

RETAIL FOOD STORE REFRIGERATION AND EQUIPMENT

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IN the United States today, over 100,000 retail food stores operate their refrigeration systems around the clock to ensure proper merchandizing and safety of their food products. [Figure 1](#) shows that supermarkets and convenient stores make the largest contribution to this total (Food Marketing Institute 2000). As shown in [Figure 2](#), refrigeration accounts for roughly 50% of the electric energy consumption of a typical supermarket (A.D. Little 1996). Supermarkets and grocery stores have one of the highest electric usage intensities in commercial buildings, at 1650 MJ/m² per year. Use for larger supermarkets with long operating hours has been measured at 2710 MJ/m² per year (Komor et al. 1998).

The modern retail food store is a high-volume sales outlet with maximum inventory turnover. Almost half of retail food sales are of perishable or semiperishable foods requiring refrigeration. These

foods include fresh meats, dairy products, perishable produce, frozen foods, ice cream and frozen desserts, and various special items such as bakery and deli products and prepared meals. These foods are displayed in highly specialized and flexible storage, handling, and display apparatus.

These food products must be kept at safe temperatures during transportation, storage, and processing, as well as during display. The back room of a food store is both a processing plant and a warehouse distribution point. It includes specialized refrigerated rooms, which must be coordinated during construction planning because of the interaction between the store's environment and the refrigeration equipment. [Chapter 2 of the ASHRAE Handbook—Applications](#) also covers the importance of coordination.

Refrigeration equipment used in retail food stores may be broadly grouped into display refrigerators, storage refrigerators, processing refrigerators, and mechanical refrigeration machines. [Chapter 48](#) presents food service and general commercial refrigeration equipment.

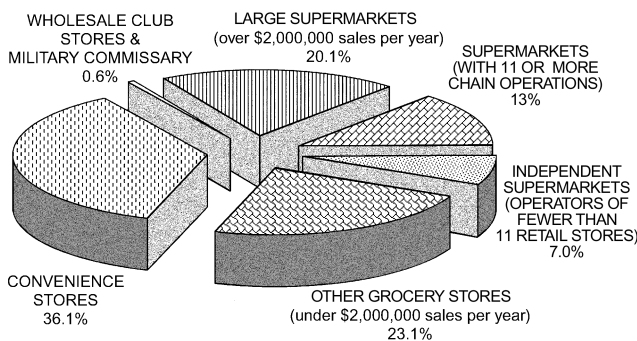


Fig. 1 Percentage of Stores, by Segment, Comprising Total Retail Food Sector

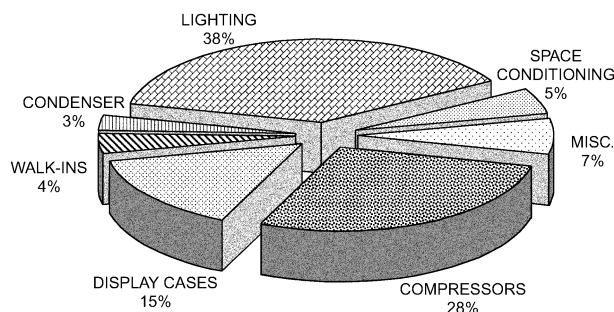


Fig. 2 Percentage of Electric Energy Consumption, by Use Category, of a Typical Large Supermarket

DISPLAY REFRIGERATORS

Each category of perishable food has its own physical characteristics, handling logistics, and display requirements that dictate specialized display shapes and flexibility required for merchandising. Also, the same food product requires different display treatment in different locations, depending on such things as local preferences, local income level, store size, sales volume, and local availability of food items by type.

Open display refrigerators for medium and low temperatures are widely used in food markets. However, glass door multideck models have also rapidly gained in popularity. Decks are shelves, pans, or racks that support the displayed product.

Medium- and low-temperature display case lineups account for roughly 68 and 32%, respectively, of a typical supermarket's total display cases ([Figure 3](#)). In addition, open vertical meat, deli, and

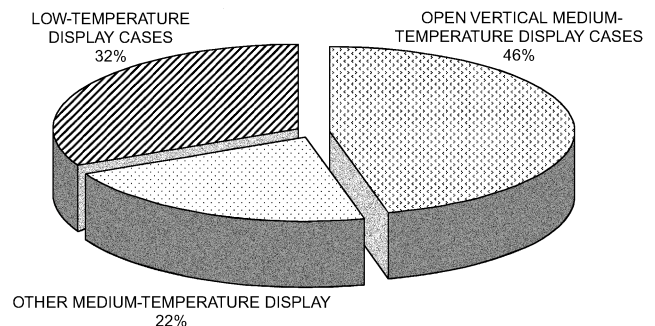


Fig. 3 Percentage Distribution of Display Cases, by Type, in a Typical Supermarket

The preparation of this chapter is assigned to TC 10.7, Commercial Food and Beverage Cooling, Display, and Storage.

dairy cases comprise about 46% of the total medium-temperature display cases (Faramarzi 2000).

Many operators combine single-deck and multideck models in most departments where perishables are displayed and sold. Closed-service refrigerators are used to display unwrapped fresh meat, delicatessen food, and, frequently, fish on crushed ice supplemented by mechanical refrigeration. A store employee assists the customer by obtaining product out of the service-type case. More complex layouts of display refrigerators have been developed as new or remodeled stores strive to be distinctive and more attractive. Refrigerators are allocated in relation to expected sales volume in each department. Thus, floor space is allocated to provide balanced stocking of merchandise and smooth flow of traffic in relation to expected peak volume periods.

Small stores accommodate a wide variety of merchandise in limited floor space. Thus, managers of these stores want to display more quantity and variety of merchandise in the available floor space. The concentration of large refrigeration loads in a small space makes year-round space temperature and humidity control essential.

Product Temperatures

Display refrigerators are designed to merchandise food to maximum advantage while providing short-term (24 to 72 h) protection. The proper maintenance of product temperature plays a critical role in food safety. Each year in the United States, there are an estimated 16,000 deaths and more than 25 million illnesses attributed to food-borne diseases. As a result, in 1993 the Food and Drug Administration (FDA) *Food Code* recommended a lowered storage temperature

Table 1 Air Temperatures in Display Refrigerators

Type of Fixture	Air Discharge Temperatures, °C ^a	
	Minimum	Maximum
Dairy		
Multideck	1.1	3.3
Produce, packaged		
Single-deck	1.7	3.3
Multideck	1.7	3.3
Meat, unwrapped (closed display)		
Display area	2.2 ^b	3.3 ^b
Deli smoked meat		
Multideck	0	2.2
Meat, wrapped (open display)		
Single-deck	−4.5	−3.3
Multideck	−4.5	−3.3
Frozen food		
Single-deck	^c	−25 ^c
Multideck, open	^c	−23 ^c
Glass door reach-in	^c	−20 ^c
Ice cream		
Single-deck	^c	−31 ^c
Glass door reach-in	^c	−25 ^c

^aThese air temperatures are measured with the thermometer in the outlet of the refrigerated airstream and not in contact with the product displayed.

^bUnwrapped fresh meat should only be displayed in a closed, service-type display case. The meat should be cooled to 2.2°C internal temperature prior to placing on display. The case air temperature should be adjusted to keep the internal meat temperature at 2.2°C or lower for minimum dehydration and optimum display life. Display case air temperature varies with manufacturer.

^cMinimum temperatures for frozen foods and ice cream are not critical (except for energy conservation); maximum temperature is important for proper preservation of product quality. The differences in display temperatures among the three different styles of frozen food and ice cream display cases are due to the orientation of the refrigeration air curtain and the size and style of the opening. The single-deck case has a horizontal air curtain and opening of approximately 760 to 1070 mm. The multideck, open case has a vertical air curtain and an opening of about 1070 to 1270 mm. The glass door reach-in case has a vertical air curtain protected by a multiple-pane insulated glass door.

for certain refrigerated food products for further prevention of food-borne diseases. The FDA 1993 *Food Code* requires that the core temperature of meat, poultry, fish, dairy, deli, and cut produce be lowered from 7 to 5°C throughout packaging, shipping, receiving, loading, and storing (FDA 1995).

Proper maintenance of product temperature relies heavily on the temperature of air discharged into the case. [Table 1](#) lists discharge air temperatures in various display refrigerators. Compliance with FDA requirements may require different case air temperatures from those listed in [Table 1](#). [Figure 4](#) depicts a relationship between discharge air, return air, and average product temperatures for an open vertical meat display case. These profiles were obtained from controlled tests conducted over a 24 h period. Discharge and return air temperatures were measured at the air grille. As shown, all temperatures reach their peak at the end of each of four defrosts (Faramarzi 2001).

The product temperatures inside a display case may also vary depending on the location of the product. [Figure 5](#) depicts product temperature profiles and variations for an open vertical meat display case over a period of 24 h. As shown, the lowest product temperatures observed at the top shelf near the discharge air grille, and the highest product temperatures are at the bottom shelf near the return air grille (Gas Research Institute 2000).

Display refrigerators are not designed to cool the product; they are designed to maintain product temperature. The merchandise, when put into the case, should be at or near the proper temperature. Food placed directly into the refrigerator or into another adequately refrigerated storage space on delivery to the store should come from properly refrigerated trucks. Little or no delay in transferring perishables from storage or trucks to the display refrigerator or storage space should be permitted.

Display refrigerators should be loaded properly. The product on display should never be piled so high that it is out of the refrigerated zone or be stacked so that circulation of refrigerated air is blocked. The load line recommendations of the manufacturer must be followed to obtain good refrigeration performance. Proper refrigerator design and loading minimize energy use, maximize the efficiency of the refrigeration equipment, and minimize product loss.

In actual applications, however, products may not always be loaded properly. Survey results reveal that improper loading of products inside display cases may fall into the following categories:

- Blocked return air (products block the return air grille)
- Overloading (products piled beyond the limit lines)
- Cavities (products loaded nonuniformly leaving empty spots on the shelves)
- Blocked air curtain (products suspended in the path of air curtain)
- Extreme (combination of blocked return air, blocked air curtain, and overloading)

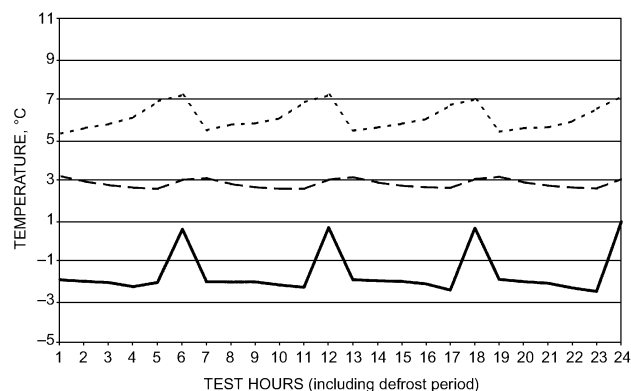


Fig. 4 Selected Temperatures in an Open Vertical Meat Display Case

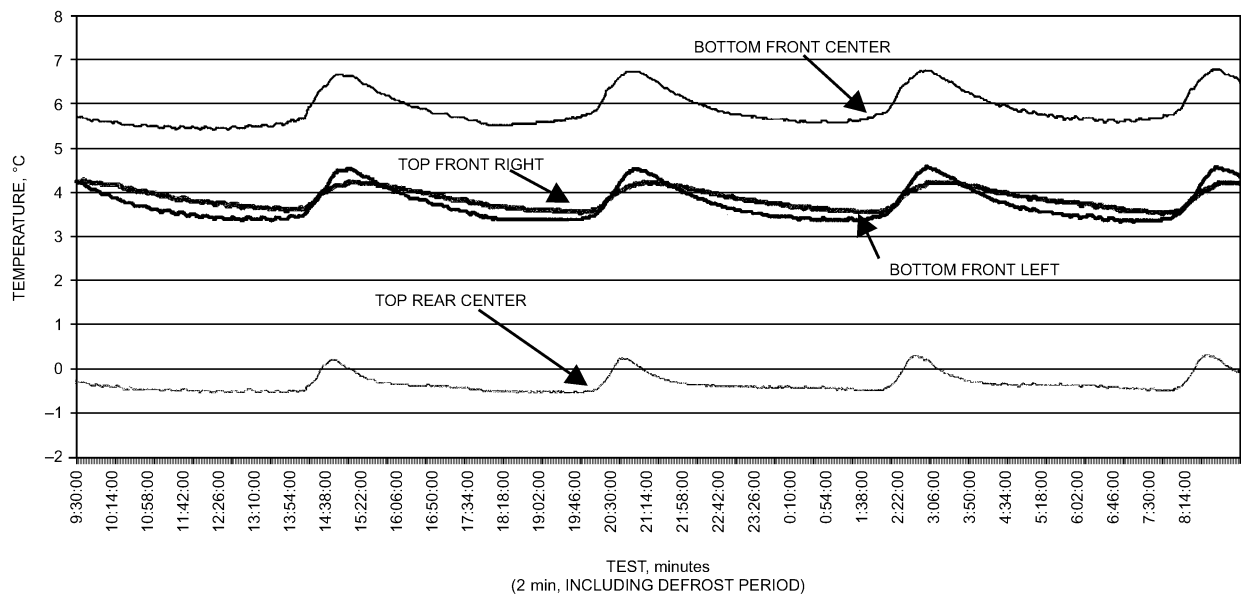


Fig. 5 Product Temperature Profiles at Four Different Locations Inside a Multideck Meat Case (Average Discharge Air Temperature of -2°C)

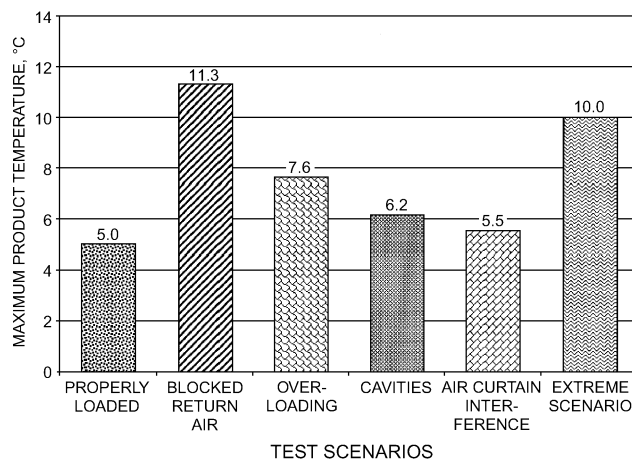


Fig. 6 Comparison of Maximum Product Temperature Variations Under Different Improper Product Loading Scenarios in an Open Vertical Meat Display Case

Improper loading of the products can significantly impact maximum product temperatures, which adversely affects food safety and product loss. [Figure 6](#) depicts the adverse impact of various improper product-loading scenarios on maximum product temperature of an open vertical meat display case (Faramarzi 2001).

Additionally, packaging may also affect food temperatures. The product surface temperature of a loosely wrapped package of meat with an air space between the film and surface may be 1 to 2 K above the ambient temperature. This is called the greenhouse effect.

Store Ambient Effect

The performance of display fixtures is affected significantly by the temperature, humidity, and movement of surrounding air. These display cases are designed primarily for supermarkets, virtually all of which are air conditioned.

[Table 2](#) summarizes a study of ambient conditions in retail food stores. Individual store ambient readings showed that only 5% of all readings (including those when the air conditioning was not

Table 2 Average Store Conditions in the United States

Season	Dry Bulb, $^{\circ}\text{C}$	Wet Bulb, $^{\circ}\text{C}$	Grams Moisture per Kilogram Dry Air	rh, %
Winter	20.6	12.2	5.4	36
Spring	21.1	14.4	7.9	50
Summer	21.7	16.1	9.1	56
Fall	21.1	14.4	7.9	50

Store Conditions Survey conducted by Commercial Refrigerator Manufacturers' Association from December 1965 to March 1967. Approximately 2000 store readings in all parts of the country, in all types of stores, during all months of the year reflected the above ambient store conditions.

working or not turned on) exceeded 24°C dry bulb or 10.2 g of moisture per kilogram of dry air. Based on these data, the industry has chosen 24°C dry bulb and 18°C wet bulb (55% rh, 14.2°C dew point) as summer design conditions. This is the ambient condition at which refrigeration load for food store display cases is normally rated.

Store humidity is one of the most critical variables that can affect the performance of display cases and refrigeration systems. Store relative humidity may depend on climatic location, seasonal changes, and most importantly, on the store dehumidification or HVAC system.

[Figure 7](#) shows an example of the relationship between case condensate and relative humidity. The increase in frost accumulation on the evaporator coils, and consequent increase in condensate weight, is more drastic for open vertical display cases. In other words, open vertical fixtures demonstrate more vulnerability to humidity variations and remove more moisture from the ambient (or store) air than other types of display cases (Gas Research Institute 2000).

Increased frost formation from higher relative humidities causes an increase in the latent load, which the refrigeration system must remove ([Figure 8](#)). The cases may also require additional defrosts to maintain the product at its desired temperature.

When store ambient relative humidity is different from that at which the cases were rated, the energy requirements for case operation will vary. Howell (1993a, 1993b) concludes that, compared to operation at 55% store rh, display case energy savings at 35% rh range from 5% for glass door reach-in cases to 29% for multideck

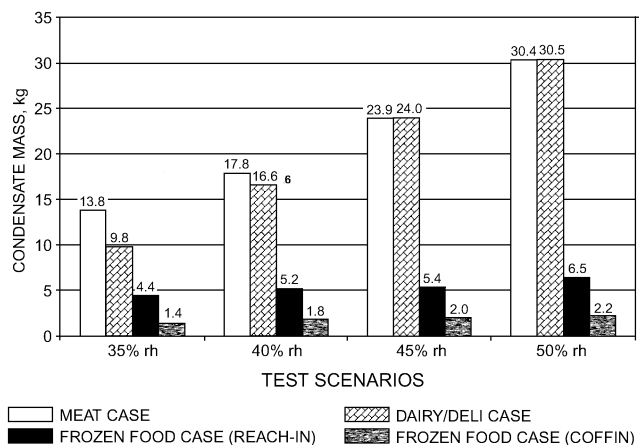


Fig. 7 Comparison of Collected Condensate vs. Relative Humidity for Open Vertical Meat, Open Vertical Dairy/Deli, Narrow Island Coffin, and Glass Door Reach-In Display Cases

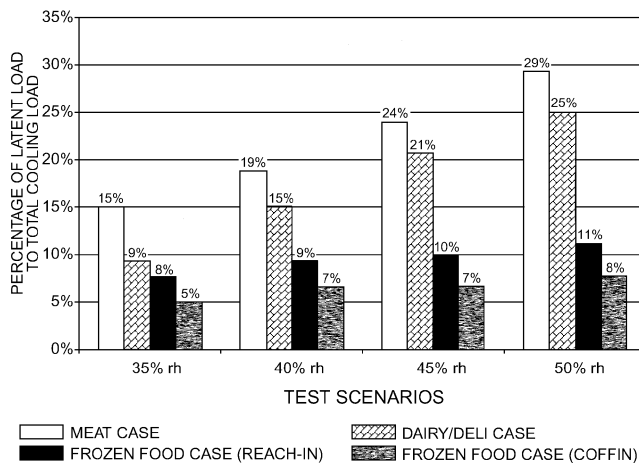


Fig. 8 Percentage of Latent Load to Total Cooling Load at Different Indoor Relative Humidities
(Gas Research Institute 2000)

Table 3 Relative Refrigeration Requirements with Varying Store Ambient Conditions

Case Model	21°C Dry-Bulb Relative Humidity, %					26°C Dry-Bulb Relative Humidity, %		
	30	40	55	60	70	50	55	65
Multideck dairy	0.90	0.95	1.00	1.08 ^a	1.18 ^b	0.99	1.08 ^a	1.18 ^b
Multideck low-temperature	0.90	0.95	1.00	1.08 ^a	1.18 ^b	0.99	1.08 ^a	1.18 ^b
Single-deck low-temperature	0.90	0.95	1.00	1.08 ^a	1.15	0.99	1.05	1.15
Single-deck red meat	0.90	0.95	1.00	1.08 ^a	1.15	0.99	1.05	1.15
Multideck red meat	0.90	0.95	1.00	1.08 ^a	1.18 ^b	0.99	1.08 ^a	1.18 ^b
Low-temperature reach-in	0.90	0.95	1.00	1.05 ^a	1.10	0.99	1.05 ^a	1.10

Note: Package warm-up may be more than indicated. Standard flood lamps are clear PAR 38 and R-40 types.

^aMore frequent defrosts required.

^bMore frequent defrosts required plus internal condensation (not recommended).

deli cases. Table 3 lists correction factors for the effect of store relative humidity on display case refrigeration requirements when the dry-bulb temperature is 21 and 26°C.

Manufacturers sometimes publish ratings for open refrigerators at lower ambient conditions than the standard because the milder conditions may significantly reduce the cooling load on the refrigerators. In addition, lower ambient conditions may permit both reductions in antisweat heaters and fewer defrosts, allowing substantial energy savings on a complete store basis.

The application engineer needs to verify that the year-round store ambient conditions are within the performance ratings of the various cases selected for the store. Because relative humidity varies throughout the year, the dew point for each period should be analyzed. The sum of these case energy requirements provides the total annual energy consumption. In a store designed for a maximum relative humidity of 55%, the air-conditioning system will dehumidify only when the relative humidity exceeds 55%.

In climates where the outdoor air temperature is low in winter, infiltration of outdoor air and mechanical ventilation can cause store humidity to drop below 55% rh. Separate calculations need to be done for periods during which mechanical dehumidification is used and periods when it is not required. For example, in Boston, Massachusetts, mechanical dehumidification is required for only about 3-1/2 months of the year, while in Jacksonville, Florida, it is required for almost 7-1/2 months of the year. Also, in Boston, there are 8-1/2 months when the store relative humidity is below 40%, while Jacksonville has these conditions for only 4-1/2 months. The engineer must weigh the savings at lower relative humidity against the cost of the mechanical equipment required to maintain relative store humidity levels at, for example, below 40% instead of 55%.

Additional savings can be achieved by controlling antisweat heaters and reducing defrost frequency at ambient relative humidities below 55%. Energy savings credit for reduced use of display case antisweat heaters can only be taken if the display cases are equipped with humidity-sensing controls that reduce the amount of power supplied to the heaters as the store dew point decreases. Also, defrost savings can be considered when defrost frequency or duration is reduced. Controls can reduce the frequency of defrost as the store relative humidity decreases. Individual manufacturers give specific antisweat and defrost values for their equipment at stated store conditions. Less defrosting is needed as store dew point temperature or humidity decreases from the design conditions.

Attention should also be given to the condition in which store dry-bulb temperatures are higher than the industry standard since this raises the refrigeration requirements and consequently the energy demand.

Display Case Cooling Load and Heat Sources

The heat transfer in a display case involves interactions between the product and the internal environment of the case, as well as heat from the surroundings that enters the case. Heat components from the surrounding environment include transmission (or conduction), radiation, and infiltration. Heat components from the internal environment include lights and evaporator fan motor. In addition, defrost and antisweat heaters also increase the cooling load of a display case. Conduction, radiation, and infiltration loads from the surroundings into the case, as well as heat exchanges between the product and parts of the case, depend on the temperatures of the ambient air and the air within the case. Open vertical display cases rely on their air curtains to keep warm ambient air from penetrating into the cold environment inside the case. An air curtain consists of a stream of air discharged from a series of small nozzles through a honeycombed baffle at the top of the display case. Air curtains play a significant role in the thermal interaction of the display case with the surrounding air (Faramarzi 1999).

The cooling load of a typical display case has both sensible and latent components. In general, the sensible portion consists of heat

gain from lights, fan motor(s), defrost (electric and hot gas), anti-sweat heater, conduction, radiation, infiltration, and product pull-down load. The latent portion consists of infiltration and product latent heat of respiration.

Conduction Load. The conduction load refers to the transmission of heat through the physical envelope of the display case. The temperature difference between the air in the room and the air inside the case is the main driving force for this heat transfer.

Radiation Load. The heat gain of the display case through radiation is a function of the conditions inside the case, including surface temperature, surface emissivity, surface area, view factor with respect to the surrounding (store) walls/objects, floor, ceiling, and their corresponding emissivities and areas.

Infiltration Load. The infiltration load of the display case refers to the entrainment of warm, moist air through the case air curtain into the refrigerated space. The infiltration load has two components—sensible and latent. The total performance of the air curtain and the amount of heat transferred across it may depend on several factors, including

- Air curtain velocity and temperature profile
- Number of jets
- Air jet width and thickness
- Dimensional characteristics of the discharge air honeycomb
- Store and display case temperatures and humidity ratios
- Rate of air curtain agitation due to shopper walking by
- Thermo-fluid boundary condition in the initial region of the jet

Sensible Infiltration. The sensible portion of infiltration refers to the direct temperature-driven heat added to the display case.

Latent Infiltration. The latent portion of infiltration refers to the heat content of the moisture added to the case by the room air drawn into the case through the air curtain.

Internal Loads. The display case internal load includes the heat from the case lights and the evaporator fan motors. The lamps, ballasts, and fan motors are typically located within the thermodynamic boundary of the display case; therefore, their total heat dissipation should be considered part of the case load. High-intensity lighting raises product temperatures, as shown in Figure 9 and can discolor meats. Case shelf ballasts are sometimes located out of the refrigerated space to reduce case cooling load. The standard lighting equipment, which typically consists of T12 fluorescent lamps with magnetic ballast, draws approximately 0.73 A at 120 V. The more efficient lamps (T8 fluorescent lamps with electronic ballast) draw only 0.49 A at 120 V. As a result, less heat is introduced into the refrigerated space by the efficient lamps and ballast, which in turn

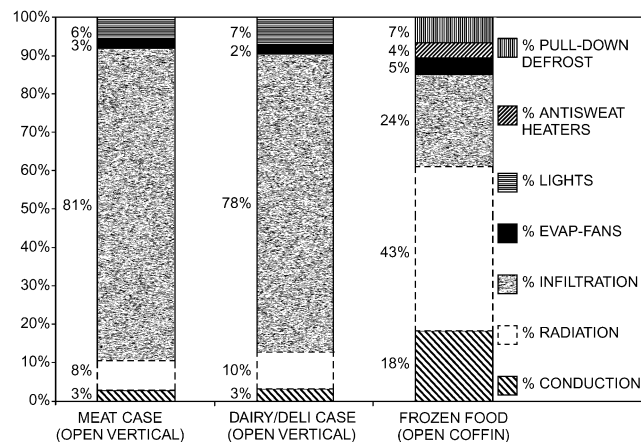


Fig. 9 Components of Refrigeration Load for Several Display Case Designs at 24°C Dry Bulb and 55% Relative Humidity

reduces the case cooling load and improves maintenance of target product temperature. Energy-efficient evaporator fan motors such as electronically commutated motors (ECMs), consume about half the power of standard shaded-pole motors, and dissipate less heat into the refrigerated case (Faramarzi and Kemp 1999).

Defrost Load. Refrigeration equipment in applications where frost can accumulate on the evaporator coils have some type of defrost mechanism. During defrost, refrigeration compressors are turned off, and heat is introduced into the case. Defrost methods vary depending on the refrigeration application and storage temperatures. These are discussed in the section Methods of Defrost. Some defrost methods deliver more heat than needed to melt the ice. A large portion of the extra heat warms the coil metal and the case. This extra heat adds to the refrigeration load, and is called the post-defrost pulldown load (Faramarzi 1999a).

Antisweat Heaters (ASH) Load. The antisweat heater load refers to the portion of the electrical load of the ASH that ends up as sensible heat inside the case. Antisweat heaters are used on most low temperature open display cases as well as reach-in cases with glass doors. These electric resistance heaters are located around the case handrails of tub cases and door frame/mullions of reach-in cases to prevent condensation on metal surfaces. They also reduce fogging of the glass doors of reach-in cases, a phenomenon that can hurt product merchandising. In the absence of appropriate control systems, ASH units stay on round-the-clock. The cooling load contribution of ASH in a typical reach-in display case can reach 35% of their connected electric load (Faramarzi et al. 2001).

Pulldown Load. The pulldown load has two components (Faramarzi 1999):

- Product shelving load. Pulldown load due to product shelving comes from delivering products into the case at a temperature higher than the designated storage temperature. It is the amount of cooling required to lower the product temperature to a desired target point.
- Post defrost load. During the defrost cycle the temperature of the product inside the case rises. Once the defrost is complete, the refrigeration system turns on and must remove the accumulated defrost heat and lower the product temperature to a desirable setpoint. This removal of defrost heat in order to lower the product temperature to a desired target point is referred to as post defrost load.

According to a test report by Gas Research Institute (2000), the major contributor to the total cooling load of open display cases are infiltration and radiation (Figure 10). Infiltration constitutes approximately 80% of the cooling load of a typical medium temperature open vertical display case. The relative role of infiltration diminishes for the low temperature open coffin (or tub) case while radiation takes over. Infiltration and radiation constitute roughly 24 and 43%, respectively, of the cooling load of a typical open coffin case.

As shown in Figure 9, infiltration through the air curtain plays a significant role in the cooling load of open vertical display cases. Figure 10 depicts the air curtain velocity streamlines of a 2.4 m open vertical meat display case. These velocity streamlines represent the actual airflow patterns using a sophisticated visualization technique. As shown, the entrainment of warm air into the display case takes place at several locations along the plane of the air curtain. Based on the law of conservation of mass, an equal (and substantial) amount of cold air from the display case spills into the room near the return air grille of the fixture (Faramarzi 1999).

Refrigerator Construction

Commercial refrigerators for market installations are usually of the endless construction type, which allows a continuous display as refrigerators are joined. Clear plastic panels are often used to separate case interiors when adjacent cases are connected to different

refrigeration circuits. Separate end sections are provided for the first and last units in a continuous display. Methods of joining self-service refrigerators vary, but they are usually bolted or cam locked together.

All refrigerators are constructed with surface zones of transition between the refrigerated area and the room atmosphere. Thermal breaks of various designs separate the zones to minimize the amount of refrigerator surface that is below the dew point. Surfaces that may be below the dew point include (1) in front of discharge air nozzles, (2) the nose of the shelving, and (3) the front rails or center flue of the refrigerator. In glass door reach-in freezers or medium-temperature refrigerators, the frame jambs and the glass can be below the dew point. In these locations, resistance heat is used effectively to raise the exterior surface temperature above the dew point to prevent accumulation of condensation.

With the current emphasis on energy efficiency, designers have developed means other than resistance heat to raise the surface temperatures above the dew point. However, when no other technique is known, resistance heating becomes a necessity. Control by cycling and/or proportional controllers to vary heat with store ambient changes can reduce energy consumption.

Store designers can do a great deal to promote energy efficiency. Not only does controlling the atmosphere within a store reduce the refrigeration requirements, it also reduces the need to heat the surfaces of refrigerators. This heat not only consumes energy; it also places added demand on the refrigeration load.

Evaporators and air distribution systems for display refrigerators are highly specialized and are usually fitted precisely into the par-

ticular display refrigerator. As a result, they are inherent in the fixture and are not standard independent evaporators. The design of the air circuit system, the evaporator, and the means of defrosting are the result of extensive testing to produce the particular display results desired.

Cleaning and Sanitizing Equipment

Because the evaporator coil is the most difficult part to clean, the operator should consider the judicious use of high-pressure, low liquid volume sanitizing equipment. This type of equipment enables personnel to spray cleaning and sanitizing solutions into the duct, grille, coil, and waste outlet areas with minimum disassembly and maximum effectiveness. However, this equipment must be used carefully because the high-pressure stream can easily displace sealing and caulking materials. High-pressure streams should not be directed toward electrical devices. Hot liquid can also break the glass on models with glass fronts and on closed-service fixtures.

Dairy Display

Dairy products include items with significant sales volume, such as fresh milk, butter, eggs, and margarine. They also include a myriad of small items such as fresh (and sometimes processed) cheeses, special above-freezing pastries, and other perishables. The available display equipment includes the following:

1. Full-height, fully adjustable shelved display units without doors in back for use against a wall ([Figure 11](#)); or with doors in back for rear service or for service from the rear through a dairy cooler. The effect of rear service openings on the surrounding refrigeration must be considered.

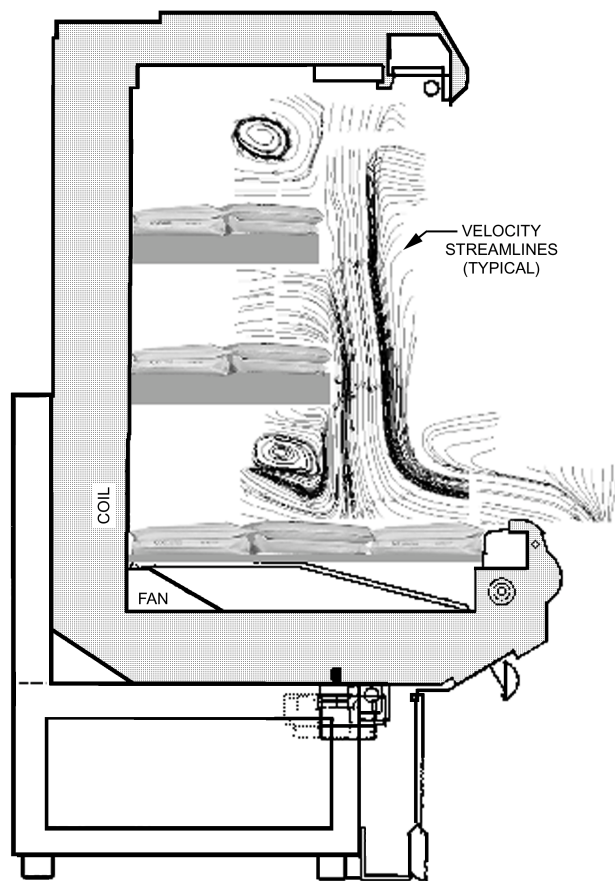


Fig. 10 Velocity Streamlines of a Single-Band Air Curtain in an Open Vertical Meat Display Case, Captured Using Digital Particle Image Velocimetry Technique

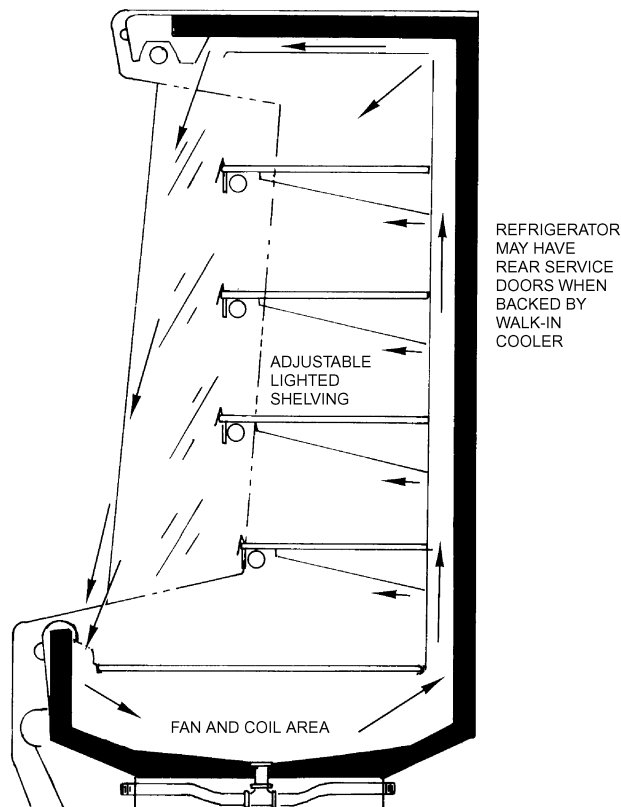


Fig. 11 Multideck Dairy Display Refrigerator

2. Closed-door displays built in the wall of a walk-in cooler with adjustable shelving behind doors. Shelves are located and stocked in the cooler (Figure 12).
3. A variety of other special display units, including single-deck and island-type display units, some of which are self-contained and reasonably portable for seasonal, perishable specialties.
4. A refrigerator, similar to Item 1, but able to receive either conventional shelves and a base shelf and front or premade displays on pallets or carts. This version comes with either front-load capability only or rear-load capability only (Figure 13). These are called front roll-in or rear roll-in display cases.

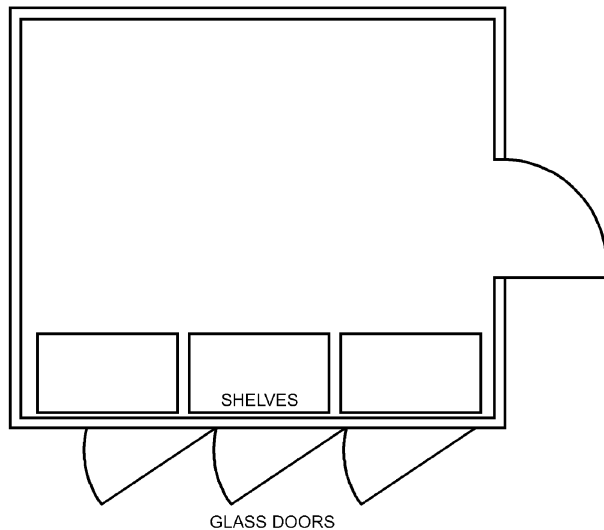


Fig. 12 Typical Walk-In Cooler Installation

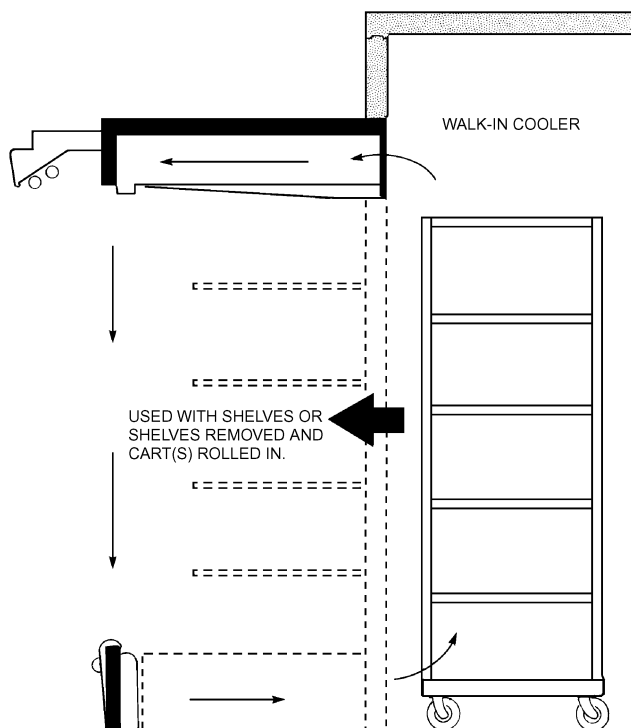


Fig. 13 Vertical Rear-Load Dairy (or Produce) Refrigerator with Roll-In Capability

Produce Display

Wrapped and unwrapped produce is often intermixed in the same display refrigerator. Ideally, unwrapped produce should have low-velocity refrigerated air forced up through the loose product. Water is usually also sprayed, either by manually operated spray hoses or by automatic misting systems, on the leafy vegetables, to retain their crispness and freshness. Produce is often displayed on a bed of ice for freshness appeal. However, packaging prevents this air from circulating through wrapped produce and requires higher velocity air. The equipment available for displaying both packaged and unpackaged produce is usually a compromise between these two desired features and is suitable for both types of product. The equipment available includes the following:

1. Wide or narrow single-deck display units with or without mirrored superstructures.
2. Two- or three-deck display units, similar to the one in Figure 14, usually for multiple-case lineups near the above display refrigerators.
3. Due to the nature of produce merchandising, a variety of non-refrigerated display units of the same family design are usually designed for connection in continuous lineup with the refrigerators.
4. A refrigerator, like Item 2, but able to receive either conventional shelves and a base shelf and front or premade displays on pallets and carts. This version comes with either front-load capability only or rear-load capability only (Figure 13).

Produce equipment is generally available with a variety of merchandising and other accessories, including bag compartments, sprayers for wetting the produce, night covers, scale racks, sliding mirrors, and other display shelving and apparatus.

Frozen Food and Ice Cream Display

To display frozen foods most effectively (depending on varied need), many types of display refrigerators have been designed and are available. These include the following:

1. Single-deck well-type refrigerators for one-side shopping (Figure 15). Many types of merchandising superstructures for related

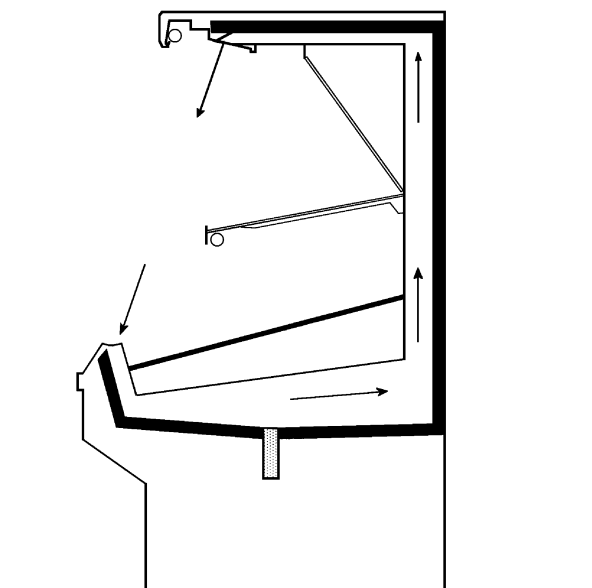


Fig. 14 Multideck Produce Refrigerator

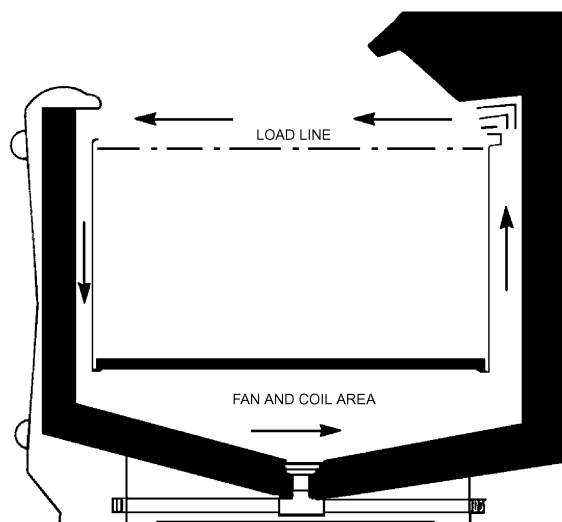


Fig. 15 Single-Deck Well-Type Frozen Food Refrigerator

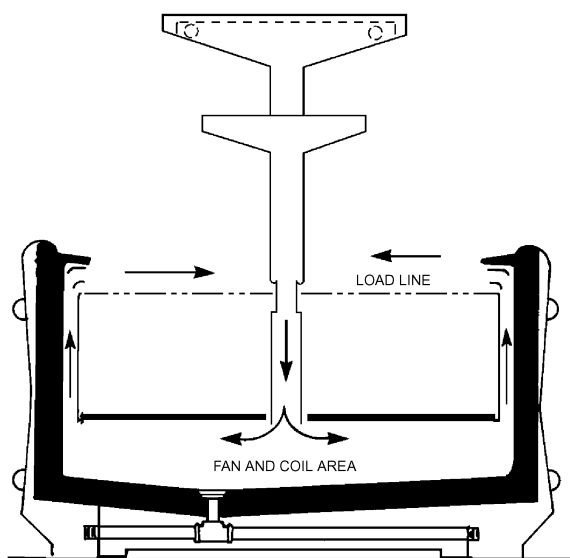


Fig. 16 Single-Deck Island Frozen Food Refrigerator

nonrefrigerated foods are available. Configurations of these refrigerators are designed for matching lineup with fresh meat refrigerators, and there are similar refrigerators for matching lineup of ice cream refrigerators with their frozen food counterparts. These refrigerators are offered with or without glass fronts.

2. Single-deck island for shop-around (Figure 16). These are available in widths ranging from the single-deck refrigerators in Item 1 to refrigerators of double width, with various sizes in between. Some across-the-end increments are available with or without various merchandising superstructures for selling related nonrefrigerated food items to complete the shop-around configuration.
3. Freezer shelving in two to six levels with many refrigeration system configurations (Figure 17). Multideck self-service frozen food and ice cream fixtures are generally more complex in design and construction than single-deck models. Because they have wide, vertical display compartments, they are more affected by ambient conditions in the store. Generally, open mul-

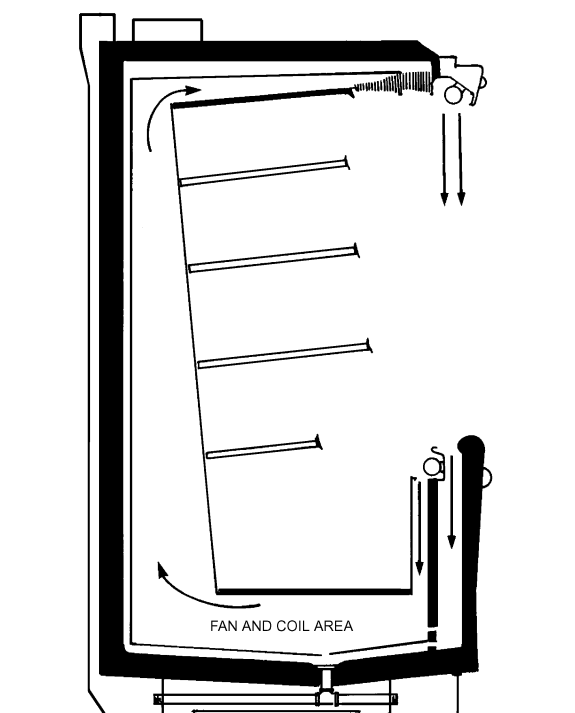


Fig. 17 Multideck Frozen Food Refrigerator

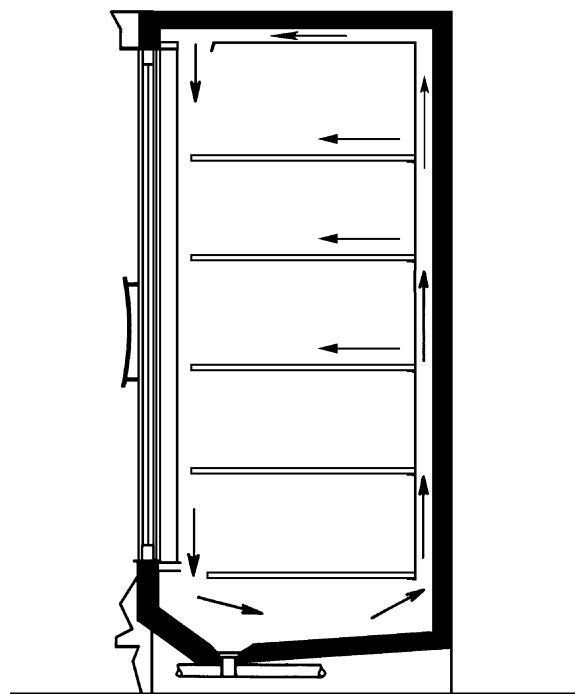


Fig. 18 Glass Door, Frozen Food Reach-In Refrigerator

tideck models have two or three air curtains to maintain product temperature and shelf life requirements.

4. Glass door, front reach-in refrigerators, usually of a continuous lineup design (Figure 18). This style allows for maximum inventory volume and variety in minimum floor space. These advantages must be balanced against the barrier produced by the doors

and the greater labor requirement in restocking. The front-to-back interior dimension of these cabinets is usually about 600 mm. Greater attention must be given to the back product to provide the desired rotation. While these refrigerators generally consume less energy in their operation than open multideck low-temperature refrigerators, specific comparisons by model should be made to determine original and operating costs.

5. Spot merchandising refrigerators, usually self-contained and sometimes arranged for quick change from nonfreezing to freezing temperature to allow for promotional items of either type (e.g., fresh asparagus or ice cream).
6. Versions of most of the above items for ice cream, usually with modified defrost heaters and other changes necessary for the approximately 5.5 K colder required temperature. As display temperature decreases to below -18°C (product temperature), the problem of frost and ice accumulation in flues and in the product zone increases dramatically. Proper product rotation and frequent restocking minimize frost accumulation.

Meat Display

Prepackaged meat is becoming more popular. Most meat is sold in packaged form. Some of this product is cut and packaged on the store premises. Control of temperature, time, and sanitation from the truck to the checkout counter is important. Surface temperature on the meat in excess of 4.4°C shortens the salable life of meat products significantly and increases the rate of discoloration.

The design of open fresh meat display refrigerators, either well-type single-deck or vertical multideck, is limited by the freezing point of meat. Ideally, the refrigerators are set to operate as cold as possible without freezing the meat. The temperatures are maintained with a minimum of fluctuations (with the exception of defrost) to ensure the coldest possible stable internal and surface meat temperatures.

Sanitation is also important. If all else is kept equal, good sanitation can as much as double the salable life of meat in a display refrigerator. In this chapter, sanitation includes the control of the time during which meat is exposed to temperatures above 4.4°C . If meat has been handled in a sanitary manner until it is placed in the display case, elevated temperatures can be more tolerable. When the meat surfaces are contaminated by dirty knives, meat saws, table tops, and so forth, even optimum display temperatures will not prevent premature discoloration and subsequent deterioration of the meat. See the section on Meat Processing for information about the refrigeration requirements of the meat wrapping area.

Along with molds and natural chemical changes, bacteria discolor meat. With good control of sanitation and refrigeration, experiments in stores have produced meat shelf life of one week and more. Bacterial population is greatest on the exposed surface of displayed meat because the surface is warmer than the interior. Although the cold airflow refrigerates each package, the surface temperature (and thus bacterial growth) is cumulatively increased by the following:

- Infrared rays from lights
- Infrared rays from the ceiling surface
- High stacking of meat products
- Voids in display
- Store drafts that disturb refrigerator air

Where these factors are handled improperly, the surface temperature of the meat is often above that allowed by food handling codes. It takes great care in every building and equipment detail, as well as in refrigerator loading, to maintain meat surface temperature below 4.4°C . However, the required diligence is rewarded by excellent shelf life, improved product integrity, higher sales volume, and less scrap or spoilage.

The surface temperature rises during defrost. Tests have compared matched samples of meat—one goes through normal defrost,

and the other is removed from the refrigerator during its defrosting cycles. Although defrosting characteristics of refrigerators vary, such tests have shown that the effects on shelf life of properly handled defrosts are negligible. Tests for a given installation can easily be run to prove the effects of defrosting on shelf life for that specific set of conditions.

Self-Service Meat Refrigerators. Self-service meat products are displayed in packaged form. The meat department planner can select from a wide variety of available meat display possibilities:

- Single-deck refrigerators with or without rear or front access storage doors ([Figure 19](#))
- Multideck refrigerators with or without rear access ([Figure 20](#))
- Either of the above with or without glass fronts

Processed meat versions of the above, often designed for somewhat higher temperatures but including special merchandising shelves or accessories

All of the above refrigerators are available with a variety of lighting, superstructures, shelving, and other accessories tailored to spe-

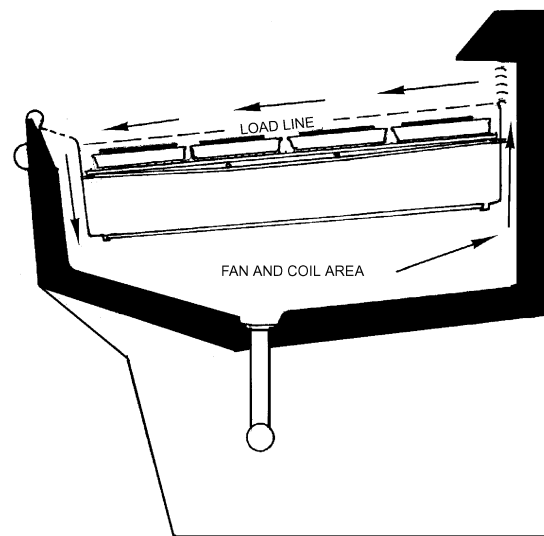


Fig. 19 Single-Deck Meat Display Refrigerator

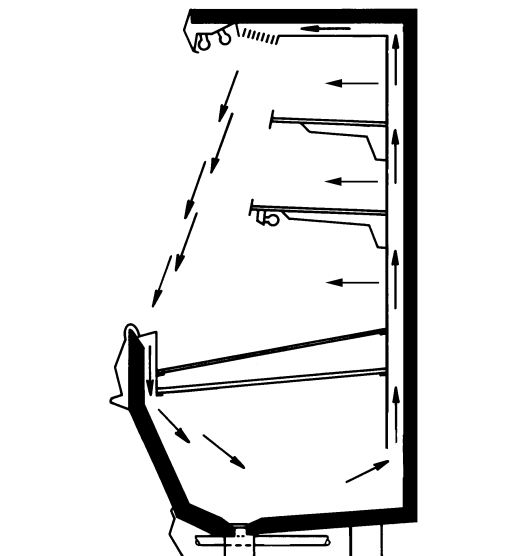


Fig. 20 Multideck Meat Refrigerator

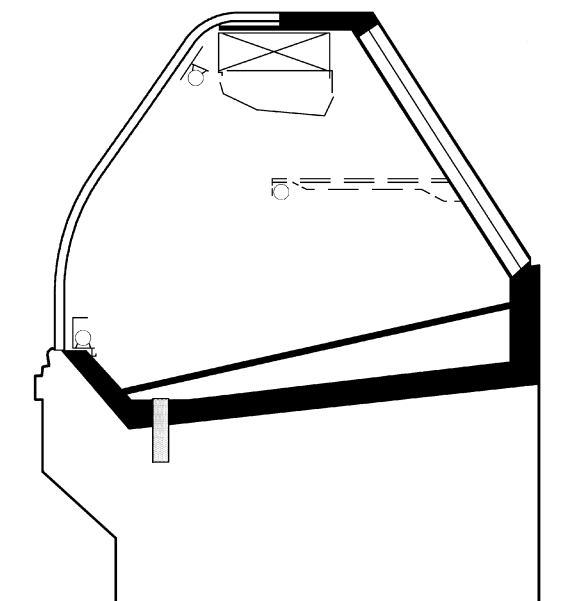


Fig. 21 Closed-Service Display Refrigerator (Gravity Coil Model with Curved Front Glass)

cial merchandising needs. Storage compartments are rarely used in self-service meat refrigerators.

Closed-Service Meat or Deli Refrigerators. Service meat products are generally displayed in bulk, unwrapped. Generally, closed refrigerators are definable in one of the following categories:

- Fresh red meat, with or without storage compartment (Figure 21)
- Deli and smoked or processed meats, with or without storage
- Fresh fish and poultry, usually without storage but designed to display the fresh fish and/or poultry on a bed of cracked ice

Closed-service meat display refrigerators are offered in a variety of configurations. They are available with gravity or forced-convection coils, and their fronts may be nearly vertical or angled up to 20° from vertical in flat or curved glass panels, either fixed or hinged. Gravity coils are usually preferred for more critical products, but forced-air coil models using various forms of humidification systems are also common.

These service refrigerators typically have sliding rear access doors, which are sometimes removed during busy periods. This practice is not recommended by manufacturers, however, because the internal product display zone temperature and humidity levels are affected.

Lighting. Excessive heat due to lighting, high ceiling temperatures, and poor display practices should be eliminated.

There is a conflict between the need to highlight the product in a closed refrigerator and the need to maintain a high moisture level in the atmosphere within the refrigerator. Even the lighting within the store is involved. Bright store lighting necessitates even brighter refrigerator lighting to highlight the product in the refrigerator. Lights in the refrigerator produce heat. Reheating refrigerated air increases the total refrigeration load on the fixture.

Light also discolors smoked, cured, and table-ready meats. No more than 750 lx of display lighting at the product level should be used on smoked, cured, and table-ready meats unless they will be sold within 24 h. Discoloration is directly proportional to both light intensity and length of time displayed.

The best solution for this problem is to subdue ambient lighting around the refrigerators so that minimal lighting within the refrigerator is not dominated. As mentioned in the section on Display

Case Cooling Load and Heat Sources, fluorescent lamps with electronic ballasts or ballasts located out of the refrigerated space have been used to reduce heat load in the case. Meat and deli refrigerators usually maintain a long shelf life when the air temperature in the refrigerator is between 1.5 and 2.5°C. At the same time, the velocity of the refrigerated air over the product should be minimized. High relative humidity and a stable temperature should be maintained in the product zone for maximum shelf life. Use of an evaporator pressure control is often recommended for refrigeration control. A minimum temperature difference (TD) thermostat is used as a backup for times when the load is small. This control method minimizes product dehydration.

MEAT PROCESSING

In a self-service meat market, the operations of cutting, wrapping, sealing, weighing, and labeling involve precise production control and scheduling to meet varying sales demands. The faster the processing, the less critical the temperature and corresponding refrigeration demand.

The wrapping room should not be too dry, but condensation on the meat, which provides a medium for bacterial growth, should be avoided by maintaining a dew point temperature within a few degrees of the sensible temperature. Fan-coil units should be selected with a maximum of 6 K TD between the entering air and the evaporator temperature. Low-velocity fan-coil units are generally used to reduce the drying effect on exposed meat. Gravity coils are also available and have the advantage of lower room air velocities.

The meat wrapping area is generally cooled to about 7 to 13°C, which is desirable for the personnel, but not low enough for meat storage. Thus, meat should be held in that room only for the cutting and packaging operation; then, as soon as possible, it should be moved to a packaged product storage cooler held at -2 to 0°C. The meat wrapping room may be a refrigerated room adjacent to the meat storage cooler or one compartment of a two-compartment cooler. In such a cooler, one compartment is refrigerated at about -2 to 0°C and used as a meat storage cooler, while the second compartment is refrigerated at 7 to 13°C and used as a cutting and packaging room. Best results are attained when the meat is cut and wrapped to minimize exposure to temperatures above -2 to 0°C.

STORAGE REFRIGERATORS

Wrapped Meat Storage

At some point between the wrapping room and the display refrigerator, refrigerated storage for the wrapped cuts of meat must be provided. Without this space, a balance cannot be maintained between the cutting/packaging rate and the selling rate for each particular cut of meat. Display refrigerators with refrigerated bottom storage compartments, equipped with racks for holding trays of meats, offer one solution to this problem. However, the amount of stored meat is not visible, and the inventory cannot be controlled at a glance.

A second option is a pass-through, reach-in cabinet. This cabinet has both front and rear insulated glass doors and is located between the wrapping room and the display refrigerators. After wrapping, the meats are passed into the cabinet for temporary storage at -2 and 0°C and then are withdrawn from the other side for restocking the display refrigerator. Because these pass-through cabinets have glass doors, the inventory of wrapped meats is visible and therefore controllable.

The third and most common option involves a section of the back room walk-in meat storage cooler or a completely separate packaged meat storage cooler. The cooler is usually equipped with rolling racks into which the trays of meat can be slid. This method of storage also offers visible inventory control. This method provides convenient access to both the wrapping room and the display cases.

The overriding philosophy in successful meat wrapping and merchandising can be summarized thus: keep it clean, keep it cold, and keep it moving.

Walk-In Storage Coolers

Each category of displayed food product that requires refrigeration for preservation is usually backed up by storage in the back room. This storage usually consists of refrigerated rooms with sectional walls and ceilings equipped with the necessary storage racks for a particular food product. Walk-in coolers are required for the storage of meat, some fresh produce, dairy products, frozen food, and ice cream. Medium and large stores have separate produce and dairy coolers usually in the 2 to 4°C range. Meat coolers are used in all food stores, with storage conditions between -2 and 0°C. Unwrapped meat, fish, and poultry should each be stored in separate coolers to prevent odor transfer. Walk-in coolers, which serve the dual purpose of storage and display, are equipped with either sliding or hinged glass doors on the front. These door sections are often prefabricated and set into an opening in the front of the cooler. In computing the refrigeration load, allowance must be made for the extra service load.

Moisture conditions must be confined to a relatively narrow range because excessive humidity encourages bacteria and mold growth, which leads to sliming. Too little moisture leads to excessive dehydration.

Air circulation must be maintained at all times to prevent stagnation, but it should not be so rapid as to cause drying of an unwrapped product. Forced-air blasts must not be permitted to strike products; therefore, low-velocity coils are recommended.

For optimum humidity control, unit coolers should be selected at about a 6 K TD between entering air temperature and evaporator temperature. Note that the published ratings of commercial unit coolers do not reflect the effect of frost accumulation on the evaporator. The unit cooler manufacturer can determine the correct frost derating factor for its published capacity ratings. From experience, a minimum correction multiplier of 0.80 is typical.

A low-temperature storage capacity equivalent to the total volume of the low-temperature display equipment in the store is satisfactory. Storage capacity requirements can be reduced by frequent deliveries.

Generally, forced-air coils are selected for low-temperature coolers where humidity is not critical for packaged products. For low-temperature coolers, gas or electric defrost is required. Off-cycle defrosts are used in produce and dairy coolers. Straight time or time-initiated, time- or temperature-terminated gas or electric defrosts are generally used for meat coolers.

REFRIGERATORS AND SYSTEMS

Food stores sell all types of perishable foods that require a variety of refrigeration systems to best preserve and most effectively display each product. Moreover, the refrigerating system must be highly reliable because it must operate 24 h per day for 10 or more years, to protect the large investment in highly perishable foods. The various refrigerators have different evaporator pressure/temperature requirements ranging from the highest for the meat processing room to the lowest for the ice cream level. Produce and meat wrapping rooms may approach the suction pressures used in air-conditioning applications. Open ice cream display cases may have suction pressures corresponding to temperatures as low as -40°C. All other cases and coolers fall between these extremes.

Temperature controls also vary greatly, from a produce preparation room (which may operate with a wet coil) requiring no defrost to the ice cream case requiring induced heat to defrost the coil periodically. Electronic sensor control is the most accurate and can also provide a temperature alarm to prevent food loss. Defrost methods

include (1) off-time defrost, (2) gas defrost, (3) electric defrost, and (4) defrost using ambient air induced into the refrigerator.

Various Refrigeration System Design Solutions

The selection of refrigeration equipment used to operate display refrigerators and storage rooms for food stores involves the following considerations: (1) cost/space limitations, (2) reliability, (3) maintainability and complexity, and (4) operating efficiency. Solutions span the very simple (one compressor and associated controls on one refrigerator) to the complex (central refrigeration plant operating all refrigerators in a store).

Condensing unit systems, which use single compressors with multiple cases or coolers, provide a popular, suitable approach. This method places produce, dairy, meat, or frozen food refrigerators in groups, each on a single compressor that may have its own condenser or may have an air- or water-cooled remote condenser.

Parallel Systems. Another common refrigeration technique couples two compressors in parallel. Oil distribution, temperature control at more than one suction pressure, and defrosting must be considered. Parallel units usually operate connected to one or more large condensers. The condensers are usually remote air-cooled or remote evaporative-cooled, but they can also be built as part of the compressor rack assembly.

Carrying the sequence one step further leads to a large assembly tying three or more compressors in parallel. The needs defined for two units in parallel apply to the larger styles as well. However, efficiency may be sacrificed when greatly differing suction pressures are grouped in one suction pressure designed system. Split suction manifolds separate load groups on a rack. To match changing evaporator loads, rack capacity is varied by cycling compressors, varying the speed of one or more compressors, and/or unloading compressor cylinders by closing valves or moving ports on screw compressors.

Running all the refrigeration equipment at the low suction pressure required for ice cream on low-temperature systems and for meat on medium-temperature systems is inefficient. In large parallel systems, the ice cream and meat refrigeration are frequently isolated. Single compressor satellites tied into the parallel compressors are often used for small ice cream or meat loads, while split-suction parallel equipment is used for larger loads. Different suction pressures are obtained, but all compressors discharge into a common header.

Secondary Coolant Systems

In secondary coolant systems, heat is removed from refrigerated spaces and display cabinets through circulation of a chilled fluid in a secondary loop cooled by a primary refrigeration system. Circulation of the fluid is typically provided using a centrifugal pump(s) designed for the flow rate and pressure drop required by the system load and piping arrangement.

Selection of secondary fluid is critical to the efficiency of the system because viscosity and heat-transfer properties impact system performance directly. In most cases, the secondary fluid is in a single-phase state, removing heat through a sensible temperature change. Inhibited propylene glycol solutions are most often used for medium-temperature systems, typically at fluid temperatures not lower than -9°C. Low-temperature fluids are commonly composed of a solution of various potassium-based organic salts and inhibitors, though several alternatives are available. Fluids involving a phase change are also possible and include carbon dioxide and water-based ice slurries. An explanation of various options for secondary fluids, including safety considerations, is found in [Chapter 4](#).

Heat is removed from the fluid using a chiller of any design, but commonly a plate-type is used, for highest efficiency. Coils engineered to remove heat effectively from the refrigerated spaces are generally of different design than those used for volatile refriger-

ants. Liquid should enter the bottom of the coil, leave at the top, and avoid trapping air. Drain and vent valves must also be equipped to assist with air removal and service.

Typically, the entire refrigeration system for supermarkets is divided into two separate temperature groups, one low (frozen food, ice cream) and one medium temperature (meat, dairy, produce, preparation rooms). To increase efficiency, the systems may be further divided into additional temperature groups, although often at a higher capital cost. Temperature is controlled by means of regulating flow using a balance valve, or cycling flow around a setpoint using a solenoid valve. Piping may be in circuited or loop arrangement, or a combination of the two. Circuited systems have the advantage of containing most of the control valves in a central location, but at the cost of a greater amount of installed piping.

There are several advantages to secondary coolant systems. Because the primary refrigeration system is mostly contained in the machine room, the amount of refrigerant required can be reduced by as much as 80-90%. Since most piping joints are factory installed, this combined with a lower charge results in significantly lower refrigerant leakage rates which reduce any environmental impacts associated with the primary refrigerant. The compressors and evaporator are close-coupled, so suction line pressure losses and heat gains are minimized, enhancing system performance. Secondary coolant systems are inherently less complex than direct expansion types, requiring fewer and less-complicated valves and control devices. Less-expensive nonmetallic piping systems and components can also be utilized since the system operating pressure is low, typically less than 414 kPa. Service of the refrigeration is basically limited to the machine room area. Because a fluid loop is used, thermal storage may be applied to reduce peak power demands and take advantage of lower off-peak utility rates. Ambient or free cooling may be applied in areas with colder climates. Secondary systems also can use primary refrigerants not typically suitable for direct expansion systems, including ammonia and hydrocarbons.

Disadvantages of secondary systems include the inherent thermodynamic loss due to the additional step of heat transfer in the chiller, as well as the energy consumed by the fluid pump and the heat it transfers to the circulating fluid. Insulation must also be applied to both coolant supply and return lines to minimize heat gain.

Two defrost methods, time-off and warm fluid, are most commonly applied to secondary systems. Time-off defrost can be used in some medium-temperature applications. However, the most effective method is warm fluid defrost, which is used for all low-temperature applications and in selected medium-temperature cases where product temperatures are critical or time-off defrost is not practical. Fluid for defrost is typically heated using refrigerant discharge gas, but system efficiency can be increased by a heat exchange with liquid refrigerant. Temperatures of warm fluid vary and must be optimized for the coil application; however, typical values are 10 to 16°C for medium and 21 to 27°C for low-temperature systems. Warm fluid defrost is most often terminated by the fluid temperature exiting the coil and is preferable compared to time-off because of the small change in temperature imparted on the products, resulting in lower postdefrost pulldown loads.

Liquid-Cooled Self-Contained Systems

In these types of systems, refrigeration condensing units connected to one or more refrigerators are located in the display area of the supermarket. The units could be located underneath, behind, above, or in an enclosure near the refrigerator(s). A low-temperature fluid, or coolant, typically a brine, or glycol solution, is pumped through a refrigerant-to-liquid heat exchanger, which serves as the condenser. The heated coolant then flows to a remote refrigeration system, or chiller, which removes the heat and then pumps it back out to the refrigerator.

As with other systems, there are advantages and disadvantages. As much as 80% less refrigerant charge is needed. There is less

potential for refrigerant loss by leakage. Initial equipment costs may be lower. Refrigerators can be performance-tested before they are shipped from the factory, and installations may be less labor-intensive.

As with secondary cooling, the biggest disadvantage is the increased energy requirement from the additional step of heat transfer and the secondary fluid pumps. Noise levels can also be higher, and servicing must be done in the display area of the supermarket. Advances in compressor technology leading to quieter, more compact, and more energy-efficient refrigeration systems, would allow liquid-cooled, self-contained systems to become more feasible for widespread application.

Load Versus Ratings

Food store refrigerator manufacturers publish case load ratings to match the proper condensing unit with the fixture load. For single-compressor applications only, the ratings can be stated, for selection convenience, as the capacity the condensing unit must deliver at an arbitrary suction pressure (evaporator temperature). In general, manufacturers of display refrigerators use ASHRAE *Standards* 72 and 117, which specify standard methods of testing open and closed refrigerators for food stores. These standards establish refrigeration load requirements at rated ambient conditions of 24°C and 55% rh in the sales area. Similar display refrigerators vary between manufacturers, so manufacturers' recommendations must be followed to achieve proper results in both efficiency and product integrity.

Multiplexed Systems

When dissimilar display case refrigerator loads are connected to the same condensing system, the manufacturer should be consulted to determine the true maximum suction pressure at the fixture refrigerant line outlet for each system and the true load that such a system adds to the total. The condensing unit must deliver the total of all the loads at a suction pressure at the machine no higher than the lowest system pressure requirement less the suction line pressure drop. The other systems must have suction line restriction (by evaporator pressure regulators or some other sure means) to prevent higher-temperature evaporators from adding unnecessarily to the load. The pressure regulator then ensures that the condensing unit will pulldown to the pressure necessary for the lowest evaporator temperature required.

Electronically or mechanically actuated pilot-operated evaporator pressure regulator (EPR) valves control evaporator pressures in multiplexed systems. These valves cause little or no measurable pressure drop when they are in the full-open position. Another design uses liquid or discharge pressure to open and close the EPR valves, so the pressure drop is negligible. Another design has no pilot valve but typically requires a minimum of 6.9 kPa pressure drop for operation.

The suction gas temperature leaving display fixtures is often superheated. Particularly on low-temperature fixtures, the suction line gas temperature increase from heat gained from the store ambient can be substantial. This increase, which adversely affects condensing unit capacity and compressor discharge gas temperature, must be considered for system design; both capacity effects and the cooling needs of compressors are involved.

One solution to excessively high superheat is to run the suction line and liquid line tightly together from the fixture refrigerant line outlet, with the pair insulated together for a distance of 10 to 20 m from the fixture outlet. This technique cannot be used with gas defrost or refrigerants requiring low suction superheat at the compressor suction (for example, low-temperature single-stage R-22 systems). Most manufacturers produce suction line to liquid line heat exchangers installed in the display fixture. This technique converts a loss into a gain by allowing the suction gas to pick up heat

from the liquid instead of the store ambient. Under all conditions, the suction line should be insulated from the point where it leaves the display case to the suction service valve on the compressor. The insulation and its installation must be vapor resistant.

To ensure proper thermostatic expansion valve operation, the engineer should verify that the liquid entering the fixture is subcooled. Some case and/or system designs require liquid line insulation. This is very important when ambient outdoor air or mechanical subcooling is being used to improve system efficiency.

COMPRESSOR CONFIGURATIONS

Matching Refrigerator Requirements with Compressor Capacity

The designer matches requirements of refrigerator lineups to the capacity of a single compressor unit or divides them into manageable circuits for parallel compressor systems. The parallel systems adapt easily to gas defrost. Gas directly from the compressor discharge, or, in some instances, from the top of the receiver at a lower temperature, flows through a manifold. Electric defrost, reverse air defrost, and off-cycle defrost can also be used on both parallel and single-unit systems. Liquid and/or suction line solenoid valves control the circuits for defrosting. Often, a suction stop is combined with the temperature-controlling EPR. The entire system with its individual circuits is controlled by a multicircuit time clock. Temperature control on the branch circuits is also achieved by refrigerator thermostats actuating liquid-line solenoid valves. Shutoff valves isolate each circuit for service convenience. Refrigerator requirements are now often given as a refrigeration load per unit length, with a lower value sometimes allowed for parallel systems. The rationale for this lower value is that peak loads are smaller with programmed defrost. Refrigerator temperature recovery after a defrost period is less of a strain than it would be to a single-compressor system.

Published refrigerator load requirements allow for extra capacity for temperature pulldown after defrost, per ASHRAE *Standard 72*. The industry considers a standard store condition to be 24°C and 55% rh, which should be maintained with air conditioning. Much of this air-conditioning load is carried by the open refrigerators, and credit for the heat removed by them should be considered in sizing the air-conditioning system.

Typical Parallel Compressor Energy Efficiency

A typical supermarket includes one or more medium-temperature parallel systems for meat, deli, dairy, and produce refrigerators and the medium-temperature walk-in coolers. The system may have a separate compressor for the meat or deli refrigerators, or all units may have a single compressor. Energy efficiency ratios typically run from 2.3 to 2.6 W/W for the main load. Low-temperature refrigerators and coolers are grouped on one or more parallel systems with ice cream refrigerators on a satellite or on a single compressor. EERs range from 1.2 to 1.5 W/W for the frozen food units and as low as 1.0 to 1.2 W/W for the ice cream units. Cutting and preparation rooms are most economically placed on a single unit because the refrigeration EER is at nearly 2.9 W/W. Air-conditioning compressors are also separate because their EERs can range up to 3.2 W/W (Figure 22).

Capacity Control of Parallel Systems

This system must be designed to maintain proper refrigerator temperatures under peak summer load. During the remainder of the year, store conditions can be easily maintained at a more ideal condition, and refrigeration load will be lower. In the past, refrigeration systems were operated at 32°C condensing conditions or above to maintain enough high-side pressure to feed the refrigerated display fixture expansion valves properly. When outdoor ambient condi-

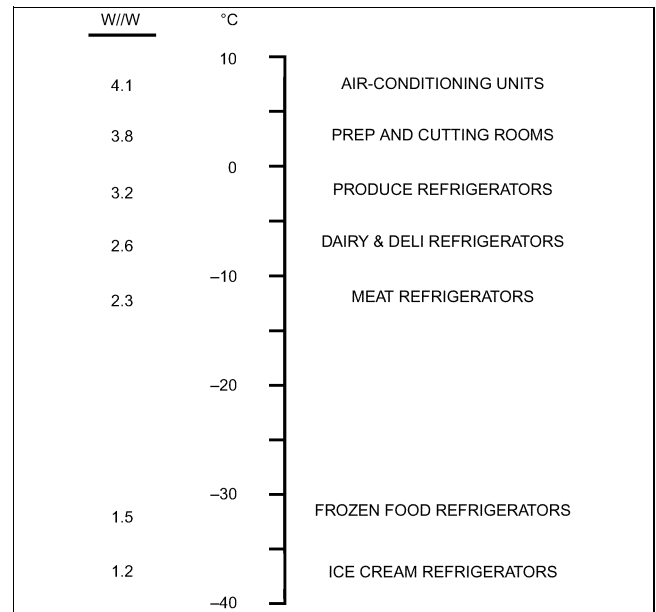


Fig. 22 Typical Single-Stage Compressor Efficiency

tions allow, today's technology permits the condensing temperature to follow the ambient down to about 21°C or less. When proper liquid-line piping practices are observed, the expansion valves feed the evaporators properly under these low condensing temperatures. Therefore, at partial load, the system has excessive capacity to perform adequately.

Multiple compressors may be controlled or staged based on a drop in system suction pressure. If the compressors are equal in size, a mechanical device can turn off one compressor at a time until only one is running. The suction pressure will be perhaps 34 kPa or more below optimum. Newer, solid-state control devices can cycle units; the run time for each compressor motor can be equalized while the system remains at one economical pressure range. Satellite compressors can be controlled accurately with one control that also monitors other components, such as oil pressure and alarm functions. Rack capacity can also be varied by compressor cylinder unloading.

Staging Unequally Sized Compressors

Unequally sized compressors can be staged to obtain more steps of capacity than the same number of equally sized compressors. Figure 23 shows seven stages of capacity from a 5, 7, and 10 kW compressor parallel arrangement. Unloaders on multibank compressors provide greater flexibility, as does variable speed (usually on the lead compressor) for capacity control.

Screw Compressor Central Plant Units

Some supermarkets have begun to use the screw compressor to replace the multireciprocating compressor rack. Precise temperature and power control is available if microprocessor controls are used to control the screw compressor(s). Microprocessors offer the option of remote control and system operation for all types of compressors.

Use of the Economizer Port on Screw Compressors

Small walk-in coolers and preparation rooms are higher-temperature applications than the medium-temperature cases. The side center port of the screw compressor is being used for these and other types of loads where a higher suction pressure is needed. This reduces the number of compressors needed for the

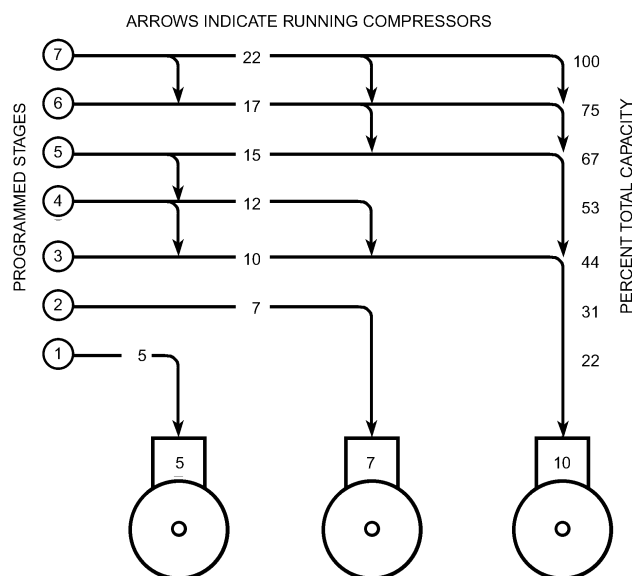


Fig. 23 Stages with Mixed Compressors

variety of load requirements. Planning the load management and the sizing of the screw compressors is very important to a successful refrigeration installation.

Factory-Assembled Equipment

Factory assembly of the necessary compressor systems with either a direct air-cooled condenser or any style of remote condenser is common practice. Both single and parallel systems can be housed, prepped, and prewired at the factory. The complete unit is then delivered to the job site for placement on the roof or beside the store.

Prefabricated Equipment Rooms

Many supermarkets have elected to purchase the compressor equipment installed in a housing to reduce real estate costs for the building. The time requirements for installation of piping and wiring may also be reduced with prefabrication. Most of the rooms are modular and prewired and include some refrigeration piping. Their fabrication in a factory setting should offer good quality control of the assembly. They are usually put into operation quickly upon arrival at the site.

Subcooling Liquid Refrigerant

Allowing refrigerant to subcool in cool weather as it returns from the remote condenser saves energy. Subcooling can be done by several means. The most common is to flood the condenser and allow the liquid refrigerant to cool close to the ambient temperature.

Mechanical subcooling may also be economical in many areas. A subcooling compressor can be combined on a parallel system. Another method is to have a separate parallel system with branches to subcoolers on the other parallel and single systems in the store. The mechanical subcooling would be set to operate when the ambient air cools the refrigerant to above the desired subcooled temperature. The advantage to this method is that the mechanical subcooling compressor can run at twice the efficiency of the main system, thus saving energy through year-round liquid temperature control.

Heat Recovery

Heat recovery may be an important feature of virtually every compressor system, parallel or single. A heat recovery coil is simply a second condenser coil placed in the air handler. If the store needs heat, this coil is energized and run in series with the regular

condenser (see Figure 25). The heat recovery coil can be sized for a 17 to 28 K TD depending on the capacity in cool weather. Lower head pressures in parallel systems permit little heat recovery. However, when heat is required in the store, simple controls create a higher head pressure for heat recovery. Compared with the cost of auxiliary gas or electric heat, the higher energy consumption of the compressor system may be compensated for by the value of the heat gained.

On a large, single unit, water can be heated by a desuperheater; on two-stage or compound R-22 parallel systems, water is commonly heated by the interstage desuperheater.

CONDENSING METHODS

Many commercial refrigeration installations use air-cooled condensers. Alternatively, evaporative condensers or water-cooled condensers with cooling towers may be specified. To obtain the lowest operating costs, equipment should operate at the lowest head pressure possible. The minimum allowable pressures are determined by other design and component considerations incorporated by the designer.

Techniques that permit a system to operate satisfactorily with lower condensing temperatures include (1) insulating liquid lines and/or receiver tank, (2) subcooling the liquid refrigerant by design, and (3) connecting the receiver as a surge tank with appropriate valving. Condensing pressure must still be controlled, at least to the lower limit required by the expansion valve, gas defrosting, and heat reclaim. The typical thermostatic expansion valve is capable of feeding the evaporator properly, assuming that a solid liquid column of refrigerant is always supplied to the expansion valve and that there is sufficient pressure drop across the valve. Balanced-port thermostatic expansion valves have enhanced the opportunity for floating pressures down with varying ambient temperatures below the design point.

Air-Cooled Machine Room

The arrangement of standard air-cooled condensing units in a separate air-cooled machine room is still used in some supermarkets. Dampers, which may be powered or gravity operated, supply air to the room; fans or blowers controlled by room temperature at a thermostat exhaust the air.

A complete air-cooled condensing unit located indoors requires ample, well-distributed ventilation. Ventilation requirements vary depending on maximum summer conditions and evaporator temperature, but 500 to 600 L/s per condensing unit kilowatt has given proper results. Exhaust fans should be spaced for an even distribution of air (Figure 24).

Roof-top air intake units should be sized for 3.8 m/s velocity or less to keep airborne moisture from entering the room. When condensing units are stacked (as shown in Figure 24), the ambient air design should provide upper units with adequate ventilation. Roof-top intakes are preferred because they are not as sensitive to wind as side wall intakes, especially in winter in cold climates. Butterfly dampers installed in upblast exhaust fans, which are controlled by a thermostat in the compressor room, exhaust warm air from the space.

The air baffle helps prevent intake air from short-circuiting to the exhaust fans (Figure 24). Because air recirculation is needed around the condensers for proper winter control, the intake air should not be baffled to flow only through the condensers.

Ventilation fans for air-cooled machine rooms normally do not have a capacity equal to the total of all the individual condenser fans. Therefore, if the air is baffled to flow only through the condenser during maximum ambient temperatures, the condensers will not receive full free air volume when all or nearly all condensing units are in operation. Also, during winter operation, tight baffling of the air-cooled condenser prevents recirculation of condenser air,

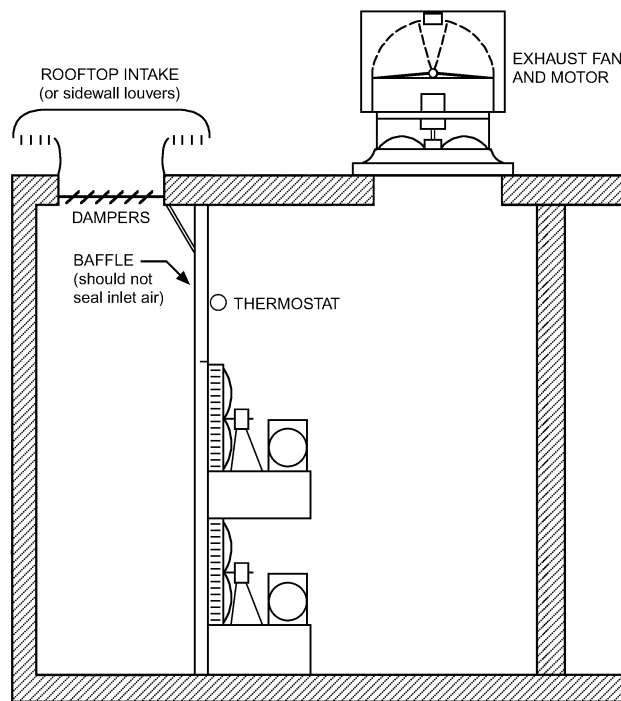


Fig. 24 Typical Air-Cooled Machine Room Layout

which is essential to maintaining sufficiently high room temperature for proper refrigeration system performance.

Machine rooms that are part of the building need to be airtight so that air from the store is not drawn by the exhaust fans into the machine room. Additional load is placed on the store air-conditioning system if the compressor machine room, with its large circulation of outside air, is not isolated from the rest of the store.

Condenser Sizing

To minimize energy consumption, condensers should be more generously sized than they are for typical air-conditioning applications. Typical condenser selection is based on the temperature difference between the air entering the condenser and the saturated condensing temperature. Generally accepted TDs for refrigeration condenser sizing are 8 K for medium-temperature systems and 6 K for low-temperature systems.

Remote Air-Cooled Condenser

The remote condenser may be placed outdoors, or it may be placed indoors to heat portions of the building in winter. Regardless of the arrangement of the remote condenser or the indoor-outdoor mechanical package, the following design points are relevant. The air-cooled condenser may be either a single-circuit or a multiple-circuit condenser. The manufacturer's heat rejection factors should be followed to ensure that the desired TD is accommodated.

Pressure must be controlled on most outdoor condensers. Fan cycle controls work well down to 10°C on condensers with single compressors or with parallel groups of compressors. Below 10°C, condenser flooding (with the refrigerant) can be used alone or with fan controls. Flooding requires a larger refrigerant charge and larger liquid receiver. In contrast, split condensers with solenoid valves in the hot-gas lines and bleedoff in the liquid return lines can reduce the condenser surface during cold weather. Natural subcooling can be integrated into the design to save energy.

Fans are controlled by pressure controls, liquid-line thermostats, or a combination of both. Ambient control of condenser fans is

commonly used; however, it may not give the degree of condensing temperature control required in systems designed for high-efficiency gain. Ambient control of condenser fans is not recommended except in mild climates down to 10°C. Sometimes, pressure switches, in conjunction with gravity louvers, cycle the condenser fan. This system requires no refrigerant flooding charge.

The sizing of the receiver tank on the high-pressure side, especially for remote condensers, must be considered. Remote condenser installations, particularly when associated with heat recovery, have substantially higher internal high-side volume than other types of systems. Much of the high side is capable of holding liquid refrigerant, particularly if runs are long and lines are large.

Roof-mounted condensers should have at least 0.9 m of space between the roof deck and the bottom of the condenser slab to minimize the radiant heat load from the roof deck to the condenser surface. Also, free airflow to the condenser should not be restricted. Remote condensers should be placed at least 0.9 m from any wall, parapet, or other airflow restriction. Two side-by-side condensers should be placed at least 1.8 m from each other. [Chapter 16 of the ASHRAE Handbook—Fundamentals](#) discusses the problems of locating equipment for proper airflow.

Evaporative Condenser Arrangements

Evaporative condensers are also available as single- or multiple-circuit condensers. Manufacturer conversion factors for operating at a given condensing temperature and wet-bulb temperature must be applied to determine the required size of the evaporative condenser.

In cold climates, the condenser must be installed to guard against freezing during winter. Evaporative condensers demand a regular program of maintenance and water treatment to ensure uninterrupted operation. The receiver tank should be capable of storing the extra liquid refrigerant during warm months. Line sizing must be considered to keep a reasonable tank size.

Closed water condenser/evaporative cooler systems are used frequently. In this arrangement, an evaporative condenser cools water instead of refrigerant. This water flows in a closed, chemically stabilized circuit with a regular water-cooled condenser (a two-stage heat transfer system). Heat from the condensing refrigerant transfers to the closed water loop in the regular water-cooled condenser. The warmed water then passes to the evaporative cooler.

The water-cooled condenser and evaporative cooler must be selected considering the temperature difference (1) between the refrigerant and the circulating water and (2) between the circulating water and the available wet-bulb temperature. The double temperature difference results in higher head pressures than when the refrigerant is condensed in the evaporative condenser. On the other hand, this arrangement causes no corrosion inside the refrigerant condenser itself because the water flows in a closed circuit and is chemically stabilized.

The extremely high temperature of the entering discharge gas is the prime cause of evaporative condenser deterioration. The severity of deterioration can be substantially reduced by using the closed water condensing arrangement. The extent of this reduction in deterioration relates directly to the reduction in the difference between the high discharge gas temperatures experienced even with generously sized evaporative condensers and the design entering water temperature for the closed water circuit.

Water flow in the closed water circuit can be balanced between multiple condensers on the same evaporative cooler circuit with water-regulating valves. Usually, low head pressures are prevented by temperature control of the closed water circuit. Three-way valves provide satisfactory water distribution control between condensers.

Cooling Tower Arrangements

Few supermarkets use water-cooled condensing units because the trend is toward air cooling. Nearly all water-cooled condensing

units are installed with a water-saving cooling tower because of the high cost of water and sewage disposal.

The engineering of water cooling towers for perishable foods is different than for air conditioning because (1) the hours of operation required are much greater than for space conditioning; (2) refrigeration is required year-round; and (3) in some applications, cooling towers must survive severe winters. A thermostat must control the tower fan for year-round control of the condensing pressure. The control is usually set to turn off the fan when the water temperature drops to a temperature that produces the lowest desired condensing pressure. Water-regulating valves are sometimes used in a conventional manner. Dual-speed fan control is also used.

Some engineers use balancing valves for water flow control between condensers and rely on water temperature control to avoid low head pressure. Proper bleedoff is required to ensure the satisfactory performance and full life of the cooling towers, condensers, water pumps, and piping. Water treatment specialists should be consulted because each locality has different water and atmospheric conditions. A regular program of water treatment is mandatory.

Condensing Units

Air-Cooled Condensing Unit. Single-unit compressors with air-cooled condenser systems can be mounted in racks up to three high to save space. These units may have condensers sized so that the TD is in the 6 to 14 K range. Optionally available next larger size condensers are often used to achieve lower TDs and higher energy efficiency ratios (EERs) in some supermarkets, convenience stores, and other applications. Single compressors with heated crankcases and heated insulated receivers and other suitable outdoor controls are assembled into weatherproof racks for outdoor installations. Sizes range from 0.4 to 22 kW.

Water-Cooled Condensing Unit. Water-cooled units range in size from 0.4 to 22 kW and are best for hot, dry climates. A city water-cooled condensing unit is usually no longer economical due to the high cost of water and sewer fees. Cooling towers, which cool the water for all compressors, are used instead. Closed water systems are also used in areas that can use an evaporative water cooler.

Remote Condenser-Compressor Unit. Remote units operate efficiently with minimum condenser maintenance. Evaporative condensers are also used in some areas. Sizes range from 0.4 to 22 kW.

Recommended sizing for remote air-cooled condensers is 6 K TD for low-temperature application and 8 K TD for medium-temperature application. Remote water-cooled condensers are often used in areas with abundant water.

Single-Compressor Control. Single-compressor units make up half of the supermarket compressor equipment presently used. A solid-state pressure control for single units can help control excess capacity when the ambient temperature drops. The control senses the pressure and adjusts the cutout point to eliminate short cycling, which ruins many compressors in low-load conditions. This control also saves energy by maintaining a higher suction pressure than would otherwise be possible and by reducing overall running time.

Parallel Compressors. Multiple compressors may be operated in parallel with a large receiver and multistation manifolds for liquid, suction, and discharge gas. These systems usually have a remote condenser and frequently recover heat from a secondary condenser coil in the air handler. A separate compressor for ice cream refrigerators on a low-temperature system or for meat refrigerators on a medium-temperature system can be physically mounted on the rack and piped so that only the heat removed from the lower temperature refrigerators is supplied at the less efficient rate. Parallel operation is also applied in two-stage or compound systems for low-temperature applications. Two-stage compression includes interstage gas cooling before the second stage of compression to avoid excessive discharge temperatures. Parallel compressors may be equal or unequal in size and may have unloaders or variable-speed drives.

Remote Air-Cooled Condenser and Heat Recovery Coil. Remote air-cooled condensers are popular for use with parallel compressors. The condenser coil TD is in the range of 6 K for low-temperature and 8 K for medium-temperature applications. For energy conservation, generous sizing of the condenser with a lower TD is recommended. Figure 25 illustrates a basic parallel system with an air-cooled condenser and heat recovery coil.

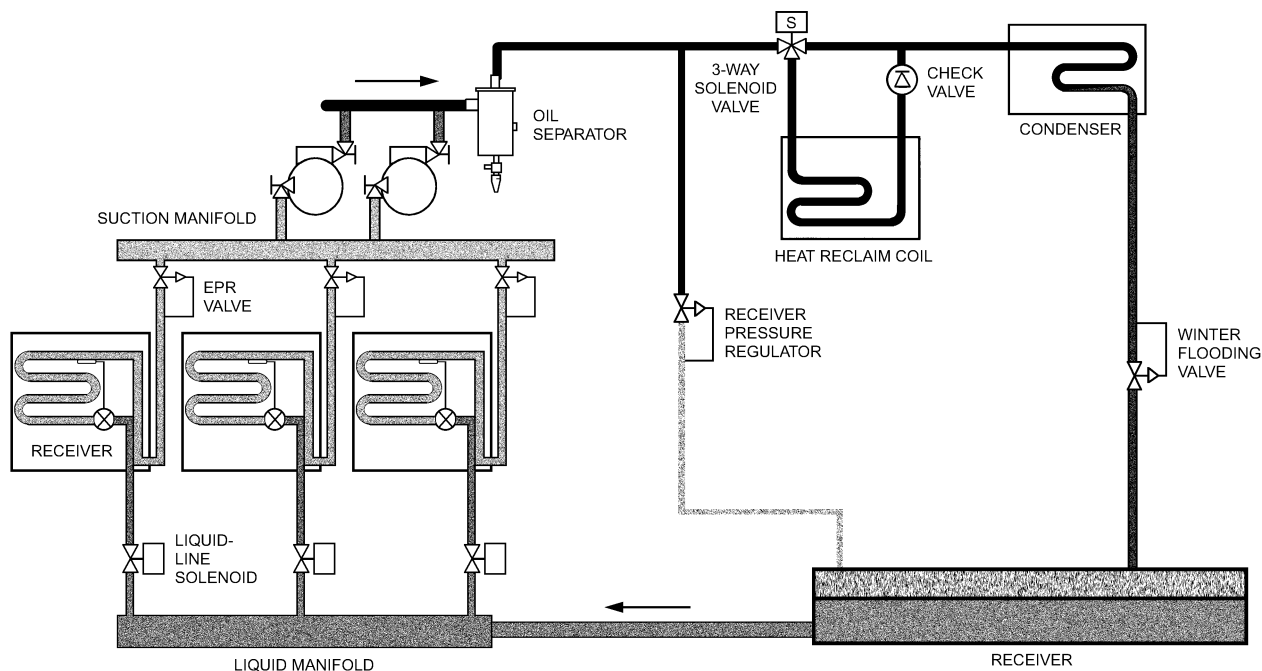


Fig. 25 Basic Parallel System with Remote Air-Cooled Condenser and Heat Recovery

Evaporative Condenser. Evaporative condensers have a coil, in which refrigerant is condensed or closed-loop circulating water is cooled, and a means of supplying air and water over its external surfaces. Heat is transferred from the condensing refrigerant inside the coil or the water in the loop to the external wetted surface and then into the moving airstream principally by evaporation. In areas where the wet-bulb temperature is about 17 K below the dry bulb, the condensing temperature can be 6 to 17 K above the wet-bulb temperature. This lower condensing temperature saves energy; one evaporative condenser can be installed for the entire store. [Chapter 35 of the ASHRAE Handbook—Systems and Equipment](#) gives more details.

Condensing Unit Noise

Air-cooled condensing units located outdoors, either as single units with weather covers or grouped in prefabricated machine rooms, produce sounds that must be evaluated. The largest source of noise is usually propeller-type condenser fans. Other sources are compressor and fan motors, high-velocity refrigerant gas, general vibration, and amplification of sound where vibration is transmitted to mounting structures (this is most critical in roof-mounted units).

A fan-speed or fan-cycle control helps control fan air noise by ensuring that only the amount of air necessary to maintain proper head pressure is generated. Care should be taken not to restrict discharge air. When possible, it should be discharged vertically upward.

Resilient mountings for fan motors and small compressors and isolation pads for larger motors and compressors help to reduce noise transmission. Proper discharge line sizing and mufflers are the best solution for high-velocity gas noise. Lining enclosures with sound-absorbing material is of minimal value. Isolation pads can help on roof-mounted units, but even more important is choosing the right location with respect to the supporting structure, so that structural member vibration does not amplify the noise.

If sound levels are still excessive after the previously mentioned controls have been implemented, location becomes the greatest single factor. Distance from a sensitive area is most important in choosing a location; each time the distance from the source is doubled, the noise level is halved. Direction is also important. Condenser air intakes should face parking lots, open fields, or streets zoned for commercial use. In sensitive areas, ground-level installation close to building walls should be avoided because walls reflect sound.

When it is impossible to meet requirements by adjusting location and direction, barriers can be used. Although a masonry wall is an effective barrier, it may be objectionable because of cost and weight. If a barrier is used, it must be sealed at the bottom because any opening will allow sound to escape. Barriers also must not restrict condenser entering air. Keep the open area at the top and sides at least equal to the condenser face area.

When noise is a consideration, (1) purchase equipment designed to operate as quietly as possible (e.g., 850 rpm condenser fan motors instead of higher-speed motors); (2) choose the location carefully; and (3) use barriers when the first two steps do not meet requirements.

See [Chapter 47 of the ASHRAE Handbook—Applications](#) for information on outdoor sound criteria, equipment sound levels, sound control for outdoor equipment, and vibration isolation.

METHODS OF DEFROST

Defrosting is accomplished by latent heat reverse-cycle gas defrosting, selective ingestion of store air, electric heaters, or cycling the compressor. In the defrost operation, particularly in low-temperature equipment, frost in the air flues and around the fan blades must be melted and completely drained.

Gas Defrost

Gas defrost uses heat from the compressor's discharge gas to defrost the evaporators. To remove the coil frost, the discharge gas is directed to the case evaporator. One method tempers the impact of the hot gas on the cold suction line by beginning the defrost cycle with saturated gas from the top of the liquid in the receiver. Occasionally, supplemental electric case heaters are added to ensure rapid and reliable defrosting. A timer generally terminates the defrost cycle, although temperature termination is sometimes used.

Air Defrost

Air defrost moves ambient air from the store into the refrigerator. A variety of systems are used; some use supplemental electric heat to ensure reliability. The heat content of the store ambient air during the winter is critical for good results from this method.

Electric Defrost

Electric defrost methods usually apply heat externally to the evaporator and require a longer defrost period than the gas defrost method, usually up to 1.5 times longer. The heating element may be in direct contact with the evaporator, depending on conduction for defrost; or it may be located between the evaporator fans and the evaporator, depending on convection or a combination of conduction and convection for defrost. In both instances, the manufacturer generally installs a temperature-limiting device on or near the evaporator to prevent excessive temperature rise if any controlling device fails to operate.

The electric defrost method simplifies the installation of low-temperature fixtures. The controls used to automate the cycle usually include one or more of these devices: (1) defrost timer, (2) solenoid valve, (3) electrical contactor, and (4) evaporator fan delay switch. Some applications of open low-temperature cases may operate the fans during the defrost cycle.

Condensing Unit Off-Time

This method simply shuts off the unit and allows it to remain off until the evaporator reaches a temperature that permits defrosting and gives ample time for condensate drainage. Because this method obtains its heat from the air circulating in the display fixture, it is slow and limited to open fixtures operating at temperatures of 1°C or above. Methods of defrost control include (1) suction pressure control (no time clock required); (2) time clock initiation and termination; (3) time clock initiation and suction pressure termination; (4) time clock initiation and temperature termination; and (5) demand defrost or proportional defrost.

Suction Pressure Control. This control is adjusted for a cut-in pressure high enough to allow defrosting during the off cycle. This method is usually used in fixtures maintaining temperatures from 3 to 6°C. Air is circulated over the coil, melting the frost on the coil. This provides some cooling effect to the product during defrost. If an excessive heat or humidity load occurs, the evaporator frost becomes ice. When the evaporator pressure is lowered to the cutout point of the control, the control initiates a defrost cycle to clear the evaporator.

However, condensing units and/or suction lines may, at times, be subjected to ambient temperatures below the evaporator's temperature. This prevents the buildup of suction pressure to the cut-in point, and the condensing unit will remain off for prolonged periods. In such instances, fixture temperatures may become excessively high, and displayed product temperatures will increase.

A similar situation can exist if the suction line from a fixture is installed in a trench or conduit with many other cold lines. The other cold lines may prevent the suction pressure from building to the cut-in point of the control.

Methods (2), (3), and (4) of controlling off-cycle defrosting use defrost time clocks to break the electrical circuit to the condensing unit initiating a defrost cycle. The difference lies in the manner in which the defrost period is terminated.

Initiation and Termination

Defrosting is usually controlled by a variety of clocks, which are often part of a compressor controller system. Electronic systems often have communication capabilities outside the store.

Time Initiation and Termination. A timer initiates and terminates the defrost cycle after the selected time interval. The length of the defrost cycle must be determined and the clock set accordingly.

Time Initiation and Suction Pressure Termination. This method is similar to the first method, except that suction pressure terminates the defrost cycle. The length of the defrost cycle is automatically adjusted to the condition of the evaporator, as far as frost and ice are concerned. However, to overcome the problem of the suction pressure not rising because of the defrost cut-in pressure previously described, the timer has a fail-safe time interval to terminate the defrost cycle after a preset time, regardless of suction pressure.

Time Initiation and Temperature Termination. This method is also similar to the time initiation and termination method, except that temperature terminates the defrost cycle. The length of the defrost cycle varies depending on the amount of frost on the evaporator or in the air stream leaving the evaporator. A temperature sensor is located on a tube of the evaporator or in the airstream leaving the evaporator. The timer also has a fail-safe setting in its circuit to terminate the defrost cycle after a preset time, regardless of the temperature.

Demand Defrost or Proportional Defrost. This system initiates defrost based on demand (need) or in proportion to humidity or dew point. Techniques vary from measuring change in the temperature spread between the air entering and leaving the coil, to changing the defrost frequency based on store relative humidity. Other systems use a device that senses the frost level on the coil.

REFRIGERANT LINES

Sizing liquid and suction refrigerant lines is critical in the average refrigeration installation due to the typically long horizontal runs and frequent use of vertical risers. Correct liquid line sizes are essential to ensure a full feed of liquid to the expansion valve. Oversizing of liquid lines must be avoided to prevent system pumpdown or defrost cycles from operating improperly in single-compressor systems.

Proper suction line sizing is required to ensure adequate oil return to the compressor without excessive pressure drop. Oil separates in the evaporator and moves toward the compressor at a lower velocity than the refrigerant. Unless the suction line is properly installed, the oil can accumulate at low places, causing problems such as compressor damage from liquid slugging or insufficient lubrication. Excessive pressure drop and reduced system capacity can also result from undersized or improperly installed suction lines. To prevent these problems, horizontal suction lines must pitch down as the gas flows toward the compressor, the bottom of all suction risers must be trapped, and the refrigerant velocity in suction risers must be maintained according to piping practices described in [Chapters 2](#) and [3](#). To overcome a large pressure drop, the suction lines may be oversized on long runs, but they still must pitch down toward the compressor.

Manufacturers' recommendations and appropriate line sizing charts should be followed to avoid adding heat to either the suction or the liquid lines. In large stores, both suction and liquid lines can be insulated profitably, particularly if subcooling is present.

REFRIGERANTS

Selection of a suitable refrigerant for food stores has been affected by international concern about the ozone-depleting effect of chlorine-containing refrigerants. International treaties no longer allow developed nations to manufacture equipment that uses chlorofluorocarbon refrigerants. Hydrochlorofluorocarbon refrigerants, such as R-22, are still popular while their prices remain low and availability is assured for a reasonable time, although their consumption and production are scheduled to be phased out entirely by 2030. Current hydrofluorocarbon alternatives in use in the United States include R-404A, R-134a, and R-507. Other refrigerants are listed in ASHRAE *Standard 34*.

Compressor performance and material compatibility are two major concerns in selecting new refrigerants. Significant research has been performed in the last years to address these concerns through which reliability of the equipment has been demonstrated. Retrofit recommendations have also been developed by the equipment and refrigerant manufacturers to guide stores in converting their systems from ozone-depleting substances to alternatives. Close consultation with equipment manufacturers must be maintained in order to stay current on this issue.

The concern about ozone depletion has led to regulations by the U.S. Environmental Protection Agency to minimize emissions of the refrigerants. Intentional venting of all refrigerants, including the substitutes, is prohibited. Additional regulations apply to chlorine-containing refrigerants such as R-22. When systems containing more than 22.7 kg of refrigerant leak more than 35% of the charge per year, equipment repairs are required. Certain servicing and record keeping practices are also required. Future regulations have been proposed to extend these regulations to the hydrofluorocarbon substitutes and to tighten the leak repair requirements. These developments should be monitored.

INTERACTION BETWEEN REFRIGERATION AND AIR CONDITIONING

Open display equipment often extracts enough heat from the store's ambient air to reduce the air temperature in the customer aisles to as much as 9 K below the desired level. The air-conditioning return duct system or fans can be used to move chilled air from the floor in front of the cases back to the store air handler. Lack of attention to this element can substantially reduce sales in these areas.

Heat Reclamation

Heat reclaim condensers and related controls operate as alternates to or in series with the normal refrigeration condensers. They can be used in winter to return most of the refrigeration and compressor heat to the store. They may also be used in mild spring and fall weather when some heating is needed to overcome the cooling effect of the refrigeration system itself. Another use is for cooling coil reheat when needed for humidity control in spring, summer, and fall. Excess humidity in the store must be avoided because it can increase the display case refrigeration load as much as 20% at the same dry-bulb temperature. Also, heat reclamation can be used to heat water for store use. The section on Supermarkets in [Chapter 2 of the ASHRAE Handbook—Applications](#) has more detailed information on the interrelation of the store environment and the refrigeration equipment.

Environmental Equipment and Control

Major components of common store environmental equipment include (1) central air handler with fresh makeup air mixing box, (2) air-cooling coils, (3) heat recovery coils, (4) supplemental heat

equipment, (5) connecting ducts, and (6) termination units such as air diffusers and return grilles.

Environmental control is the heart of energy management. Control panels designed for the unique heating, cooling, and humidity control requirements for food stores provide several stages of heating (up to eight) and cooling (up to three), plus a dehumidification stage. When high humidity exists in the store, cooling is activated to remove moisture. The controller receives input from temperature and dew point sensors that are located in the sales area.

Some controllers include night setback for cool climates and night setup for warm climates. This feature may save energy by turning the air handler off and allowing the store temperature to fluctuate several degrees above or below the set point temperature. However, store warm-up practices impose an energy use penalty to the display case refrigeration systems and affect display case performance, particularly open models.

Following are rules for good air distribution in food stores:

Air Circulation. Operate 100% of the time the store is open at a volumetric flow of 3 to 5 L/s per square metre of sales area. Air supply and return grilles should be located so they do not disturb the air in open display cases and negatively affect case performance.

Fresh Air. Introduce whenever the air handler is operating. Supply should meet the required indoor air quality or equal the total for all exhaust fans, whichever is greater.

Discharge Air. Discharge most or all of the air in areas where heat loss or gain occurs. This load is normally at the front of the store and around glass areas and doors.

Return Air. Locate return air registers as low as possible. With low registers, return air temperature may be 10 to 13°C. Low returns reduce heating and cooling requirements and temperature stratification. A popular practice, where store construction allows, is to return air under case ventilated bases and through trenches.

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