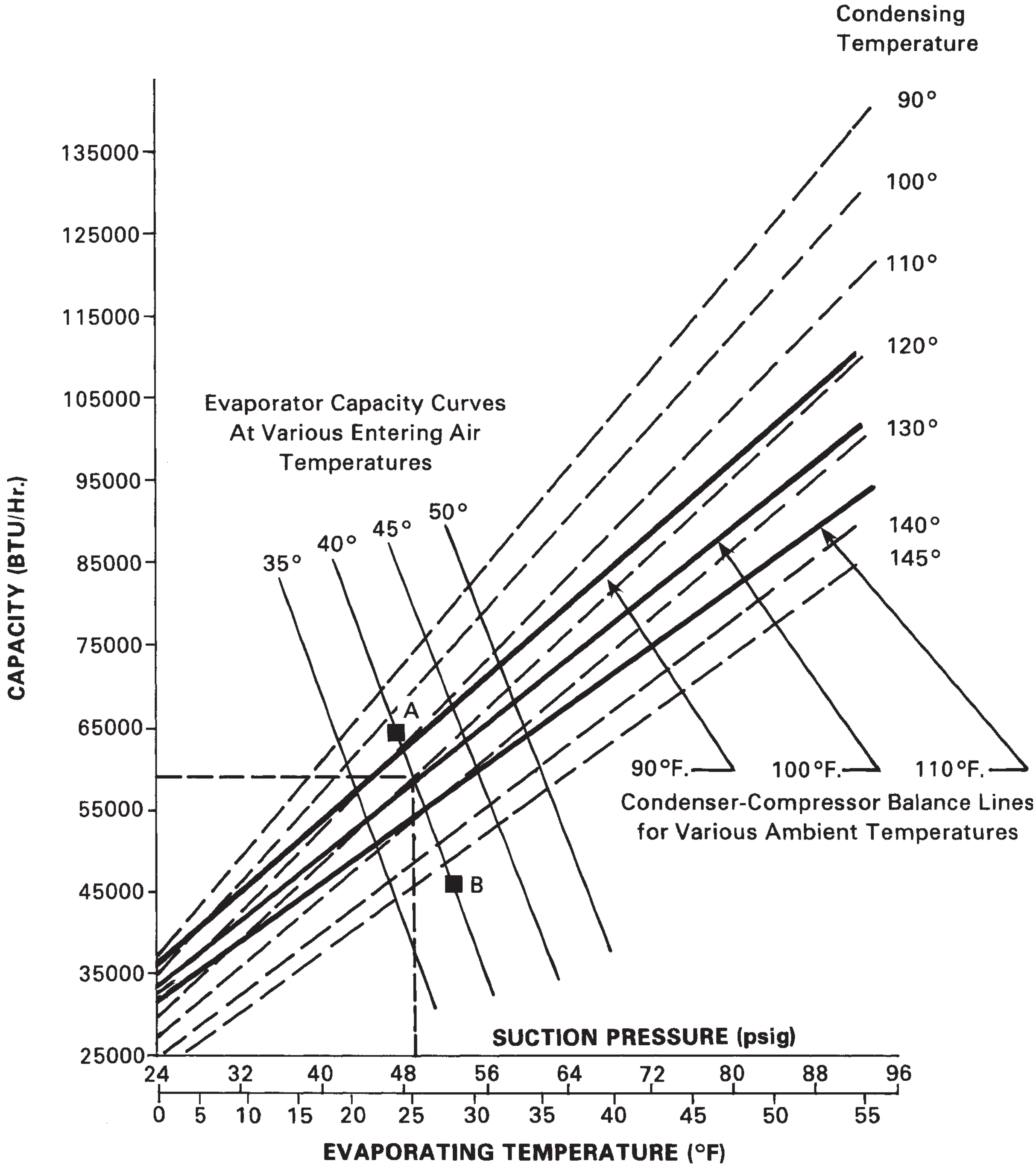
CONDENSER- COMPRESSOR BALANCE LINE
PLOTTED FOR 100°F. AMBIENT

Figure 71



CONDENSER-COMPRESSOR BALANCE LINES FOR VARIOUS AMBIENT TEMPERATURES

Figure 72



SYSTEM BALANCE CHART WITH EVAPORATOR CAPACITY CURVES SUPERIMPOSED ON CONDENSER-COMPRESSOR BALANCE LINES

Figure 73

a condensing temperature 20°F above the specified ambient temperature of 100°F., or 120°F. In a similar manner balance point B can be located by the intersection of the 25°F. TD condenser capacity curve and the compressor capacity curve (estimated) for 125°F. condensing, and balance point C can be located by the intersection of the 15°F. TD condenser capacity curve with the compressor capacity curve (estimated) for 115°F. condensing. The line connecting points A, B, and C represents all the possible balance points when the system is operating with air entering the condenser at a temperature of 100°F. In a similar fashion, condenser-compressor balance lines can be determined for other ambient temperatures, and plotted as shown in Figure 72. (To simplify the illustration, condenser capacity curves have not been shown)

The tentative evaporator coil selected was rated by the manufacturer only in terms of BTU/hr per degree temperature difference between the entering dry bulb temperature and the refrigerant evaporating temperature, and have a capacity of 4,590 BTU/hr/°TD. In Figure 73 evaporator capacity curves have been plotted and superimposed on the compressor capacity curves and the condenser-compressor balance lines. An evaporator capacity curve for each entering air temperature can be constructed by plotting any two points.

Point A represents the evaporator capacity at 14°TD which for an entering air temperature of 40°F. would require a refrigerant evaporating temperature of 26°F. However, an allowance must be made for line friction losses since the pressure in the evaporator will always be higher than the suction pressure at the compressor because of pressure drop in the suction line. Allowing 2°F. as an estimated allowance for line pressure drop, an evaporating temperature of 26°F. would result in a pressure at the compressor equivalent to a saturated evaporating temperature of 24°F. Therefore the capacity of the evaporator for a 14° TD and 40°F. entering air would be plotted at the corresponding compressor capacity at 24°F.

Point B represents the evaporator capacity at 10° TD, which for 40°F. entering air temperature requires a refrigerant evaporating temperature of 30°F., and after allowing for suction line losses, a corresponding compressor capacity at 28°F. A line can then be drawn through these two points, representing all possible capacities of the evaporator with 40°F. entering air and varying refrigerant evaporating temperatures. In a similar fashion, capacity curves can be constructed for other entering air temperatures.

The system performance can now be forecast for any condition of evaporator entering air temperature and ambient temperature. With 100°F. ambient temperature and an evaporator entering air temperature of 40°F., the original design conditions, the system would have a capacity of 59,000 BTU/hr, a compressor suction pressure equivalent to an evaporating temperature of 26°F., and a condensing temperature of 120°F. Even under extreme load conditions of 50°F. entering air and 110°F. ambient, the condensing temperature would not exceed 133°F. These conditions are close enough to the original design requirement to insure satisfactory performance.

This type of graphical analysis can be quickly and easily made by using the compressor specification sheet as the basic chart, and superimposing condenser and evaporator capacity curves.

THE EFFECT OF CHANGE IN COMPRESSOR ONLY ON SYSTEM BALANCE

Occasionally the exact replacement compressor may not be available, and the question arises as to whether an alternate compressor with either more or less capacity might provide satisfactory performance. The graphical balance chart provides a convenient means of forecasting system performance.

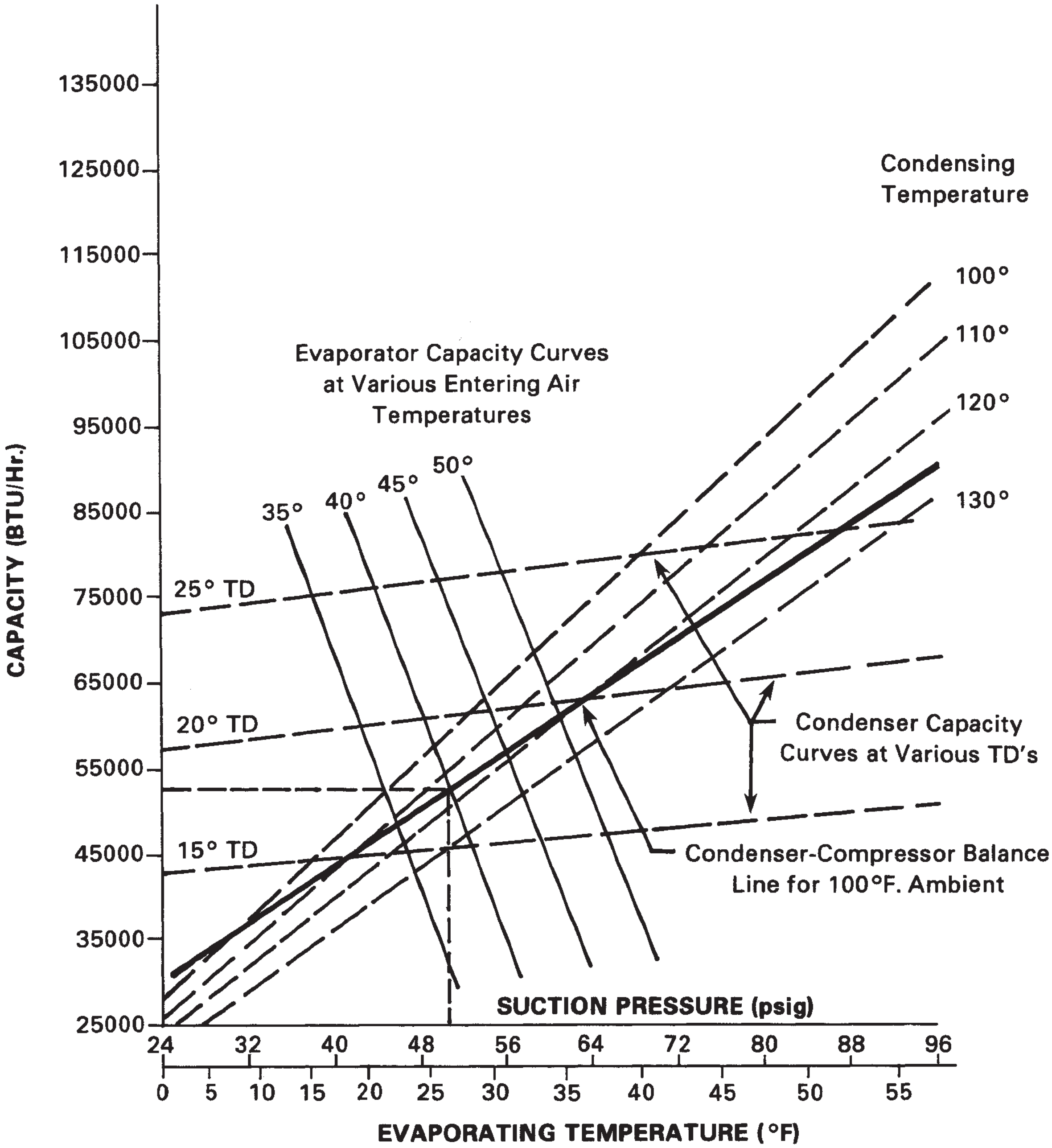
Figure 74 is a revised balance chart for a system utilizing the same evaporator and condenser as in the previous example, but with a compressor having only 5/6 of the previous capacity. New compressor capacity curves for the smaller compressor have been plotted on the same capacity chart used previously. Since there is no change in the basic capacity of the condenser or evaporator, the condenser capacity and evaporator capacity curves are unchanged.

However, a new compressor-condenser balance line must be plotted, and to avoid excessive detail in the illustration, a balance line for 100° ambient temperature only has been shown.

A comparison can now be made between the system with the original compressor, Figure 73, and the system with the smaller compressor, Figure 74.

	Original System	Revised System
Ambient Temperature	100°F.	100°F.
Air Entering Evaporator	40°F.	40°F.
Refrigerant Evaporating Temp.	26°F.	27°F.
Condensing Temperature	120°F.	115°F.
Capacity at 100°F. Ambient and 40°F. Entering Air, BTU/hr.	59,000	53,000

(continued on p. 16-11)



SYSTEM BALANCE CHART WITH COMPRESSOR CHANGED AND ALL OTHER COMPONENTS UNCHANGED

Figure 74

Note that although the compressor capacity was decreased by 1/6 or 16 2/3%, the net system capacity decreased only about 10%. Since the condenser and evaporator were unchanged, the compressor could operate at more efficient conditions, with decreased condensing pressure and increased suction pressure.

The same type of analysis can be applied to determine the effect on system capacity if the compressor on a unit designed for 60 cycle operation is operated on 50 cycle power. However for the evaporator and condenser capacity to remain constant, the air flow across both evaporator and condenser must be unchanged. If the original balance chart was made on the basis of fans operating on 60 cycle power, and the fan air delivery is decreased by operation of the fan motors on 50 cycle power, then both the evaporator and condenser capacity curves must be changed to reflect the decrease in capacity.

Another type of application where this type of analysis may be valuable is on systems with fluctuating loads and compressors with capacity control features. Since the evaporator and condenser remain unchanged, the reduced compressor capacity can be plotted as demonstrated, and new balance points determined, taking into effect any changes in the temperature of the air entering the evaporator.

QUICK SELECTION TABLES FOR WALK-IN COOLERS

The most accurate means of determining the refrigeration load is by calculating each of the factors contributing to the load as was done in the previous example. However, for small walk-in coolers, various types of short cut estimating methods are frequently used.

The transmission load will always be dependent on the external surface, and an actual calculation should be made where possible.

As an aid in rapid selection of a condensing unit for the normal walk-in cooler application, Tables 19 and 20 give recommended refrigeration capacities for various sized coolers. The condensing unit capacity must be equal to or greater than the capacity shown at the required refrigerant evaporating temperature after allowance for the desired evaporating and condensing TD.

The capacities given are for average applications. If the load is unusual, these tables should not be used. The low temperature tables do not include any allowance for a freezing load, and if a product is to be frozen, additional capacity will be required.

Table 18

RECOMMENDED CONDENSING UNIT CAPACITY FOR WALK-IN COOLERS 35° F. TEMPERATURE

9 feet height, 95° F. ambient temperature, 4″ insulation

Outside dimensions ft.	Btu/hr for 16-hr operation		Outside dimensions ft.	Btu/hr for 16-hr operation	
	Average service	Heavy service		Average service	Heavy service
6×5	2,580	3,180	14×10	8,640	10,900
6×6	2,960	3,540	14×12	9,720	12,300
7×5	2,930	3,540	14×14	10,800	13,700
7×6	3,380	4,080	16×8	8,140	10,000
7×7	3,790	4,620	16×10	9,340	12,000
8×5	3,240	3,920	16×12	10,700	13,450
8×6	3,710	4,530	16×14	12,000	15,000
8×7	4,200	5,170	16×16	13,100	16,600
8×8	4,680	5,680	18×10	10,300	13,000
9×6	4,080	4,960	18×12	11,700	14,800
9×7	4,600	5,640	18×14	13,100	16,400
9×8	5,080	6,260	18×16	14,400	17,400
9×9	5,580	6,920	18×18	15,800	19,600
10×6	4,450	5,450	20×10	11,300	13,700
10×7	5,010	6,200	20×12	12,800	15,700
10×8	5,520	6,880	20×14	14,300	17,600
10×9	6,080	7,520	20×16	15,600	19,400
10×10	6,630	8,150	20×18	17,000	21,100
11×6	4,820	5,910	20×20	18,700	22,700
11×7	5,380	6,630	22×12	13,700	17,100
11×8	6,000	7,350	22×14	15,300	18,900
11×9	6,520	8,050	22×16	16,800	20,800
11×10	7,100	8,800	22×18	18,300	22,000
12×6	5,150	6,350	24×12	14,700	18,200
12×8	6,400	7,700	24×14	16,200	20,300
12×10	7,590	9,380	24×16	17,300	22,100
12×12	8,800	10,800	24×18	19,300	24,000
14×8	7,300	9,050			

Note: Heat gain based on insulation with "K" factor of .25. Required capacity must be corrected for different "K" factor, or different thickness of insulation.

Table 19

RECOMMENDED CONDENSING UNIT CAPACITY FOR WALK-IN COOLERS LOW TEMPERATURE

9 feet height, 90° F. ambient temperature

Outside Dimensions in Feet		BTU/hr FOR 18 HOUR OPERATION		
Length	Width	—20° F. Storage 8″ Insulation	—10° F. Storage 6″ Insulation	0° F. Storage 6″ Insulation
6	6	4,000	4,500	3,750
6	10	5,700	5,800	5,050
7	7	5,000	5,300	4,650
7	10	6,400	6,450	5,800
8	8	5,900	6,200	5,500
8	12	7,200	7,650	7,000
9	9	6,700	7,000	6,300
10	10	7,600	7,900	7,100
10	14	9,200	9,600	8,700
12	12	9,400	9,900	9,600
12	16	11,300	11,800	10,900
14	14	11,400	12,000	11,200
14	18	13,300	13,900	12,700
16	16	13,400	14,000	12,900
16	20	15,100	16,000	14,900
18	18	15,200	16,100	15,000
18	20	16,100	17,200	15,600
20	20	16,800	18,400	16,600

Note: Heat gain based on insulation with "K" factor of .25. Required capacity must be corrected for different "K" factor, or different thickness of insulation.

FAHRENHEIT - CENTIGRADE TEMPERATURE CONVERSION CHART

The numbers in bold-face type in the center column refer to the temperature, either in Centigrade or Fahrenheit, which is to be converted to the other scale. If converting Fahrenheit to Centigrade, the equivalent temperature will be found in the left column. If converting Centigrade to Fahrenheit, the equivalent temperature will be found in the column on the right.

Temperature			Temperature			Temperature			Temperature		
Cent.	C or F	Fahr	Cent.	C or F	Fahr	Cent.	C or F	Fahr	Cent.	C or F	Fahr
−40.0	**−40**	−40.0	−6.7	**+20**	+68.0	+26.7	**+80**	+176.0	+60.0	**+140**	+284.0
−39.4	**−39**	−38.2	−6.1	**+21**	+69.8	+27.2	**+81**	+177.8	+60.6	**+141**	+285.8
−38.9	**−38**	−36.4	−5.5	**+22**	+71.6	+27.8	**+82**	+179.6	+61.1	**+142**	+287.6
−38.3	**−37**	−34.6	−5.0	**+23**	+73.4	+28.3	**+83**	+181.4	+61.7	**+143**	+289.4
−37.8	**−36**	−32.8	−4.4	**+24**	+75.2	+28.9	**+84**	+183.2	+62.2	**+144**	+291.2
−37.2	**−35**	−31.0	−3.9	**+25**	+77.0	+29.4	**+85**	+185.0	+62.8	**+145**	+293.0
−36.7	**−34**	−29.2	−3.3	**+26**	+78.8	+30.0	**+86**	+186.8	+63.3	**+146**	+294.8
−36.1	**−33**	−27.4	−2.8	**+27**	+80.6	+30.6	**+87**	+188.6	+63.9	**+147**	+296.6
−35.6	**−32**	−25.6	−2.2	**+28**	+82.4	+31.1	**+88**	+190.4	+64.4	**+148**	+298.4
−35.0	**−31**	−23.8	−1.7	**+29**	+84.2	+31.7	**+89**	+192.2	+65.0	**+149**	+300.2
−34.4	**−30**	−22.0	−1.1	**+30**	+86.0	+32.2	**+90**	+194.0	+65.6	**+150**	+302.0
−33.9	**−29**	−20.2	−0.6	**+31**	+87.8	+32.8	**+91**	+195.8	+66.1	**+151**	+303.8
−33.3	**−28**	−18.4	.0	**+32**	+89.6	+33.3	**+92**	+197.6	+66.7	**+152**	+305.6
−32.8	**−27**	−16.6	+0.6	**+33**	+91.4	+33.9	**+93**	+199.4	+67.2	**+153**	+307.4
−32.2	**−26**	−14.8	+1.1	**+34**	+93.2	+34.4	**+94**	+201.2	+67.8	**+154**	+309.2
−31.7	**−25**	−13.0	+1.7	**+35**	+95.0	+35.0	**+95**	+203.0	+68.3	**+155**	+311.0
−31.1	**−24**	−11.2	+2.2	**+36**	+96.8	+35.6	**+96**	+204.8	+68.9	**+156**	+312.8
−30.6	**−23**	−9.4	+2.8	**+37**	+98.6	+36.1	**+97**	+206.6	+69.4	**+157**	+314.6
−30.0	**−22**	−7.6	+3.3	**+38**	+100.4	+36.7	**+98**	+208.4	+70.0	**+158**	+316.4
−29.4	**−21**	−5.8	+3.9	**+39**	+102.2	+37.2	**+99**	+210.2	+70.6	**+159**	+318.2
−28.9	**−20**	−4.0	+4.4	**+40**	+104.0	+37.8	**+100**	+212.0	+71.1	**+160**	+320.0
−28.3	**−19**	−2.2	+5.0	**+41**	+105.8	+38.3	**+101**	+213.8	+71.7	**+161**	+321.8
−27.8	**−18**	−0.4	+5.5	**+42**	+107.6	+38.9	**+102**	+215.6	+72.2	**+162**	+323.6
−27.2	**−17**	+1.4	+6.1	**+43**	+109.4	+39.4	**+103**	+217.4	+72.8	**+163**	+325.4
−26.7	**−16**	+3.2	+6.7	**+44**	+111.2	+40.0	**+104**	+219.2	+73.3	**+164**	+327.2
−26.1	**−15**	+5.0	+7.2	**+45**	+113.0	+40.6	**+105**	+221.0	+73.9	**+165**	+329.0
−25.6	**−14**	+6.8	+7.8	**+46**	+114.8	+41.1	**+106**	+222.8	+74.4	**+166**	+330.8
−25.0	**−13**	+8.6	+8.3	**+47**	+116.6	+41.7	**+107**	+224.6	+75.0	**+167**	+332.6
−24.4	**−12**	+10.4	+8.9	**+48**	+118.4	+42.2	**+108**	+226.4	+75.6	**+168**	+334.4
−23.9	**−11**	+12.2	+9.4	**+49**	+120.2	+42.8	**+109**	+228.2	+76.1	**+169**	+336.2
−23.3	**−10**	+14.0	+10.0	**+50**	+122.0	+43.3	**+110**	+230.0	+76.7	**+170**	+338.0
−22.8	**−9**	+15.8	+10.6	**+51**	+123.8	+43.9	**+111**	+231.8	+77.2	**+171**	+339.8
−22.2	**−8**	+17.6	+11.1	**+52**	+125.6	+44.4	**+112**	+233.6	+77.8	**+172**	+341.6
−21.7	**−7**	+19.4	+11.7	**+53**	+127.4	+45.0	**+113**	+235.4	+78.3	**+173**	+343.4
−21.1	**−6**	+21.2	+12.2	**+54**	+129.2	+45.6	**+114**	+237.2	+78.9	**+174**	+345.2
−20.6	**−5**	+23.0	+12.8	**+55**	+131.0	+46.1	**+115**	+239.0	+79.4	**+175**	+347.0
−20.0	**−4**	+24.8	+13.3	**+56**	+132.8	+46.7	**+116**	+240.8	+80.0	**+176**	+348.8
−19.4	**−3**	+26.6	+13.9	**+57**	+134.6	+47.2	**+117**	+242.6	+80.6	**+177**	+350.6
−18.9	**−2**	+28.4	+14.4	**+58**	+136.4	+47.8	**+118**	+244.4	+81.1	**+178**	+352.4
−18.3	**−1**	+30.2	+15.0	**+59**	+138.2	+48.3	**+119**	+246.2	+81.7	**+179**	+354.2
−17.8	**0**	+32.0	+15.6	**+60**	+140.0	+48.9	**+120**	+248.0	+82.2	**+180**	+356.0
−17.2	**+1**	+33.8	+16.1	**+61**	+141.8	+49.4	**+121**	+249.8	+82.8	**+181**	+357.8
−16.7	**+2**	+35.6	+16.7	**+62**	+143.6	+50.0	**+122**	+251.6	+83.3	**+182**	+359.6
−16.1	**+3**	+37.4	+17.2	**+63**	+145.4	+50.6	**+123**	+253.4	+83.9	**+183**	+361.4
−15.6	**+4**	+39.2	+17.8	**+64**	+147.2	+51.1	**+124**	+255.2	+84.4	**+184**	+363.2
−15.0	**+5**	+41.0	+18.3	**+65**	+149.0	+51.7	**+125**	+257.0	+85.0	**+185**	+365.0
−14.4	**+6**	+42.8	+18.9	**+66**	+150.8	+52.2	**+126**	+258.8	+85.6	**+186**	+366.8
−13.9	**+7**	+44.6	+19.4	**+67**	+152.6	+52.8	**+127**	+260.6	+86.1	**+187**	+368.6
−13.3	**+8**	+46.4	+20.0	**+68**	+154.4	+53.3	**+128**	+262.4	+86.7	**+188**	+370.4
−12.8	**+9**	+48.2	+20.6	**+69**	+156.2	+53.9	**+129**	+264.2	+87.2	**+189**	+372.2
−12.2	**+10**	+50.0	+21.1	**+70**	+158.0	+54.4	**+130**	+266.0	+87.8	**+190**	+374.0
−11.7	**+11**	+51.8	+21.7	**+71**	+159.8	+55.0	**+131**	+267.8	+88.3	**+191**	+375.8
−11.1	**+12**	+53.6	+22.2	**+72**	+161.6	+55.6	**+132**	+269.6	+88.9	**+192**	+377.6
−10.6	**+13**	+55.4	+22.8	**+73**	+163.4	+56.1	**+133**	+271.4	+89.4	**+193**	+379.4
−10.0	**+14**	+57.2	+23.3	**+74**	+165.2	+56.7	**+134**	+273.2	+90.0	**+194**	+381.2
−9.4	**+15**	+59.0	+23.9	**+75**	+167.0	+57.2	**+135**	+275.0	+90.6	**+195**	+383.0
−8.9	**+16**	+60.8	+24.4	**+76**	+168.8	+57.8	**+136**	+276.8	+91.1	**+196**	+384.8
−8.3	**+17**	+62.6	+25.0	**+77**	+170.6	+58.3	**+137**	+278.6	+91.7	**+197**	+386.6
−7.8	**+18**	+64.4	+25.6	**+78**	+172.4	+58.9	**+138**	+280.4	+92.2	**+198**	+388.4
−7.2	**+19**	+66.2	+26.1	**+79**	+174.2	+59.4	**+139**	+282.2	+92.8	**+199**	+390.2

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