Related Commercial Resources

CHAPTER 46

RETAIL FOOD STORE REFRIGERATION AND EQUIPMENT

IN the United States, almost 200,000 retail food stores operate their refrigeration systems around the clock to ensure proper merchandising and safety of their food products. Figure 1 shows that supermarkets and convenience stores make the largest contribution to this total (Food Marketing Institute 2004). In U.S. retail food stores, refrigeration consumes about 2.3% of the total electricity consumed by all commercial buildings (EIA 2003). 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 43 kWh/ft^2 per year. Use for larger supermarkets with long operating hours has been measured at 70 kWh/ft^2 per year (Komor et al. 1998).

The modern retail food store is a high-volume sales outlet with maximum inventory turnover. The Food Marketing Institute defines a **supermarket** as any full-line self-service grocery store with an annual sales volume of at least $2 million (Food Marketing Institute 2004). These stores typically occupy approximately 50,000 ft^2 and offer a variety of meat, produce, and groceries. A new category of supermarkets, called **supercenters**, incorporates a supermarket section and a general merchandise/dry goods section in one building. Almost half of retail food sales are of perishable or semiperishable foods requiring refrigeration, including fresh meats, dairy products, perishable produce, frozen foods, ice cream and frozen desserts, and various specialty items such as bakery and deli products and prepared meals. These foods are displayed in highly specialized and flexible storage, handling, and display apparatus. Many supermarkets also incorporate food service operations that prepare the food.

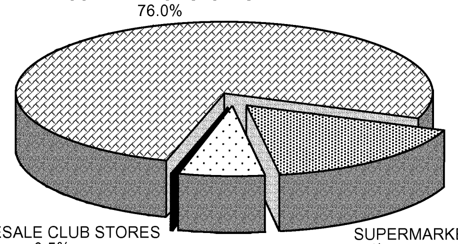

Fig. 1 Distribution of Stores in Retail Food Sector

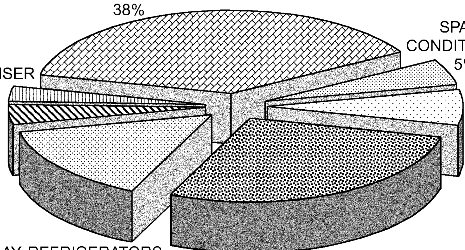

Fig. 2 Percentage of Electric Energy Consumption, by Use Category, of a Typical Large Supermarket

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 that includes specialized refrigerated rooms. All refrigeration-related areas must be coordinated during construction planning because of the interaction between the store's environment and its refrigeration equipment. Chapter 2 of the 2003 *ASHRAE Handbook—HVAC 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 47 presents food service and general commercial refrigeration equipment. Equipment may also be categorized by temperature: **medium-temperature** refrigeration equipment maintains an evaporator temperature between 0 and 40°F and product temperatures above freezing; **low-temperature** refrigeration equipment maintains an evaporator temperature between –40 and 0°F and product temperatures below freezing.

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 local preferences, local income level, store size, sales volume, and local availability of food items by type. Display refrigerators provide easy product access and viewing, and typically include additional lighting to highlight the product for sale.

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

Medium- and low-temperature display refrigerator lineups account for roughly 68 and 32%, respectively, of a typical supermarket's total display refrigerators (Figure 3). In addition, open vertical meat, deli, and dairy refrigerators comprise about 46% of the total display refrigerators (Faramarzi 2000).

Many operators combine single- and multideck models in most departments where perishables are displayed and sold. Closed-service refrigerators are used to display unwrapped fresh meat,

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

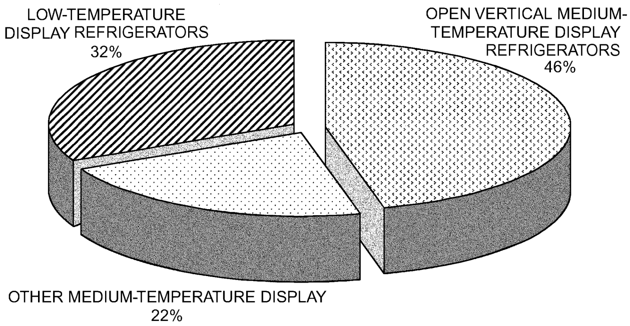

Fig. 3 Percentage Distribution of Display Refrigerators, by Type, in a Typical Supermarket

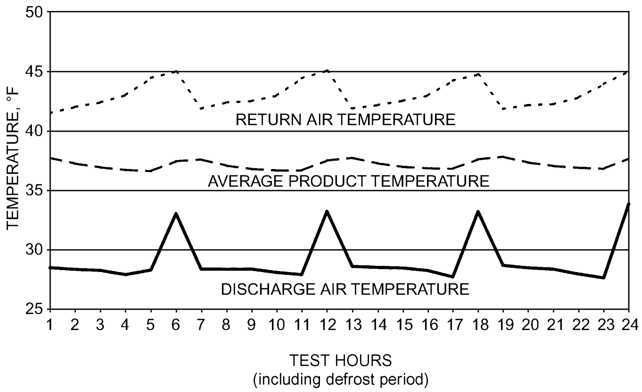

Fig. 4 Selected Temperatures in an Open Vertical Meat Display Refrigerator

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 refrigerator. 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 storage. Proper maintenance of product temperature plays a critical role in food safety. An estimated 24 to 81 million people annually become ill from microorganisms in food, resulting in an estimated 10,000 needless deaths every year. As a result, in 1995 the Food and Drug Administration (FDA) *Food Code* recommended a lower storage temperature for certain refrigerated food products for further prevention of foodborne diseases. The FDA 2001 *Food Code* requires that the core temperature of meat, poultry, fish, dairy, deli, and cut produce not exceed 41°F throughout packaging, shipping, receiving, loading, and storing (FDA 2001).

Proper maintenance of product temperature relies heavily on the temperature of air discharged into the refrigerator. Table 1 lists discharge air temperatures in various display refrigerators. Compliance with FDA requirements may require different refrigerator air

Table 1 Air Temperatures in Display Refrigerators

	Air Discharge Temperatures, °F [a]	
Type of Fixture	**Minimum**	**Maximum**
Dairy		
Multideck	34	38
Produce, packaged		
Single-deck	35	38
Multideck	35	38
Meat, unwrapped (closed display)		
Display area	36[b]	38[b]
Deli smoked meat		
Multideck	32	36
Meat, wrapped (open display)		
Single-deck	24	26
Multideck	24	26
Frozen food		
Single-deck	[c]	−13[c]
Multideck, open	[c]	−10[c]
Glass door reach-in	[c]	−5[c]
Ice cream		
Single-deck	[c]	−24[c]
Glass door reach-in	[c]	−13[c]

[a]Air temperatures measured with thermometer in outlet of refrigerated airstream and not in contact with displayed product.
[b]Unwrapped fresh meat should only be displayed in a closed, service-type display refrigerator. Meat should be cooled to 36°F internal temperature before placing on display. Refrigerator air temperature should be adjusted to keep internal meat temperature at 36°F or lower for minimum dehydration and optimum display life. Display refrigerator air temperature varies with manufacturer.
[c]Minimum temperatures for frozen foods and ice cream are not critical (except for energy conservation); maximum temperature is important for proper preservation of product quality. Differences in display temperatures among the three different styles of frozen food and ice cream display refrigerators are caused by orientation of refrigeration air curtain and size and style of opening. Single-deck refrigerators have a horizontal air curtain and opening of approximately 30 to 42 in. Multideck, open refrigerators have a vertical air curtain and an opening of about 42 to 50 in. Glass door reach-in refrigerators have a vertical air curtain protected by a multiple-pane insulated glass door.

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 refrigerator. 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 et al. 2001).

Product temperatures inside a display refrigerator may also vary, depending on the location of the product. Figure 5 depicts product temperature profiles and variations for an open vertical meat display refrigerator over a period of 24 h. As shown, the lowest product temperatures are 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. When put into the refrigerator, merchandise 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. Most manufacturers provide indicators of physical load limits that define the refrigerated zone. The product on display should never be loaded so that it is out of the load limit 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,

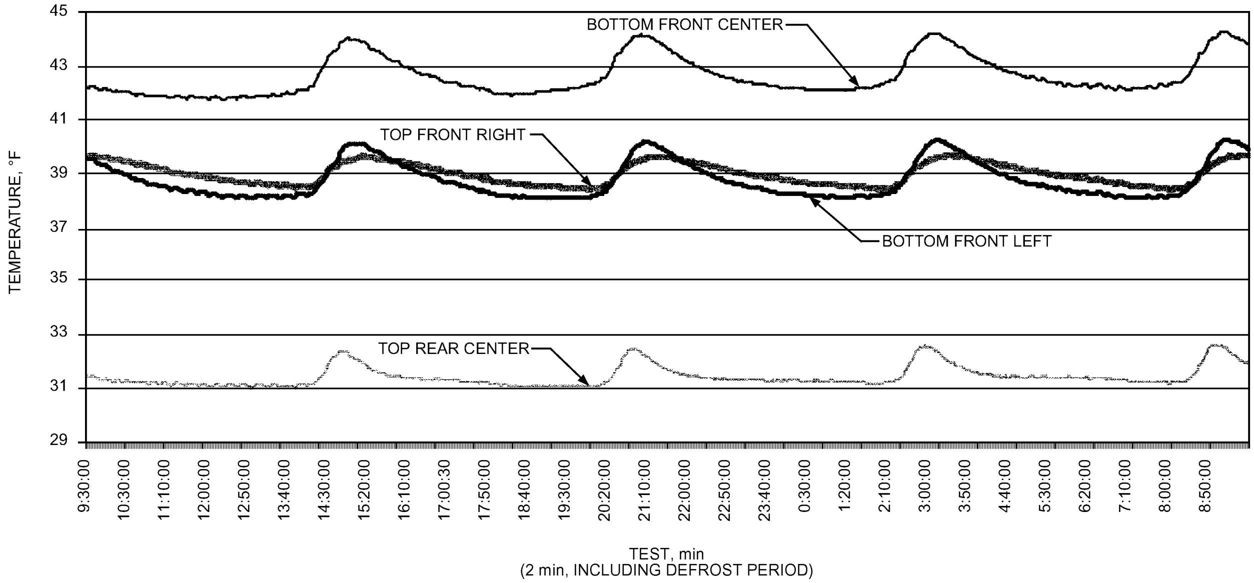

Fig. 5 Product Temperature Profiles at Four Different Locations Inside a Multideck Meat Refrigerator (Average Discharge Air Temperature of 29°F)

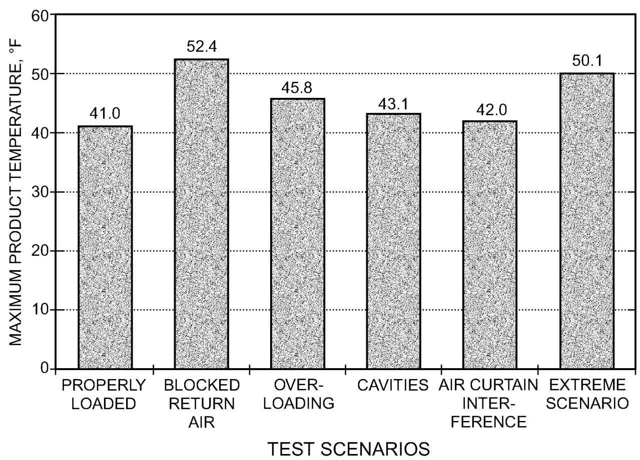

Fig. 6 Comparison of Maximum Product Temperature Variations Under Different Improper Product Loading Scenarios in an Open Vertical Meat Display Refrigerator

maximize efficiency of the refrigeration equipment, maximize food safety, and minimize product loss.

In actual applications, however, products may not always be loaded properly. Survey results (Faramarzi 2003) reveal that improper loading of products inside display refrigerators may fall into the following categories:

- Blocked return air (products block the return air grille)
- Overloading (products loaded beyond the load limit zones)
- Cavities (products loaded nonuniformly, leaving empty spots or voids 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)

Improper loading of the products can significantly affect maximum product temperatures, which adversely affects food safety and product loss. Figure 6 depicts the consequences of various improper product-loading scenarios on maximum product temperature of an open vertical meat display refrigerator (Faramarzi 2003).

Additionally, packaging may also affect food temperatures. The surface temperature of a loosely wrapped package of meat with an air space between the film and surface may be 2 to 4°F higher than the surrounding air inside the display refrigerator.

Table 2 Average Store Conditions in the United States

Season	Dry-Bulb Temperature, °F	Wet-Bulb Temperature, °F	Pounds Moisture per Pound Dry Air	rh, %
Winter	69	54	0.0054	36
Spring	70	58	0.0079	50
Summer	71	61	0.0091	56
Fall	70	58	0.0079	50

Store Conditions Survey conducted by Commercial Refrigerator Manufacturers' Association from December 1965 to March 1967. About 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.

Store Ambient Effect

Display fixture performance is affected significantly by the temperature, humidity, and movement of surrounding air. Display refrigerators 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 operating) exceeded 75°F db or 0.0102 lb of moisture per pound of dry air. Based on these data, the industry chose 75°F db and 64°F wb (55% rh, 57.5°F dew point) as summer design conditions. This is the ambient condition at which refrigeration load for food store display refrigerators is normally rated.

Store humidity is one of the most critical variables that can affect performance of display refrigerators 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 refrigerator condensate and relative humidity. The increase in frost accumulation on the evaporator coils, and consequent increase in

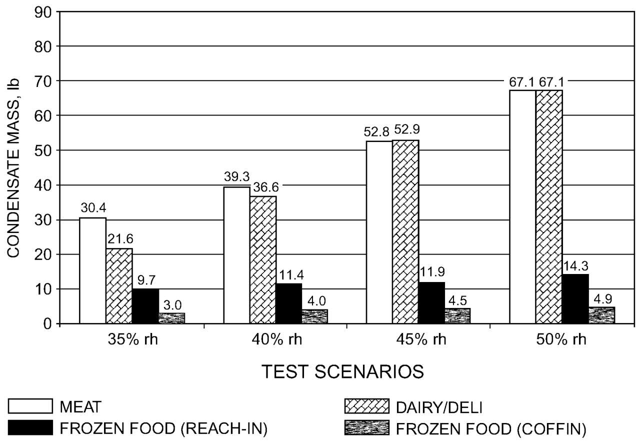

Fig. 7 Comparison of Collected Condensate vs. Relative Humidity for Open Vertical Meat, Open Vertical Dairy/Deli, Narrow Island Coffin, and Glass Door Reach-In Display Refrigerators

(Gas Research Institute 2000)

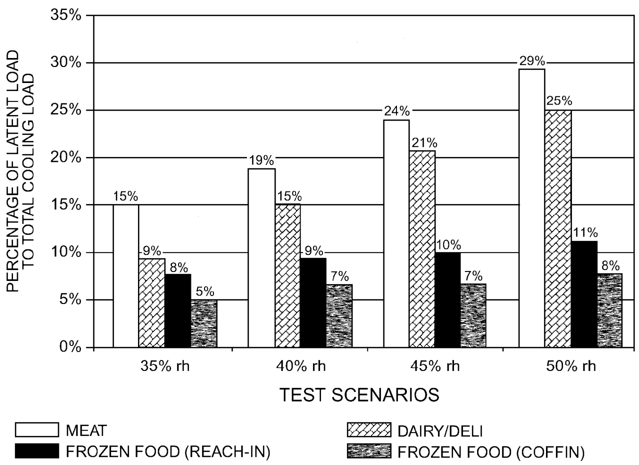

Fig. 8 Percentage of Latent Load to Total Cooling Load at Different Indoor Relative Humidities

(Gas Research Institute 2000)

condensate weight, is more drastic for open vertical display refrigerators. 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 refrigerators (Gas Research Institute 2000).

Increased frost formation from higher relative humidities increases latent load, which the refrigeration system must remove (Figure 8). Additional defrosts may be needed to maintain the product at its desired temperature.

When store ambient relative humidity is different from that at which the refrigerators were rated, the energy requirements for refrigerator operation will vary. Howell (1993a, 1993b) concludes that, compared to operation at 55% store rh, display refrigerator energy savings at 35% rh range from 5% for glass door reach-in refrigerators to 29% for multideck deli refrigerators. Table 3 lists correction factors for the effect of store relative humidity on display refrigerator refrigeration requirements when the dry-bulb temperature is 70 and 78°F.

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

Table 3 Relative Refrigeration Requirements with Varying Store Ambient Conditions

Refrigerator Model	70°F db					78°F db		
	Relative Humidity, %					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.

[a]More frequent defrosts required.

[b]More frequent defrosts required plus internal condensation (not recommended).

reductions in antisweat heaters and fewer defrosts, allowing substantial energy savings on a storewide basis.

The application engineer needs to verify that the year-round store ambient conditions are within the performance ratings of the various refrigerators selected for the store. Because relative humidity varies throughout the year, the dew point for each period should be analyzed. The sum of these refrigerator 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, whereas 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%, whereas 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 refrigerator antisweat heaters can only be taken if the display refrigerators 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 store relative humidity decreases (**demand defrost**). 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, because this raises the refrigeration requirements and consequently the energy demand.

Display Refrigerator Cooling Load and Heat Sources

Heat transfer in a display refrigerator involves interactions between the product and the internal environment of the refrigerator, as well as heat from the surroundings that enters the refrigerator. Heat components from the surrounding environment include transmission (or conduction), radiation, and infiltration, whereas heat components from the internal environment include lights and evaporator fan motor(s). In addition, defrost and antisweat heaters also increase the cooling load of a display refrigerator. Conduction, radiation, and infiltration loads from the surroundings into the refrigerator, as well as heat exchanges between the product and parts of the refrigerator, depend on the temperatures of ambient air and air within the refrigerator. Open vertical display refrigerators rely on their air curtains to keep warm ambient air from penetrating into the cold environment inside the refrigerator. 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 refrigerator. Air curtains play a significant role in the thermal interaction of the display refrigerator with the surrounding air (see Figure 10).

The cooling load of a typical display refrigerator 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), antisweat heater, conduction, radiation, infiltration, and product pulldown load. The latent portion consists of infiltration and product latent heat of respiration.

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

Radiation Load. The heat gain of the display refrigerator through radiation is a function of conditions inside the refrigerator, 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 refrigerator refers to the net entrainment of warm, moist air through the 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 refrigerator temperatures and humidity ratios
- Rate of air curtain agitation caused by shoppers passing
- Thermo-fluid boundary condition in the initial region of the jet

Sensible Infiltration. The sensible portion of infiltration refers to the direct heat added by the temperature difference between cold air in the refrigerator and warm room air drawn into the refrigerator.

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

Internal Loads. The internal load includes heat from refrigerator lights and evaporator fan motors. The lamps, ballasts, and fan motors are typically located within the thermodynamic boundary of the display refrigerator; therefore, their total heat dissipation should be considered part of the refrigerator load. High-intensity lighting raises product temperatures and can discolor meats. Refrigerator shelf ballasts are sometimes located out of the refrigerated space to reduce refrigerator cooling load. Standard lighting equipment, which typically consists of T12 fluorescent lamps with magnetic ballast, draws approximately 0.73 A at 120 V.

Defrost Load. Refrigeration equipment in applications where frost can accumulate on the evaporator coils have some type of defrost mechanism. During defrost, refrigeration is stopped on the defrosting circuits and heat is introduced into the refrigerator. Defrost methods vary, depending on the refrigeration application and storage temperatures, as discussed in the section on Methods of Defrost. Some defrost methods deliver more heat than is needed to melt the ice. A large portion of the extra heat warms the coil metal, product (see Figures 4 and 5), and refrigerator. This extra heat adds to the refrigeration load and is called the postdefrost pulldown load (Faramarzi 1999).

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 refrigerator. Antisweat heaters are used on most low-temperature open display refrigerators, as well as reach-in refrigerators with glass doors. These electric resistance heaters are located around the handrails of tub refrigerators and door frame/mullions of reach-in refrigerators to prevent condensation on metal surfaces. They also reduce fogging of the glass doors of reach-in refrigerators, a phenomenon that can hurt product merchandising. Without appropriate control systems, ASH units stay on round the clock. The cooling load contribution of ASH in a typical reach-in display refrigerator can reach 35% of their connected electric load (Faramarzi et al. 2001).

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

- **Case product load.** This pulldown load is caused by product delivery into the refrigerator 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 temperature.
- **Postdefrost load.** During the defrost cycle, product temperature inside the refrigerator rises. Once defrost is complete, the refrigeration system turns on and must remove the accumulated defrost heat and lower the product temperature to a desirable set point.

According to a test report by Gas Research Institute (2000), the major contributor to the total cooling load of open display refrigerators are infiltration and radiation (Figure 9). Infiltration constitutes approximately 80% of the cooling load of a typical medium-temperature open vertical display refrigerator. The relative role of infiltration diminishes for low-temperature open coffin (or tub) refrigerators, and is supplanted by radiation. Infiltration and radiation constitute roughly 24 and 43%, respectively, of the cooling load of a typical open coffin refrigerator.

Multideck open refrigerator shelves are an integral part of the air curtain and airstream. Without shelves, there will be substantial air distribution problems. An air deflector may be required when shelves are removed. As shown in Figure 9, infiltration through the air curtain plays a significant role in the cooling load of open vertical display refrigerators (Faramarzi 1999). Figure 10 depicts the air curtain velocity streamlines of an 8 ft open vertical meat display refrigerator. These velocity streamlines represent the actual airflow patterns using

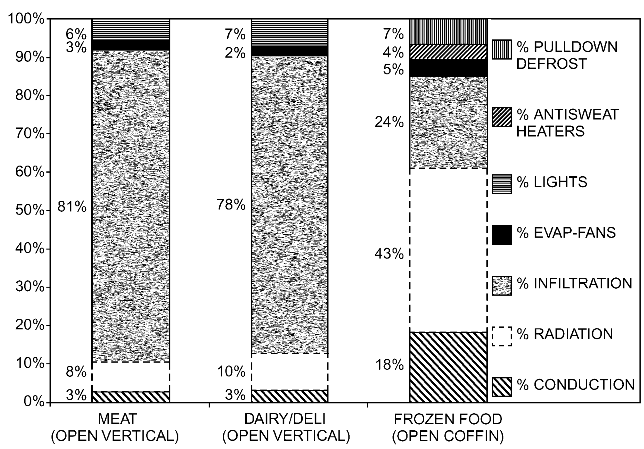

Fig. 9 Components of Refrigeration Load for Several Display Refrigerator Designs at 75°F db and 55% rh

digital particle image velocimetry. As shown, warm air is entrained into the display refrigerator 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 refrigerator spills into the room near the return air grille of the fixture.

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 refrigerator interiors when adjacent refrigerators 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) front rails or center flue of the refrigerator. In glass door reach-in freezers or medium-temperature refrigerators, the frame jambs and 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 necessary. 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 refrigeration requirements, it also reduces the need to heat the surfaces of refrigerators. This heat not only consumes energy, but 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 particular 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.

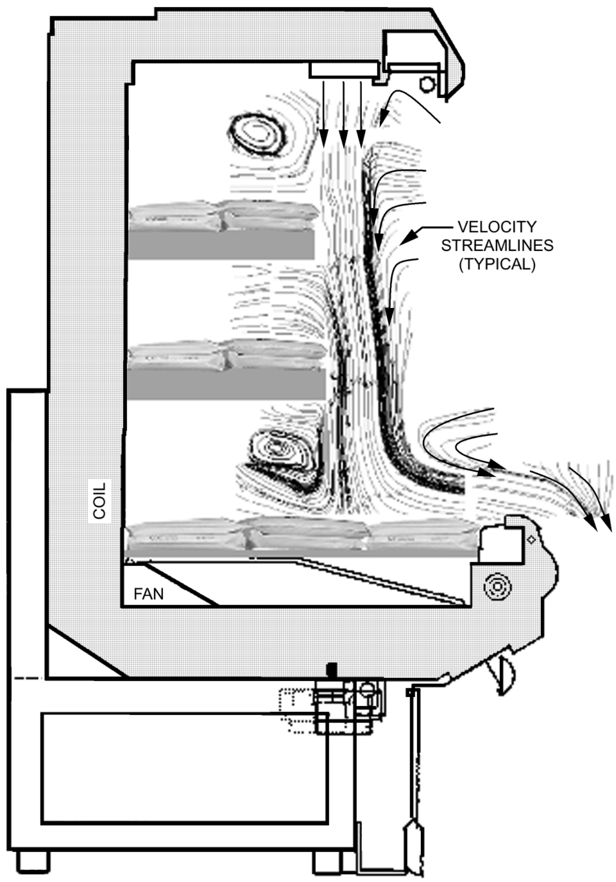

Fig. 10 Velocity Streamlines of a Single-Band Air Curtain in an Open Vertical Meat Display Refrigerator, Captured Using Digital Particle Image Velocimetry Technique

Cleaning and Sanitizing Equipment

Because the evaporator coil is the most difficult part to clean, 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.

Refrigeration Systems for Display Refrigerators

Self-Contained. Self-contained systems, in which the condensing unit and controls are built into the refrigerator structure, are usually air-cooled and are of two general types. The first type has the condensing unit beneath the cabinet; in some designs, it takes up the entire lower part of the refrigerator, but in others it occupies only one lower corner. The second type has the condensing unit on top.

Remote. Remote refrigeration systems are often used if cabinets are installed in a hot or otherwise unfavorable location where the noise or heat of the condensing units would be objectionable. Remote systems can take advantage of cool ambient air and provide lower condensing temperatures, which allows more efficient operation of the refrigeration system.

Merchandising Applications

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. 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. The front of the refrigerator may be open or have glass doors.
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 refrigerators.

Meat Display. Most meat is sold prepackaged. 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. Meat surface temperatures over 40°F shorten its salable life significantly and increase the rate of discoloration.

The design of open fresh meat display refrigerators, either tub-type single-deck or vertical multideck, is limited by the freezing point of meat. Ideally, refrigerators are set to operate as cold as possible without freezing the meat. Temperatures are maintained with minimal 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 increase the salable life of meat in a display refrigerator. In this chapter, sanitation includes limiting the amount of time meat is exposed to temperatures above 40°F. If meat has been handled in a sanitary manner before being placed in the display refrigerator, elevated temperatures can be more tolerable. When meat surfaces are contaminated by dirty knives, meat saws, table tops, etc., even optimum display temperatures will not prevent premature discoloration and subsequent deterioration of the meat. See the section on Meat Processing Rooms 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 cold airflow refrigerates each package, the surface temperature (and thus bacterial growth) is cumulatively increased by

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

Improper control of these factors may cause meat surface temperatures to rise above values 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 40°F. However, the required diligence is rewarded by excellent shelf life, improved product integrity, higher sales volume, and less scrap or spoilage.

Surface temperatures rise 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.

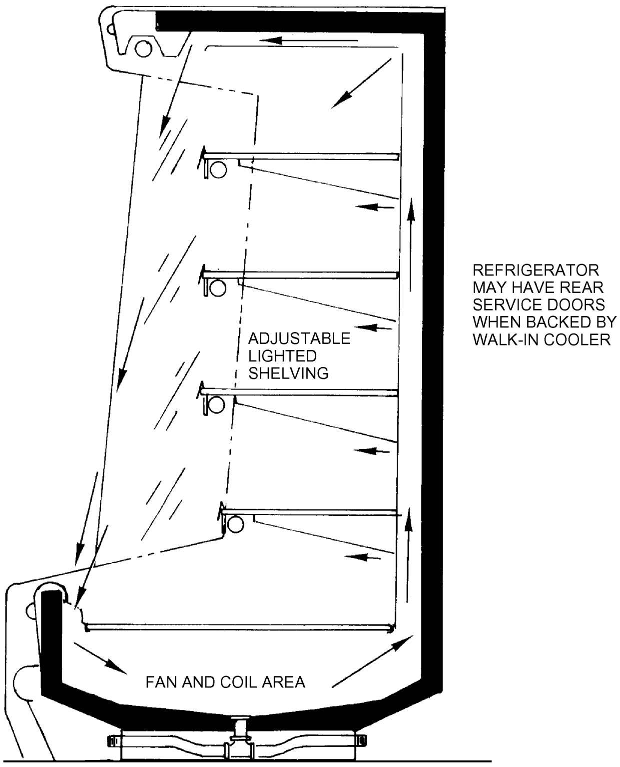

Fig. 11 Multideck Dairy Display Refrigerator

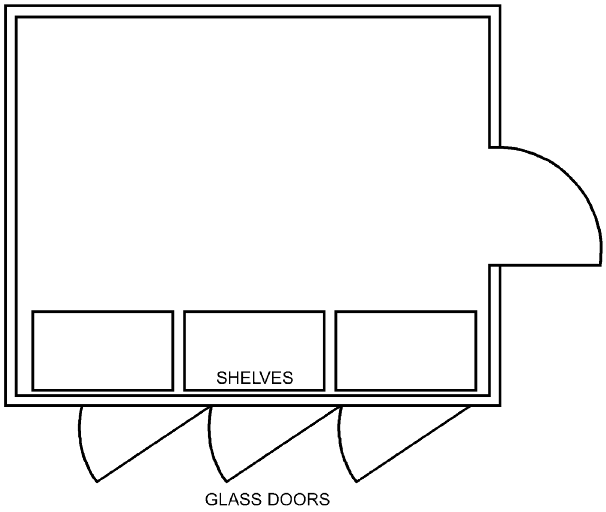

Fig. 12 Typical Walk-In Cooler Installation

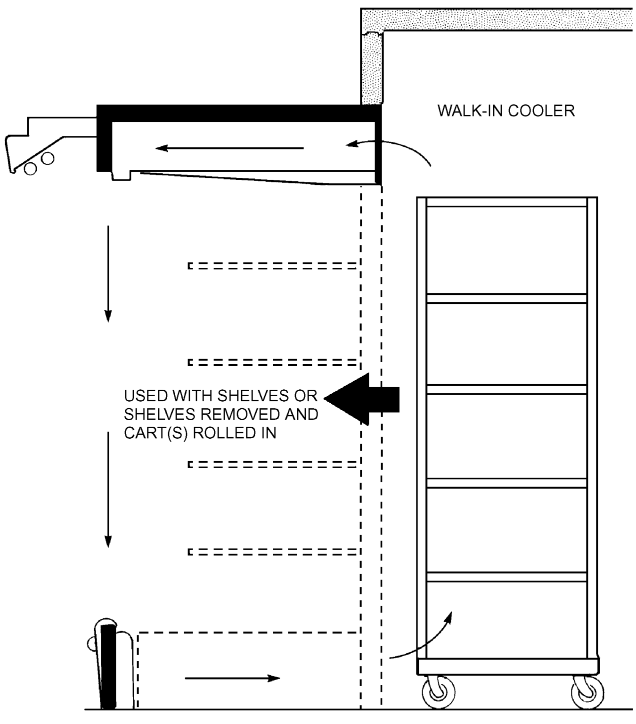

Fig. 13 Vertical Rear-Load Dairy (or Produce) Refrigerator with Roll-In Capability

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. Processed meat can be displayed in similar refrigerators as fresh packaged meat, but at slightly higher temperatures. The meat department planner can select from a wide variety of available meat display possibilities:

- Single-deck refrigerators, with optional rear or front access storage doors (Figure 14)
- Multideck refrigerators, with optional rear access (Figure 15)
- Either of the preceding, with optional glass fronts

All these refrigerators are available with a variety of lighting, superstructures, shelving, and other accessories tailored to special 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 can be grouped in one of the following categories:

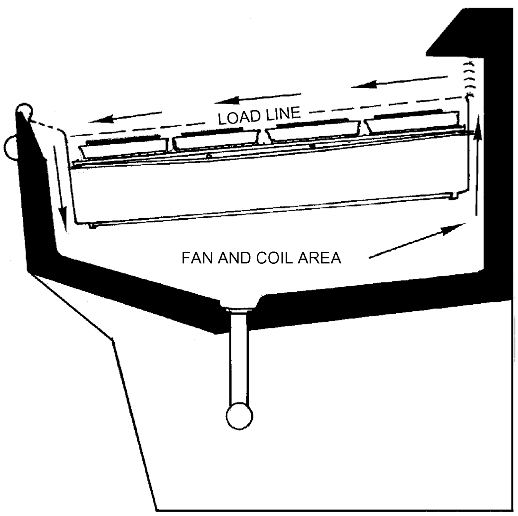

Fig. 14 Single-Deck Meat Display Refrigerator

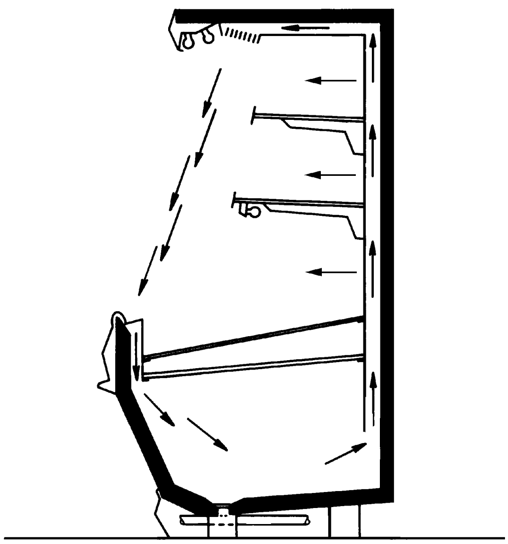

Fig. 15 Multideck Meat Refrigerator

- Fresh red meat, with optional storage compartment (Figure 16)
- Deli and smoked or processed meats, with optional storage
- Fresh fish and poultry, usually without storage but designed to display products on a bed of cracked ice

Closed-service meat display refrigerators are offered in a variety of configurations. Their fronts may be nearly vertical or angled up to 20° from vertical in flat or curved glass panels, either fixed or hinged, and they are available with gravity or forced-convection coils. 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 it affects the internal product display zone temperature and humidity.

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 leafy vegetables to retain their crispness and freshness. Produce is often displayed on a bed of ice for visual appeal. However, packaging prevents air from circulating through wrapped produce and requires higher-velocity air. 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. Available equipment 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 17, usually for multiple-refrigerator lineups near single-deck display refrigerators.
3. Because of the nature of produce merchandising, a variety of nonrefrigerated display units of the same family design are usually designed for connection in continuous lineup with the refrigerators.
4. A refrigerator, similar to 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 or rear-load capability (see Figure 13).

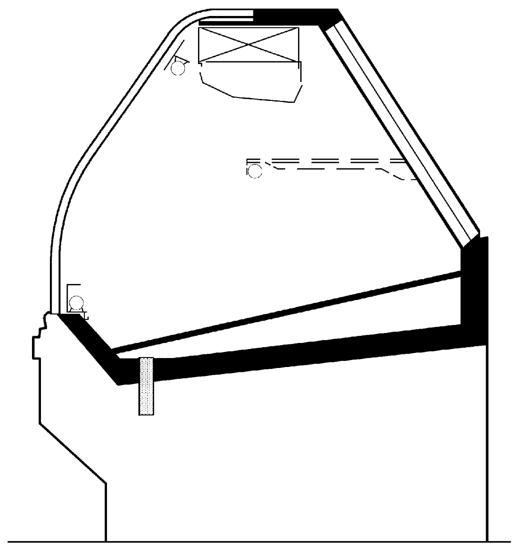

Fig. 16 Closed-Service Display Refrigerator (Gravity Coil Model with Curved Front Glass)

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 tub-type refrigerators for one-side shopping (Figure 18). Many types of merchandising superstructures for related nonrefrigerated foods are available. Configurations 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 19). 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 20). 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 multideck models have two or three air curtains to maintain product temperature and shelf life requirements.
4. Glass door, front reach-in refrigerators (Figure 21), usually of a continuous lineup design. This style allows for maximum inventory volume and variety in minimum floor space. The front-to-back interior dimension of these cabinets is usually about 24 in.

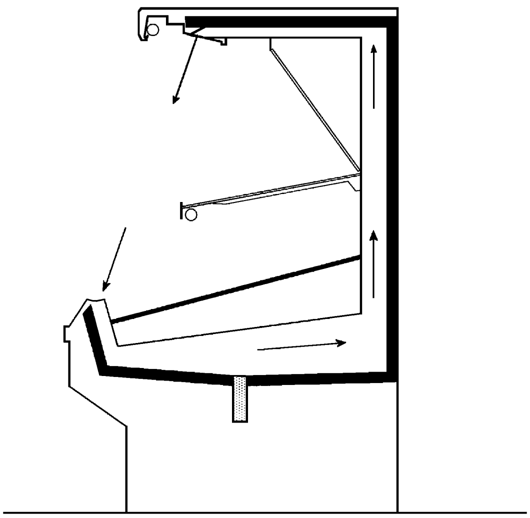

Fig. 17 Multideck Produce Refrigerator

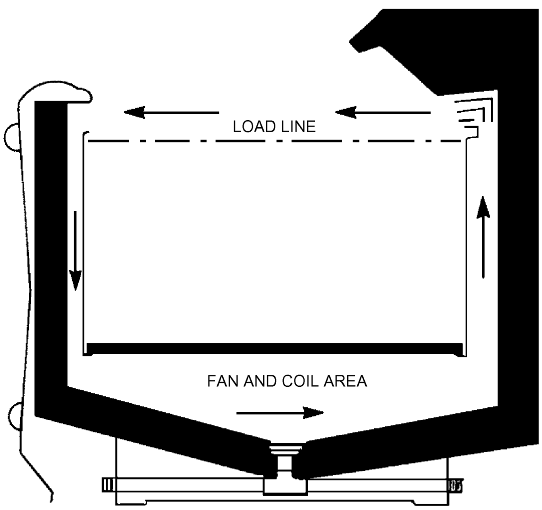

Fig. 18 Single-Deck Tub-Type Frozen Food Refrigerator

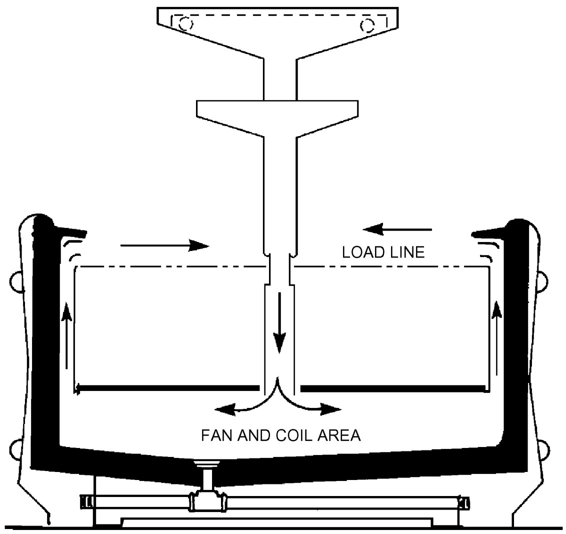

Fig. 19 Single-Deck Island Frozen Food Refrigerator

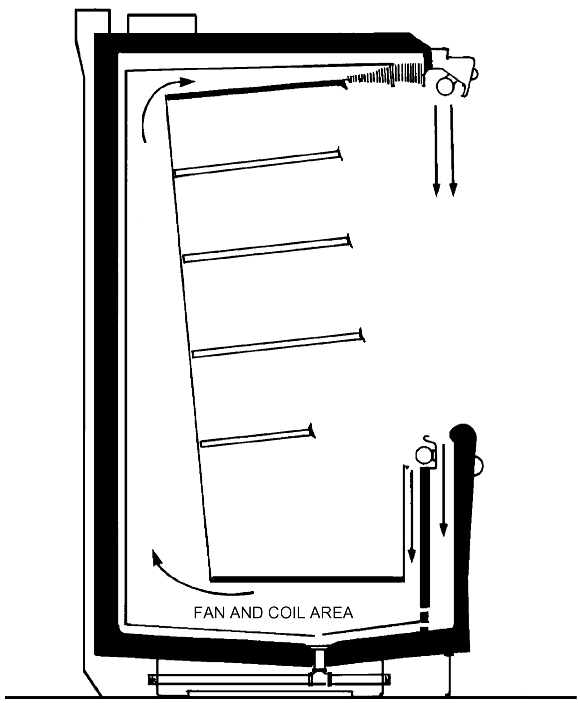

Fig. 20 Multideck Frozen Food Refrigerator

Greater attention must be given to the back product to provide the desired rotation. Although these refrigerators generally consume less energy than open multideck low-temperature refrigerators, specific comparisons by model should be made to determine capital 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 10°F colder required temperature. As display temperature decreases to below 0°F (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.

Energy Efficiency Opportunities in Display Refrigerators

Energy efficiency of display refrigerators can be improved by carefully selecting components and operating practices. Typically, efficiency is increased through one or more of the methods discussed in this section. Different products use different components and design strategies. Some of the following options are mature and tested in the industry, whereas others are emerging technologies. Designers must balance energy savings against customer requirements, manufacturing cost, system performance, reliability, and maintenance costs.

Cooling Load Reduction. Cooling load reduction is the first step to take when attempting to increase refrigeration equipment efficiency. Reducing the amount of heat that needs to be removed from a space leads to instant savings in energy consumption. Display refrigerators should be located to minimize drafts or air curtain disturbance from ventilation ducts, and away from heat sources or direct sunlight. Cooling load of a typical refrigerator is dependent on infiltration, conduction, and radiation from surroundings, as well as heat dissipation from internal components.

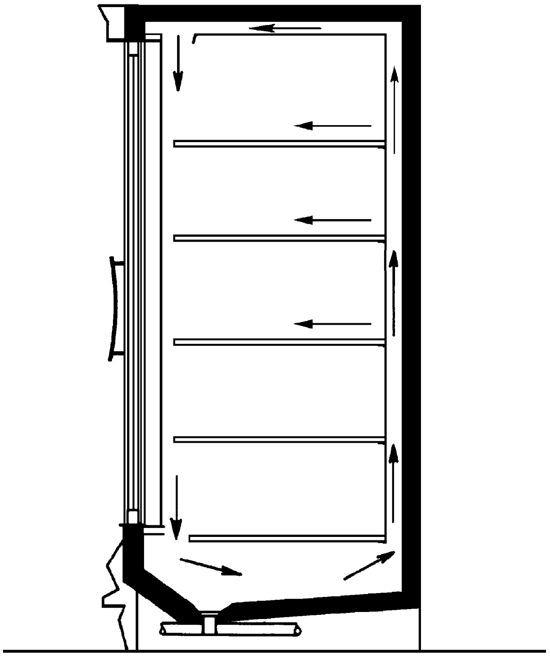

Fig. 21 Glass Door, Medium-Temperature and Frozen Food Reach-In Refrigerator

Infiltration. Research indicates that infiltration of warm and moist air from the sales area into an open vertical display refrigerator accounts for 70 to 80% of the display refrigerator total cooling load (Faramarzi 1999). Infiltrated air not only raises product temperatures, but moisture in the air also becomes frost on the evaporator coil, reducing its heat transfer abilities and forcing the fan to work harder to circulate air through the refrigerator. There are several ways to reduce the amount of infiltration into refrigerators:

- Installing **glass doors on open vertical display refrigerators** provides a permanent barrier against infiltration. Similarly, vertical refrigerators with factory-installed doors eliminate most infiltration and significantly reduce cooling load.
- **Optimizing the air curtain** can drastically reduce its entrainment of ambient air. This ensures that a larger portion of cold air supplied by the refrigerator makes it back to the evaporator through the return air duct.
- In stores that do not operate 24 h per day, installing **night covers** can provide an infiltration barrier during unoccupied hours. Faramarzi (1997) found that 6 h of night cover use can reduce the cooling load by 8% and the compressor power requirement by 9%. Select night curtains that do not condense water on the outside, creating potential for slippery floors. Local health inspectors should also be consulted to ensure that the curtain is considered cleanable and acceptable for use in a grocery store.

Thermal Radiation. Warm objects near the display refrigerator radiate heat into the refrigerated space. Night covers protect against radiation heat transfer.

Thermal Conduction. Improving the R-value of insulation, whether by using materials with low thermal conductivity or simply increasing insulation thickness, reduces conduction heat transfer through walls of the refrigerated space. Conduction accounts for less than 5% of cooling load of medium-temperature refrigerators but almost 20% for low-temperature refrigerators (see Figure 9).

Display Refrigerator Component Improvements. Careful selection of components based on proper application, energy efficiency attributes, and correct sizing can play a significant role in increasing overall system efficiency.

Evaporator. Evaporator coil design can significantly affect refrigerator performance. Efficient evaporator coils allow the refrigerator to maintain its target discharge air temperature while operating at a higher evaporator temperature. Higher evaporator temperature (or suction pressure) has the benefit of increasing its refrigeration effect; however, it also hampers refrigeration system performance by increasing the density of refrigerant entering the compressor, thus increasing compressor work. Evaporator coil characteristics can be improved in four ways:

- **Increased heat transfer effectiveness.** Efficient coils have a greater heat transfer surface area made of materials with improved heat transfer properties to absorb as much heat from the air as possible using optimized fin design. Evaporator fans should also be selected to evenly distribute air through the maximum possible coil face area.
- **Improved coil tube design: low friction and high conduction.** Materials used to construct coils, such as copper, have increased conductivity, which allows heat to transfer through the coil materials more easily. Enhancements to the inside surface of coil tubes can assist heat transfer from the coil material to the refrigerant by creating turbulence in the refrigerant, thereby increasing its contact time with the tube surface. However, caution must be taken when designing these features, because excessive turbulence can cause a pressure drop in the refrigerant and force the compressor to work harder, negating any savings resulting from the enhancement (Dossat 1997).
- **Improved refrigerant distribution.** Coil performance depends on the refrigerant's path through the evaporator coil. For optimal

coil design, the coldest refrigerant should come into contact with the coldest air to ensure maximum heat transfer capability.

- **Frost-tolerant surface.** Typically, the leading edge of the coil shows the worst frosting because moisture in return air condenses as soon as it hits the cold surface. This frost can grow to the point that it severely restricts airflow through the coil. Coils can be manufactured from modules with different fin spacing so that the frost formation is controlled. Larger fin spacing on the leading edge allows moisture to be removed and frost to build, but prevents the coil from becoming totally clogged. Smaller fin spacing can be used toward the trailing edge to maximize heat transfer to lower the air temperature to required levels.

Defrost. Heat added while the refrigeration system is in defrost can raise product temperatures and must be removed later. Defrost methods should be chosen so that the minimum amount of heat is added to the refrigerator. For example, hot-gas defrost can be considered an improved technique.

Demand defrost technologies can sense frost formation on the coil, enabling a controller to determine exactly when the refrigerator should begin its defrost cycle. Unnecessary defrosts and excessive frost formation leading to coil blockage can be eliminated. Care must be used when selecting a demand defrost system: if the system malfunctions, the refrigerators will require service, and there is the potential for product loss.

Sensors may also be used to verify the end of defrost cycles (**intelligent defrost termination**). Typically, the refrigerator is allowed to defrost for a set amount of time or until the air temperature leaving the coil reaches a specified level. This usually means that the defrost cycle is running for a longer period of time than necessary, allowing more heat to enter the refrigerator and raise product temperatures. Intelligent defrost termination sensors can determine exactly when the coil is free of frost and immediately restart the refrigeration system. An intelligent defrost termination sensor can be a simple electromechanical thermostat, a solid-state sensor, or other device.

Antisweat. Antisweat heaters (ASHs) with a low watt-per-door rating should be used whenever possible. In addition to using less energy at the antisweat heater level, less heat will be introduced into the refrigerated space, thus indirectly reducing the cooling load.

Some controllers can recognize the antisweat heat needs of the door and ensure that the heaters only operate when needed. They adjust their operation accordingly, through pulsation or other mechanisms. **Condensate sensors** on reach-in glass doors activate ASHs when droplets are detected; **RH-based controllers** sense the psychrometric properties of air and activate ASHs when needed.

New methods of glass **door construction** have brought products that require little or no antisweat heat to maintain customer-friendly fog-free panes. This performance is achieved by either using advanced glass types or special door frames, both of which greatly reduce or eliminate the amount of glass heating necessary to resist condensation.

Alternative Expansion Valves. **Dual-port thermostatic expansion valves (TXVs)** have capacity modulation capabilities not seen in other expansion valves. When the refrigerator emerges from defrost, there is typically a much higher load because of increased product temperatures. In this case, the large port of the expansion valve opens, allowing the system to operate at a higher capacity to account for the increased pulldown load.

Superheat can be most easily controlled by **electronic expansion valves**, which have a much faster response time than bulb-sensing TXVs. Manufacturers should test the valve and controller to ensure it maintains stable control at targeted superheats.

Liquid-to-Suction Heat Exchanger. Liquid-to-suction heat exchangers allow suction gas exiting the display refrigerator to absorb heat from liquid refrigerant entering the display refrigerator, increasing the cooling capacity of the refrigerant (Figure 22). These devices are most effective for low- and very-low-temperature applications (EPRI 1992). The effectiveness of liquid-to-suction heat exchangers also depends on which refrigerant is chosen. The system designer must be cautious in choosing when to use a liquid-to-suction heat exchanger (Klein et al. 2000).

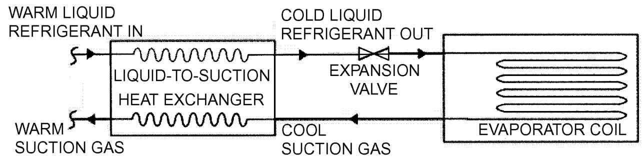

Fig. 22 External Liquid-to-Suction Heat Exchanger
(EPRI 1992)

Sophisticated Refrigerator Controls. All components of a display refrigerator should be linked to one master control system, which can optimally control the operation of individual components.

Power-Reducing Measures. Reducing power use of individual components will result in energy savings over time, and can also reduce the cooling load for components located inside the refrigerated space.

Energy-efficient **evaporator fan motors** such as electronically commutated motors (ECMs) and permanent split capacitor (PSC) motors consume about half the power of standard shaded-pole motors (Faramarzi and Kemp 1999). These motors, located inside the refrigerated space, produce less heat, thereby reducing the load on the refrigeration equipment. These motors also can incorporate variable-speed controls to slow fans as the cooling load is satisfied.

Standard **lighting** equipment, which typically consists of T12 fluorescent lamps with magnetic ballast, draws about 0.73 A at 120 V. More efficient lamps (T8 fluorescent lamps with electronic ballast) draw only 0.49 A at 120 V. As a result, they introduce less heat into the refrigerated space, which in turn reduces the refrigerator cooling load and improves maintenance of target product temperature without sacrificing light quality.

REFRIGERATED STORAGE ROOMS

Meat Processing Rooms

In a self-service meat market, cutting, wrapping, sealing, weighing, and labeling operations 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 10°F temperature difference (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 45 to 55°F, which is desirable for workers but not low enough for meat storage. Thus, meat should be held in that room only for cutting and packaging; then, as soon as possible, it should be moved to a packaged product storage cooler held at 28 to 32°F. 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 28 to 32°F and used as a meat storage cooler, and the second compartment is refrigerated at 45 to 55°F and used as a cutting and packaging room. Best results are attained when meat is cut and wrapped to minimize exposure to temperatures above 28 to 32°F.

Wrapped Meat Storage

At some point between the wrapping room and 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 28 to 32°F 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 holding slide-in trays of meat. This method also offers visible inventory control and provides convenient access to both the wrapping room and the display refrigerators.

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 Coolers and Freezers

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 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 35 to 40°F range. Meat coolers are used in all food stores, with storage conditions between 28 and 32°F. 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 refrigeration load, allow 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 10°F 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. For more details, see the section on Walk-In Coolers/Freezers in Chapter 47.

REFRIGERATION 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. Temperature controls vary greatly, from a produce preparation room (which may operate with a wet coil) requiring no defrost to the ice cream refrigerator requiring induced heat to defrost the coil periodically.

Design Considerations

When selecting refrigeration equipment to operate display refrigerators and storage rooms for food stores, consider (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).

Suction Groups. Various refrigerators have different evaporator pressure/temperature requirements. Produce and meat wrapping rooms, which have the highest requirements, may approach the suction pressures used in air-conditioning applications. Open ice cream display refrigerators, which have the lowest, may have suction pressures corresponding to temperatures as low as –40°F. All other refrigerators and coolers fall between these extremes.

Refrigeration Loads. Refrigerator requirements are often given as refrigeration load per unit length, with a lower value sometimes allowed for more complex parallel systems. The rationale for this lower value is that peak loads are smaller with programmed defrost, making refrigerator temperature recovery after defrost less of a strain than on a single-compressor system.

Published refrigerator load requirements allow for extra capacity for temperature pulldown after defrost, per ASHRAE *Standards* 72 and 117. The industry considers a standard store ambient condition to be 75°F and 55% rh, which should be maintained with air conditioning. A portion of this air-conditioning load is carried by the open refrigerators, and credit for heat removed by them should be considered in sizing the air-conditioning system.

Equipment Selection. The designer matches the load requirements of the refrigerator lineups to the capacity of the chosen refrigeration system. Manufacturers publish load ratings to help match the proper refrigeration system with the fixture loads. 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 75°F and 55% rh in the sales area with specific door-opening patterns. Display refrigerators for similar applications are commercially available from many manufacturers. Manufacturers' recommendations must be followed to achieve proper results in both efficiency and product integrity. Appropriate equipment selection depends on a number of factors.

Life-Cycle Cost. The total cost elements of the refrigeration system include not only the purchase price but also the operating cost (energy), cost of installation and commissioning, cost of maintenance and service, and the environmental cost.

Space Limitations. Store size, location, and price per square foot play a role in determining the type and location of equipment. Locations can include an equipment room at the back of the store, on a mezzanine, in a machine house on the roof, or distributed throughout or on top of the store.

Refrigerant Selection. 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 the United States include R-404A, R-134a, and R-507. Other refrigerants are listed in ASHRAE *Standard* 34. Secondary loop systems are covered in the section on Low-Charge Systems in this chapter.

Compressor performance and material compatibility are two major concerns in selecting new refrigerants. Research has found good equipment reliability. Retrofit recommendations have also been developed by equipment and refrigerant manufacturers to guide stores in converting from ozone-depleting substances to alternatives; close consultation with equipment manufacturers is necessary to stay current on this issue.

Concern about ozone depletion has led to U.S. Environmental Protection Agency regulations to minimize refrigerant emissions. Intentional venting of all refrigerants, including the substitutes, is prohibited. Additional regulations apply to chlorine-containing refrigerants such as R-22. If systems that contain more than 50 lb of refrigerant leak at an annual rate exceeding 35%, equipment repairs are required. Certain servicing and record-keeping practices are also required (EPA 1990). Proposed regulations extend these regulations to the hydrofluorocarbon substitutes and tighten the leak repair requirements. These developments should be monitored. Chapters 19 and 20 of the 2005 *ASHRAE Handbook—Fundamentals* have more information on refrigerants and their properties.

Refrigerant Lines. Sizing liquid and suction refrigerant lines is critical in the average refrigeration installation, because of 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 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 more slowly than the refrigerant. Unless the suction line is properly installed, oil can accumulate in low places, causing problems such as compressor damage from liquid slugging or insufficient lubrication, excessive pressure drop, and reduced system capacity. To prevent these problems, horizontal suction lines must pitch down as gas flows toward the compressor, the bottoms of all suction risers must be trapped, and refrigerant speed in suction risers must be maintained according to piping practices described in Chapters 2 and 3. To overcome the larger pressure drop necessary in suction risers, suction lines may be oversized on long horizontal runs; however, they still must pitch down toward the compressor for good oil return.

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

Typical Systems

Refrigeration systems in use today can generally be categorized into one of the following types: single (a single compressor connected to one or more evaporator loads), multiplex (or parallel compressor) rack, loop, distributed, and secondary refrigerant. Each type has distinct advantages and disadvantages, and may be chosen based on the weight a designer assigns to the different components of equipment life-cycle cost.

The most common compressors used in a typical supermarket refrigeration system include reciprocating, scroll, and screw compressors, which are discussed in Chapter 34 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment.* Planning load management and sizing the compressors are very important to a successful refrigeration installation.

Single System. A single-compressor/single-evaporator system is sometimes referred to as a *conventional system*. Each compressor may be piped to an individual condenser, or several single compressors may be piped to a larger condenser with multiple circuits. Some single-compressor systems are connected to two or more evaporator systems, in which case each evaporator system uses its own liquid and suction lines and is controlled independently.

A solid-state pressure control for single systems can help control excess capacity when 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.

Multiplex System. Another common refrigeration technique couples two or more compressors in parallel, piped together with common suction and discharge lines. The compressors share a common oil management system and usually operate connected to one or more large condensers. The condensers are usually remotely air- or evaporatively cooled, but they can also be built as part of the compressor rack assembly. The multiplex rack system has several evaporator systems, individually controlled and connected to the compressor rack's common suction line.

Multiple-evaporator systems are usually designed such that each evaporator system operates at a different saturated suction pressure (temperature). Because they are connected to one common suction pressure, the compressors are forced to operate at the lowest evaporator pressure to achieve the coldest evaporator system temperature. The obvious result is a sacrifice in efficiency. Running all the equipment at the low suction pressure required for ice cream (on low-temperature systems) or for meat (on medium-temperature systems) causes all the compressors to operate at lower suction pressures than are necessary. To overcome this inefficiency, large parallel systems frequently isolate ice cream and meat refrigeration. Satellite compressors may be used for extreme loads. The satellite compressor has its own independent suction but shares the rack system's common discharge piping and oil management system. Split-suction manifolds are often used for larger loads: different suction pressures are obtained, but all compressors discharge into a common header and share the oil management system.

Manufacturers should be consulted to determine the appropriate suction pressure (temperature) at the fixture and the load that each system adds to the total. The multiplex rack system must then be designed to deliver the total of all the loads at a common suction pressure no higher than the lowest system pressure requirement less the suction line pressure drop. Systems designed to operate at suction pressures higher than the common must use some means of suction line regulation to prevent higher-temperature evaporators from operating at temperatures below what is necessary to maintain product temperatures.

Suction pressure can be regulated with either electronically [**electric evaporator pressure regulating (EEPR)**] or mechanically actuated [**evaporator pressure regulating (EPR)**] valves. When sized according to manufacturers' recommendations, these valves cause little or no pressure drop in the full-open position. When regulating, they create pressure drop to maintain the fixtures using them at their design condition above the common rack suction pressure. Larger pilot-operated EPR valves may use discharge pressure to open and close the valves, or may be internally piloted, with upstream pressure used to open and close. Although each type has advantages and disadvantages, electric valves are being used more frequently because of their ability to communicate with the rack's energy management system.

The suction gas temperature leaving display fixtures should be superheated to ensure that only vapor enters the compressor suction intake. Particularly on low-temperature fixtures, the suction line gas temperature increase from heat gained from the store ambient can be substantial and adversely affect both refrigeration system capacity and compressor discharge gas temperature. This must be considered for system design. One solution to reduce excessively high superheat is to run the suction and liquid lines tightly together between the fixture and compressor system if the liquid is subcooled, with the pair insulated together for a distance of 30 to 60 ft 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). Suction-to-liquid line heat exchangers can be installed in the display fixture. This technique allows 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 refrigerator 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 refrigerator and/or system designs require liquid-line insulation, which is very important when ambient outdoor air or mechanical subcooling is used to improve system efficiency.

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. A multiplex rack system with multiple compressors of equivalent capacity is called an *even parallel system*; with compressors of different capacities, it is called an *uneven parallel system*.

Parallel compressor systems must be designed to maintain proper refrigerator temperatures under peak summer load. During the rest 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 90°F condensing conditions or above to maintain enough high-side pressure to feed the refrigerated display fixture expansion valves properly. When outdoor ambient conditions allow, current technology permits the condensing temperature to follow the ambient down to about 70°F or less. When proper liquid-line piping practices and valve selection guidelines are observed, the expansion valves will feed the evaporators properly under these low condensing pressures (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 5 psi or more below optimum. Microprocessors offer the option of remote control and system operation for all types of compressors, managing compressor cycling and run time for each compressor, and ensuring the common suction pressure is optimized. Satellite compressors can be controlled accurately with one control that also monitors other components, such as oil pressure and alarm functions. To match changing evaporator loads, rack capacity can be 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.

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 hp compressor parallel arrangement.

Loop Systems. A loop system is simply a variation of the multiplex rack system. Rather than piping the different evaporator systems (or circuits) back to the machine room, the loop system is designed so that a single suction and liquid "loop" is piped out to the store for each common suction pressure. The individual circuits are then connected to the loop near the fixtures. If EPRs and solenoid valves are used, they will typically be installed nearer the refrigerator lineups.

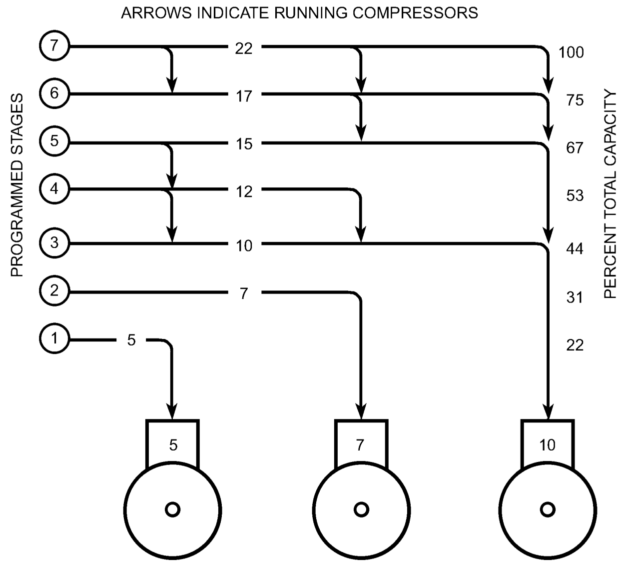

Fig. 23 Stages with Mixed Compressors

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, prepiped, 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 supermarket designers choose to have compressor equipment installed in factory-prefabricated housing, commonly called a **mechanical center**, 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.

Energy Efficiency. A typical supermarket includes one or more medium-temperature parallel compressor systems for meat, deli, dairy, and produce refrigerators and medium-temperature walk-in coolers. The system may have a satellite compressor for the meat or deli refrigerators, or all units may have a single compressor. Energy efficiency ratios (EERs) typically range from 8 to 9 Btu/h per watt 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 4 to 5 Btu/h per watt for frozen-food units to as low as 3.5 to 4.0 Btu/h per watt for ice cream units. Cutting and preparation rooms are most economically placed on a single unit because the refrigeration EER is nearly 10 Btu/h per watt. Air-conditioning compressors are also separate because their EERs can range up to 11 Btu/h per watt (Figure 24).

Low-Charge Systems

Over the last decade, different supermarket refrigeration system configurations with lower refrigerant charges have been considered in attempts to mitigate the environmental issues of ozone depletion and global warming. The Montreal Protocol established due dates to

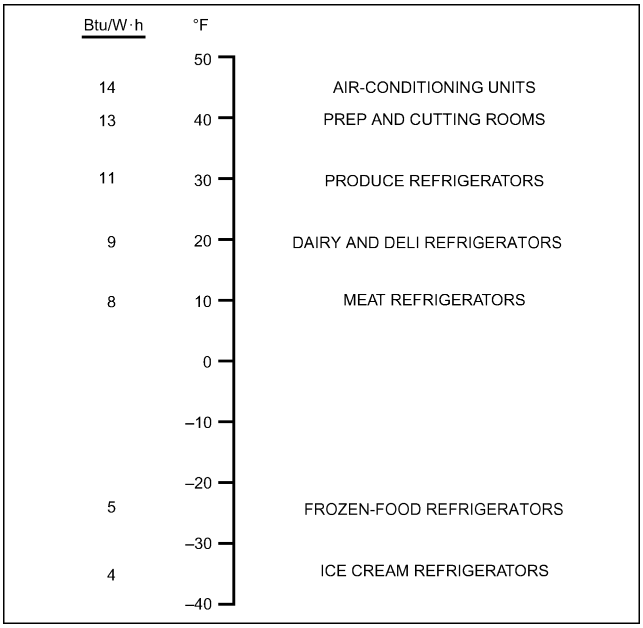

Fig. 24 Typical Single-Stage Compressor Efficiency

phase out different refrigerants worldwide. The production and use of hydrochlorofluorocarbons (HCFCs), such as R-22, in refrigeration systems will be totally phased out by the year 2030. Commercial refrigeration is one of the largest consumers of refrigerant worldwide, and special attention has been devoted to minimizing use of refrigerant in existing and new sites. This section discusses the following three types of low-charge systems: secondary loop, distributed, and liquid-cooled self-contained.

Secondary Loop. In secondary coolant systems, heat is removed from refrigerated spaces and display cabinets by circulating a chilled fluid in a secondary loop cooled by a primary refrigeration system. Fluid circulation is typically provided by 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 system efficiency because viscosity and heat transfer properties directly affect system performance. 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 15°F. Low-temperature fluids are commonly composed of solutions of various potassium-based organic salts and inhibitors, though several alternatives are available and corrosion remains a concern. Fluids involving a phase change, including carbon dioxide and water-based ice slurries, are also possible. For an explanation of various options for secondary fluids, including safety considerations, see Chapter 4.

Heat can be 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 refrigerated spaces are generally designed differently from those used for volatile refrigerants. 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 air removal and service.

Typically, the entire refrigeration system for supermarkets is divided into two temperature groups: one low-temperature (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 regulating flow using a balance valve, or cycling flow around a set point 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.

Performance Characteristics. Secondary coolant systems have several advantages. Because primary refrigeration piping is located almost wholly within the machine room, the amount of piping and refrigerant required can be reduced by as much as 80 to 90%. Because field piping of the primary system is typically limited to only a few joints, the majority of the primary system piping joints are factory-installed. Factory-installed joints are generally higher-quality than field-installed joints, because they are formed in controlled conditions by skilled labor, using nitrogen and a variety of pressure-testing and leak-identification methods. Higher-quality joints combined with a lower refrigerant charge can significantly lower refrigerant leakage rates, which reduce the environmental effects 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 used, because the system operating pressure is low, typically less than 60 psig. Service of the refrigeration system is basically limited to the machine room area, and maintenance costs can be reduced. 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 thermodynamic loss inherent in 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.

Distributed Systems. Distributed systems eliminate the long lengths of piping needed to connect display fixtures with compressor racks in back-room parallel compressor systems. The compressors are located in cabinets, close-coupled to the display refrigerator lineups, placed either at the end of the refrigerator lineup or, more often, behind the refrigerators around the store's perimeter.

Distributed systems are typically located in the store to provide refrigeration to a particular food department, such as meat, dairy, or frozen food. With this arrangement, the saturated suction temperature (SST) for each rack closely matches the evaporator temperature of the display refrigerators and walk-in coolers. This is not always the case for parallel-rack DX systems, because a single rack often serves display refrigerators with three or four different evaporator temperatures, and the parallel-rack DX system must operate at an SST that will satisfy the requirements of the lowest-temperature one connected. Better evaporator temperature matching with distributed systems can decrease the system's overall energy consumption.

Distributed systems typically require a much lower refrigerant charge than parallel-rack DX systems, because of the former's shorter suction and liquid lines to display refrigerators. Refrigerant piping to remote condensers can be eliminated by using a closed-loop water-cooled system.

Close-coupling display refrigerators to distributed systems has other ramifications for energy consumption. Shorter suction lines mean that pressure drop between evaporators and the compressor suction manifold is less than with parallel-rack DX systems, so the SST of distributed systems will be closer to the display refrigerator evaporator temperature: about 1 to 2°F less than refrigerator evaporator temperature, compared to 2 to 4°F difference with a parallel-rack DX. Shorter suction lines also mean less heat gain.

For a closed-loop water-cooled system, a central pump station contains the circulation pump and all valves needed to control fluid flow between the parallel compressor cabinets and fluid cooler. Inlet and outlet pipes sized for the entire system flow are provided to and from the fluid cooler and pump station. Flow to each distributed system is branched from these central supply and return pipes at a continuous rate; flow to each distributed compressor system is controlled by manual balancing valves set at installation to ensure proper flow to each cabinet.

Liquid-Cooled, Self-Contained Systems. In these systems, refrigeration condensing units connected (underneath, behind, above, or in a nearby enclosure) to one or more refrigerators are located in the display area of the supermarket. 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, and initial equipment costs may be lower. In addition, refrigerators can be performance-tested before they are shipped from the factory, and installations may be less labor-intensive.

As with secondary cooling systems, 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 compressor service must be done in the display area of the supermarket. Advances in compressor technology leading to quieter, more compact, and energy-efficient systems would allow liquid-cooled, self-contained systems to become more feasible low-charge alternatives for widespread applications.

Environmental Considerations: Total Equivalent Warming Impact (TEWI). The environmental benefit of advanced low-charge refrigeration systems is a significant reduction in the amount of halogenated refrigerants now used in supermarkets. Present supermarkets use as much as 3000 lb of refrigerant, most of which is HCFC-22, which has an ozone depletion potential (ODP) of 0.055 and a global warming potential (GWP) of 1700. The latest replacement refrigerants are HFCs, such as R-134a, R-404A, and R-507, which have ODPs of 0, but have high GWP values (1300, 3260, and 3300, respectively).

All refrigeration systems considered here offer better approaches in terms of reduction and containment of refrigerant. There is some variation in charge requirement, depending on the type of heat rejection. The lowest charge is required by systems using a fluid loop for heat rejection. The charge requirement for close-coupled distributed and secondary loop systems is less because of reduced suction-side piping.

The total equivalent warming impact accounts for both direct and indirect effects of refrigeration systems on global warming potential:

$$\underset{\text{(refrigerant leakage and recovery losses)}}{\text{Direct effect}} + \underset{\text{(greenhouse gas emissions from power generation)}}{\text{Indirect effect}} = \text{TEWI}$$

CONDENSING METHODS

Many commercial refrigeration installations use air-cooled condensers, although evaporative or water-cooled condensers with cooling towers may be specified. To obtain the lowest operating costs, equipment should operate at the lowest condensing pressure allowed by ambient temperatures, determined by other design and component considerations; the equipment manufacturer should be consulted for recommendations. Techniques that allow a system to operate satisfactorily with lower condensing temperatures include (1) insulating liquid lines and/or receiver tank, (2) optimum subcooling of 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. Expansion valve capacity is affected by entering liquid temperature and pressure drop across its port. If selected properly, the thermostatic expansion valve can feed the evaporator at lower pressures, assuming that liquid refrigerant is always supplied to the expansion valve inlet.

To minimize energy consumption, refrigeration condensers should be sized more generously and based on lower TDs than for typical air-conditioning applications. Condenser selection is usually based on the TD between the cooling medium entering the condenser and the saturated condensing temperature.

Condenser Types

Air-Cooled. The remote condenser may be placed outdoors or indoors (to heat portions of the building in winter). Regardless of the arrangement, 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 50°F on condensers with single or parallel groups of compressors. Below 50°F, condenser flooding (using system refrigerant) can be used alone or with fan-cycle controls. Flooding requires a larger refrigerant charge and liquid receiver. In conjunction, splitting condensers with solenoid valves in the hot-gas lines can reduce the condenser surface during cold weather, thereby minimizing the additional refrigerant charge. 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 common; however, it may not give the degree of condensing temperature control required in systems designed for high-efficiency gain. Thus, it is not recommended except in mild climates down to 50°F. Sometimes, pressure switches, in conjunction with gravity louvers, cycle the condenser fans. This system requires no refrigerant flooding charge.

The receiver tank on the high-pressure side, especially for remote condensers, must be sized carefully. 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 3 ft of space between the roof deck and 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 3 ft from any wall, parapet, or other airflow restriction. Two side-by-side condensers should be placed at least 6 ft from each other. Chapter 16 of the 2005 *ASHRAE Handbook—Fundamentals* discusses the problems of locating equipment for proper airflow.

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 10 to 25°F 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 0.5 to 30 hp.

Generally accepted TDs for remote air-cooled refrigeration condenser sizing are 15°F for medium-temperature systems and 10°F for low-temperature systems.

Remote air-cooled condensers are popular for use with parallel compressors. Figure 25 illustrates a basic parallel system with an air-cooled condenser and heat recovery coil.

Air-Cooled Machine Room. Standard air-cooled condensing units in a separate air-cooled machine room are 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 indoor air-cooled condensing unit requires ample, well-distributed ventilation. Ventilation requirements vary, depending on maximum summer conditions and evaporator temperature, but 750 to 1000 cfm per condensing unit horsepower has given proper results. Exhaust fans should be spaced for an even distribution of air (Figure 25).

Rooftop air intake units should be sized for 750 fpm velocity or less to keep airborne moisture from entering the room. When condensing units are stacked (as shown in Figure 25), the ambient air design should provide upper units with adequate ventilation. Rooftop 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 25). Because air recirculation is needed around the condensers for proper winter control, 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 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, 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.

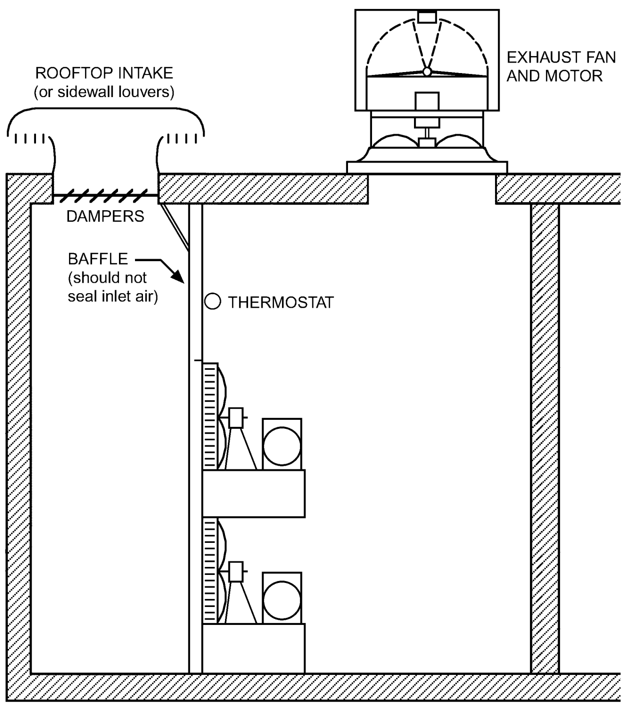

Fig. 25 Typical Air-Cooled Machine Room Layout

Evaporative. Evaporative condensers are equipped with a fan, circulating water-spray pump, and a coil. The circulating pump takes water from the condenser sump and sprays it over the surface of the coil, while the fan introduces an ambient airstream that comes into contact with the wet coil surface. Heat is transferred from condensing refrigerant inside the coil to the external wet surface and then into the moving airstream, principally by evaporation. Where the wet-bulb temperature is about 30°F below the dry-bulb, the condensing temperature can be 10 to 30°F above the wet-bulb temperature. This lower condensing temperature saves energy, and one evaporative condenser can be installed for the entire store. Chapter 35 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment* gives more details.

Evaporative condensers are also available as single- or multiple-circuit condensers. Manufacturer conversion factors for operating at a given condensing 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 help minimize tank size.

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 deterioration is reduced depends on how much the difference is reduced 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-Cooled. Water-cooled conventional compressor units range in size from 0.5 to 30 hp and are best for hot, dry climates where air-cooled condensers will not operate properly or evaporative condensers are not economically feasible. Water-cooled condensers can also be applied to parallel-compressor systems. A city-water-cooled condensing unit that dumps hot water to a drain is usually no longer economical because of the high cost of water and sewer fees. Cooling towers or evaporative fluid coolers, which cool water for all compressor systems in a single loop, are used instead. If open cooling towers are used to remove heat from condensing water, shell-and-tube heat exchangers must be used, and brazed-plate heat exchangers avoided.

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

Fluid Cooler. In a closed-loop water condenser/evaporative cooler arrangement, an evaporative fluid cooler removes heat from water instead of refrigerant. This water flows in a closed, chemically stabilized circuit through a regular water-cooled condenser (a two-stage heat transfer system). Heat from 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 differences between the (1) refrigerant and circulating water and (2) circulating water and available wet-bulb temperature. The double temperature difference results in higher condensing temperature 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.

Cooling Tower Arrangements. Few supermarkets use water-cooled condensing units; the trend is instead 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.

Designing water cooling towers for perishable foods is different than for air conditioning because (1) the hours of operation 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 set to turn off the fan when the water temperature drops to a point 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 condensing temperature. Proper bleed-off is required to ensure 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.

Energy Efficiency of Condensers

Hardware. Condenser design can significantly affect refrigeration equipment performance. The characteristics of condensers can be improved in three ways:

- **Increased heat transfer effectiveness.** Efficient coils are designed with an increased heat transfer surface area using materials with improved heat transfer properties to reject as much heat to the air as possible, using an optimized fin design.
- **Improved coil tube design: low friction and high conduction.** Materials (e.g., copper) used to construct the coils have increased conductivity, which allows heat to transfer through the coil materials more easily. The inside surface of tubes in the coil can also be enhanced to assist heat transfer from the coil material into the refrigerant: the enhancements create turbulence in the refrigerant, thus increasing its contact time with the tube surface. However, use caution when designing these features because excessive turbulence can cause a pressure drop in the refrigerant and force the compressor to work harder, negating any savings resulting from the enhancement.
- **Downsized fan motor.** Condenser fan motors are can be downsized if coils are efficient. Downsizing the fan motor decreases motor energy use but still allows sufficient heat transfer with the ambient air.

Controls. Allowing discharge pressure to float lower during low-ambient periods of can save considerable energy compared to fixed-pressure systems. Careful system design consideration is needed to ensure proper operation of the expansion valve and refrigerant feed to the evaporator coil during lower ambient conditions. Balanced-port thermostatic expansion valves and electronic expansion valves enhance the opportunity for floating pressures down with varying ambient temperatures.

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 (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 condensing temperature is generated. Take care 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 vibration does not amplify the noise.

If sound levels are still excessive after these 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 effective, it may be objectionable because of cost and weight. If a barrier is used, it must be sealed at the bottom because any opening allows 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 2003 *ASHRAE Handbook—HVAC Applications* for information on outdoor sound criteria, equipment sound levels, sound control for outdoor equipment, and vibration isolation.

HEAT RECOVERY STRATEGIES

Heat recovery may be important in refrigeration system design, parallel or single. Heat recovered from the refrigeration system can be used to heat a store or to heat water used in daily operations. The section on supermarkets in Chapter 2 of the 2003 *ASHRAE Handbook—HVAC Applications* has more information on the interrelation of the store environment and the refrigeration equipment.

Space Heating

Heat reclaim condensers and related controls operate as alternatives 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 for humidity control in spring, summer, and fall. Excess humidity in the store can increase the display refrigerator refrigeration load as much as 20% at the same dry-bulb temperature, so it must be avoided.

In this application, a heat recovery coil is placed in the air handler for store heat. If the store needs heat, this coil is energized and usually run in series with the regular condenser (see Figure 26). The heat recovery coil can be sized for a 30 to 50°F TD, depending on the capacity in cool weather. Lower condensing temperature in parallel systems allow little heat recovery unless designed properly. When heat is required in the store, simple controls can create the higher condensing temperature needed during heat recovery. Compared with the cost of auxiliary gas or electric heat, the higher

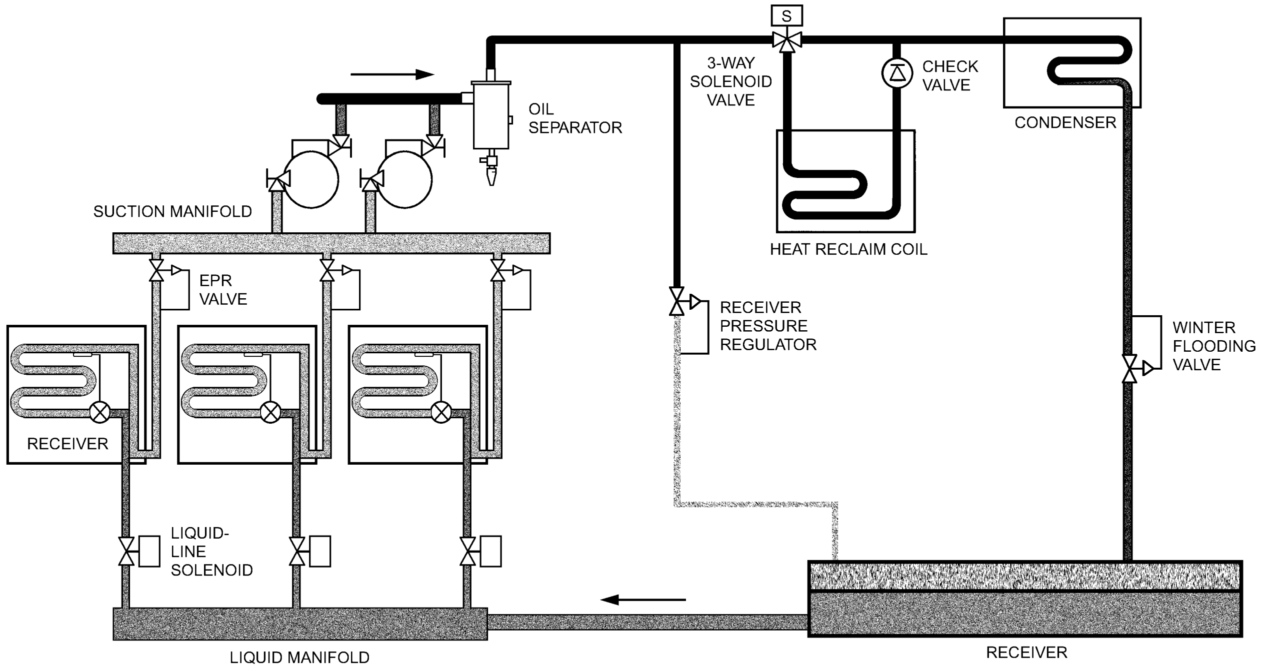

Fig. 26 Basic Parallel System with Remote Air-Cooled Condenser and Heat Recovery

energy consumption of the compressor system may be offset by the value of the heat gained.

Water Heating

Heat reclamation can also be used to heat water for store use. Recovery tanks are typically piped in series with the normal condenser and sized based on the refrigerant pressure drop through the tank and on the water temperature requirements.

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.

LIQUID SUBCOOLING STRATEGIES

Allowing refrigerant to subcool in cool weather as it returns from the remote condenser can save energy if the system is designed properly. One method is to flood the condenser and allow the liquid refrigerant to cool close to the ambient temperature. The cooler liquid can then reduce the total mass flow requirements if used properly to feed the expansion valves. This may require a diverting valve around the warmer receiver or a special surge-type receiver design.

Mechanical subcooling may also be economical in many areas. This method uses a direct-expansion heat exchanger to cool the main liquid line feeding the evaporator systems. A subcooling satellite compressor can be used on one parallel system, or the medium-temperature rack can be designed with a circuit to handle the subcooling requirement of the low-temperature system. The advantage is that mechanical subcooling is accomplished at higher efficiency than the main system, thus saving energy through year-round liquid temperature control. The mechanical subcooling would be set to operate when the exiting liquid temperature is above the desired setpoint.

Given the wide range of loads on a mechanical subcooler, temperature control can be accomplished in various ways. Two solenoid valves may feed two different-sized thermostatic expansion valves, allowing for multiple stages. This method usually controls subcooling temperature by maintaining the evaporator pressure of the subcooler using a suction regulator. An electric expansion valve with a controller can be used to simplify the piping arrangement and to eliminate the need for suction regulation.

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 defrost, particularly for low-temperature equipment, frost in the air flues and around the fan blades must be melted and completely drained.

Defrost methods use (1) off-time, (2) gas, (3) electric, and (4) ambient air induced into the refrigerator.

Parallel systems adapt easily to gas defrost. Compressor discharge gas, or gas from the top of the warm receiver at saturated conditions, flows through a manifold to the circuit requiring defrost. Electric, reverse-air, and off-cycle defrost can be used on both parallel and single-unit systems.

Conventional Refrigeration Systems

Gas Defrost. Gas defrost requires careful design consideration and the use of additional differential valves to keep liquid refrigerant from accumulating in the defrosting evaporator coils. One rule of thumb for gas defrost is that no more than 25% of the circuits can call for defrost at one time, to ensure that enough heat is available from circuits still in refrigeration mode to supply the gas necessary for those in defrost. Given the size of many modern supermarket refrigerator lineups, it is often practical to sequence the gas defrosts such that no two circuits are in defrost at the same time.

Hot-gas defrost uses heat from the compressor's discharge gas to defrost the evaporators. To remove the coil frost, discharge gas is introduced upstream of the suction stop control and directed to the evaporator system calling for defrost. Occasionally, supplemental electric refrigerator heaters are added to ensure rapid and reliable defrosting. Temperature generally terminates the defrost cycle, although a timers are used as a backup.

Saturated-gas defrost is similar to hot-gas defrost but is piped a little differently and uses saturated gas from the top of the liquid in the receiver for defrost purposes.

Off-Cycle or Off-Time Air Defrost. 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 defrost heat from air circulating in the display fixture, it is slow and limited to open fixtures operating at 34°F or above. 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 up to 1.5 times longer to defrost than gas defrost. The heating element may be in direct contact with the evaporator, relying on conduction for defrost, or may be located between the evaporator fans and the evaporator, relying 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.

Electric defrost simplifies 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 refrigerators may operate the fans during the defrost cycle.

Low-Charge Systems

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 refrigerators 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 heat exchange with liquid refrigerant. Warm fluid temperatures vary and must be optimized for the coil application; however, typical values are 50 to 60°F for medium-temperature systems and 70 to 80°F 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.

Defrost Control Strategies

Defrost control methods 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.

Defrosting is usually controlled by a variety of clocks, which are often part of a compressor controller system. Electronic sensor control is the most accurate and can also provide a temperature alarm to prevent food loss. Electronic systems often have communication capabilities outside the store.

Liquid and/or suction line solenoid valves can be used to control the circuits for defrosting. Often, a suction-stop EPR is used to allow a single valve to isolate the defrosting circuit from the suction manifold and allow introduction of defrost gas upstream of the valve. Individual circuit defrosts are typically controlled by the rack's energy management system, or rack controller.

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 36 to 43°F. 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 build-up 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.

Initiation and Termination. Methods (2), (3), and (4) control defrosting using 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.

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 airstream leaving the evaporator, as detected by a temperature sensor in either location. 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.

SUPERMARKET AIR-CONDITIONING SYSTEMS

Major components of common store environmental equipment include rooftop packaged units or central air handler with (1) fresh makeup air mixing box, (2) air-cooling coils, (3) heat recovery coils, and (4) supplemental heat equipment. Additional items include (5) connecting ducts, and (6) termination units such as air diffusers and return grilles. Exhaust hoods, used for cooking, can dramatically affect store ventilation rates.

System Types

Constant Volume with Heat Reclaim Coils. This is typically done with one or two large HVAC units. The conditioned air must then be ducted throughout the store.

Multiple Zone. This is typically done with many smaller packaged rooftop units (RTUs), which reduces ductwork but increases electrical and gas infrastructure. Off-the-shelf RTUs do not typically accommodate heat reclaim coils, which is an energy disadvantage in both heating and dehumidification modes.

Comfort Considerations

Open display equipment often extracts enough heat from the store's ambient air to reduce the air temperature in customer aisles to as much as 16°F 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 refrigerators back to the store air handler. Lack of attention to this element can substantially reduce sales in these areas. This free cooling spilling out of refrigerated cases is commonly referred to as **case credits**. More information on display case effects can be found in the section on Supermarkets in Chapter 2 of the 2003 *ASHRAE Handbook—HVAC Applications* or in Pitzer and Malone (2005).

Interaction with Refrigeration

Rules for good air distribution in food stores are as follows.

Air Circulation. Supply fans operate 100% of the time the store is open, at a volumetric flow of 0.6 to 1 cfm per square foot of sales area. Some chains may have multiple-speed fans, or operate the fan with variable-speed drives (VSDs). Fan speed variation can be based on a number of variables (e.g., store temperature, hood operation, building pressurization, CO_2 level), with the primary objective of minimizing fan energy usage.

Air supply and return grilles must be located so they do not disturb the air in open display refrigerators and negatively affect refrigerator performance. Directional diffusers are helpful in directing air away from cases. Return air can also be positioned to pull treated air into areas with many open refrigerated cases, thus avoiding the higher air speeds created by diffusers.

Outside Air. Introduce outside air 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, maintaining a positive store pressure. See ASHRAE *Standard* 62.1-2004 for more information on indoor air quality.

Supply 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 50 to 55°F. Low returns reduce heating and cooling requirements and temperature stratification. A popular practice, where store construction allows, is to return air under refrigerator ventilated bases and through floor trenches, or shafts built into walls behind the cases.

Environmental Control

Environmental control is the heart of energy management. Control panels designed for the unique heating, cooling, and humidity control requirements of food stores provide several stages of heating and cooling, plus a dehumidification stage. When high humidity exists in the store, cooling is activated to remove moisture, and the heat reclaim coil may be activated to prevent the store from overcooling. The controller receives input from temperature and dewpoint sensors in the sales area. If the store does not need sensible cooling during dehumidification, then a heat reclaim coil is activated to temper the cold, dry air with waste heat from the refrigeration system.

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

Energy Efficiency

Energy efficiency must be approached from a total-store perspective. Building envelope, lighting, HVAC, refrigeration, antisweat circuits, indoor air quality (IAQ), human comfort, and local utility cost all must be considered in the store design. Once the store is built and operational, effective commissioning and maintenance practices are critical to keeping energy cost at a minimum.

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