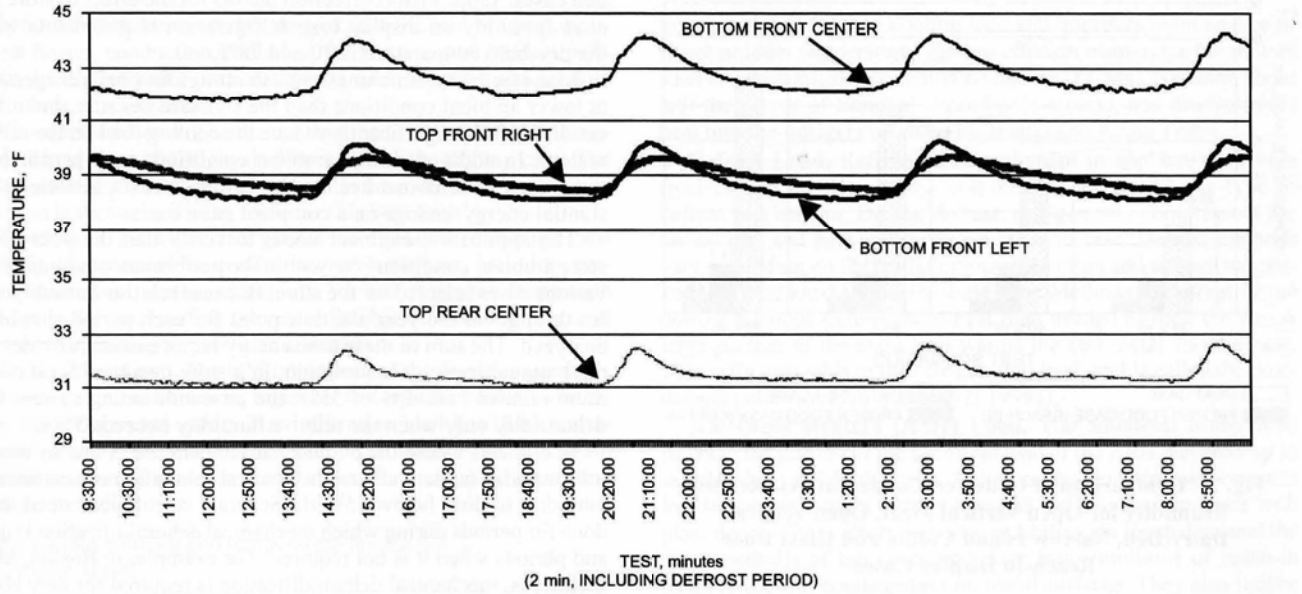


Fig. 5 Product Temperature Profiles at Four Different Locations Inside a Multideck Meat Case (Average Discharge Air Temperature of 29°F)

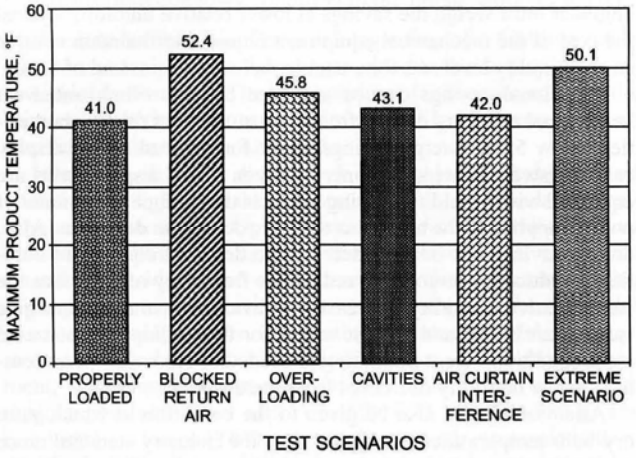


Fig. 6 Comparison of Maximum Product Temperature Variations Under Different Improper Product Loading Scenarios in an Open Vertical Meat Display Case

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

Additionally, packaging may also affect food temperatures. The product surface temperature of a loosely wrapped package of meat with an air space between the film and surface may be 2 to 4°F above the ambient temperature. This is called the greenhouse effect.

Store Ambient Effect

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

Table 2 summarizes a study of ambient conditions in retail food stores. Individual store ambient readings showed that only 5% of all readings (including those when the air conditioning was not working or not turned on) exceeded 75°F dry bulb or 0.0102 lb of moisture per pound of dry air. Based on these data, the industry has chosen 75°F dry bulb and 64°F wet bulb (55% rh, 57.5°F dew point) as summer design conditions. This is the ambient condition at which refrigeration load for food store display cases is normally rated.

Table 2 Average Store Conditions in the United States

Season	Dry Bulb, °F	Wet Bulb, °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. Approximately 2000 store readings in all parts of the country, in all types of stores, during all months of the year reflected the above ambient store conditions.

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

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

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

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

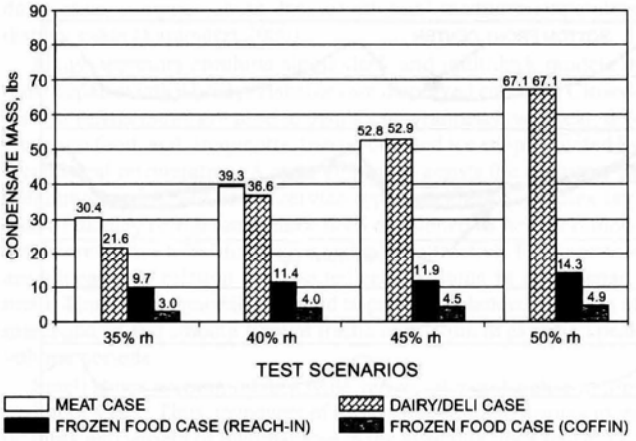


Fig. 7 Comparison of Collected Condensate vs. Relative Humidity for Open Vertical Meat, Open Vertical Dairy/Deli, Narrow Island Coffin, and Glass Door Reach-In Display Cases

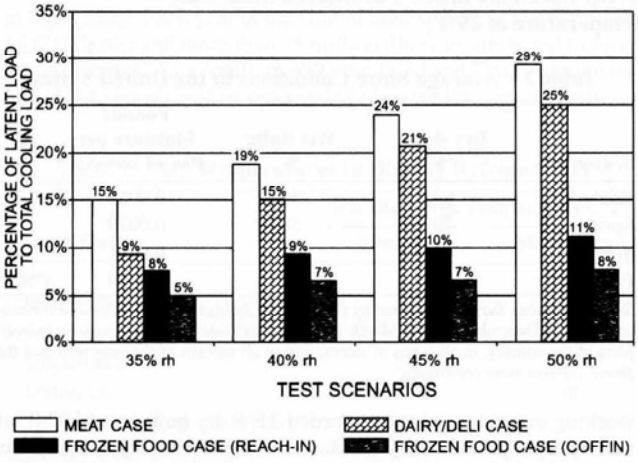


Fig. 8 Percentage of Latent Load to Total Cooling Load at Different Indoor Relative Humidities
(Gas Research Institute 2000)

Table 3 Relative Refrigeration Requirements with Varying Store Ambient Conditions

	70°F Dry-Bulb Relative Humidity, %					78°F Dry-Bulb Relative Humidity, %		
Case Model	**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).

deli cases. Table 3 lists correction factors for the effect of store relative humidity on display case refrigeration requirements when the dry-bulb temperature is 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 reductions in antisweat heaters and fewer defrosts, allowing substantial energy savings on a complete store basis.

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

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

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

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

Display Case Cooling Load and Heat Sources

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

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

gain from lights, fan motor(s), defrost (electric and hot gas), 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 transmission of heat through the physical envelope of the display case. The temperature difference between the air in the room and the air inside the case is the main driving force for this heat transfer.

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

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

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

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

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

Internal Loads. The display case internal load includes the heat from the case lights and the evaporator fan motors. The lamps, ballasts, and fan motors are typically located within the thermodynamic boundary of the display case; therefore, their total heat dissipation should be considered part of the case load. High-intensity lighting raises product temperatures, as shown in Figure 9, and can discolor meats. Case shelf ballasts are sometimes located out of the refrigerated space to reduce case cooling load. The standard lighting equipment, which typically consists of T12 fluorescent lamps with magnetic ballast, draws approximately 0.73 amps at 120 V. The more efficient lamps (T8 fluorescent lamps with electronic ballast) draw only 0.49 amps at 120 V. As a result, less heat is introduced into the refrigerated space by the efficient lamps and ballast, which in turn reduces the case cooling load and improves maintenance of target product temperature. Energy-efficient evaporator fan motors such as electronically commutated motors (ECMs), consume about half the power of standard shaded-pole motors, and dissipate less heat into the refrigerated case (Faramarzi and Kemp 1999).

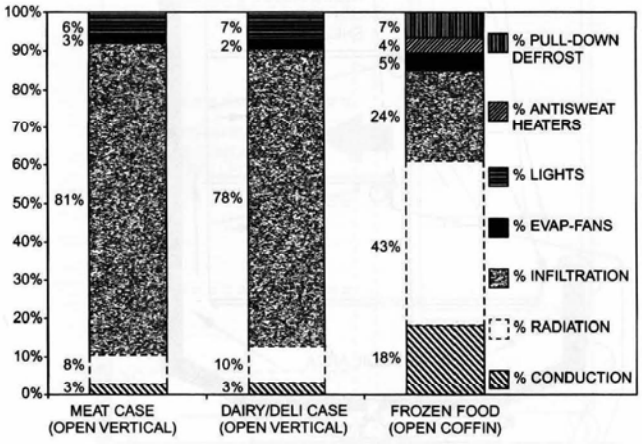


Fig. 9 Components of Refrigeration Load for Several Display Case Designs at 75°F Dry Bulb and 55% Relative Humidity

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

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

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

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

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

As shown in Figure 9, infiltration through the air curtain plays a significant role in the cooling load of open vertical display cases. Figure 10 depicts the air curtain velocity streamlines of an 8 ft open vertical meat display case. These velocity streamlines represent the actual airflow patterns using a sophisticated visualization technique. As shown, the entrainment of warm air into the display case takes place at several locations along the plane of the air curtain. Based on the law of conservation of mass, an equal (and substantial) amount of cold air from the display case spills into the room near the return air grille of the fixture (Faramarzi 1999).

Refrigerator Construction

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

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

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

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

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

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

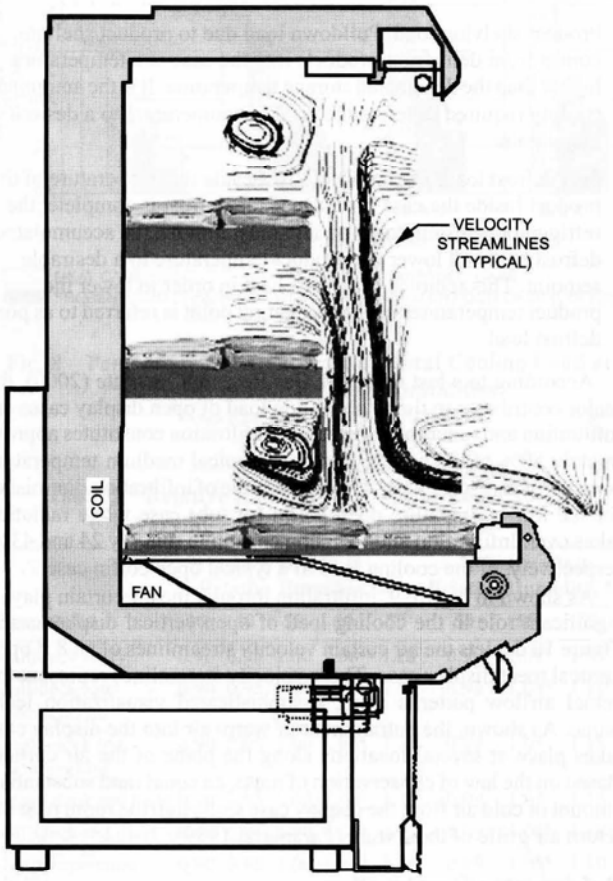


Fig. 10 Velocity Streamlines of a Single-Band Air Curtain in an Open Vertical Meat Display Case, Captured Using Digital Particle Image Velocimetry Technique

Cleaning and Sanitizing Equipment

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

Dairy Display

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

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

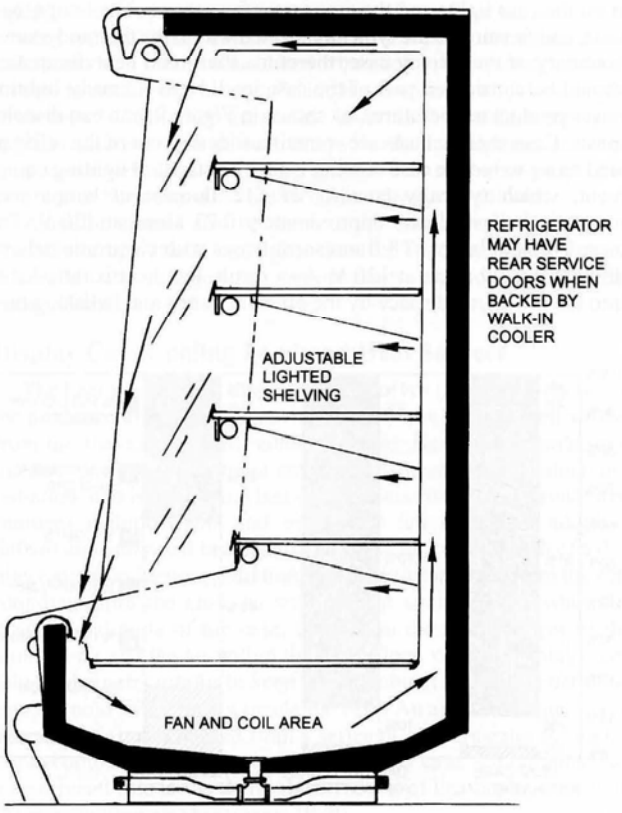


Fig. 11 Multideck Dairy Display Refrigerator

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

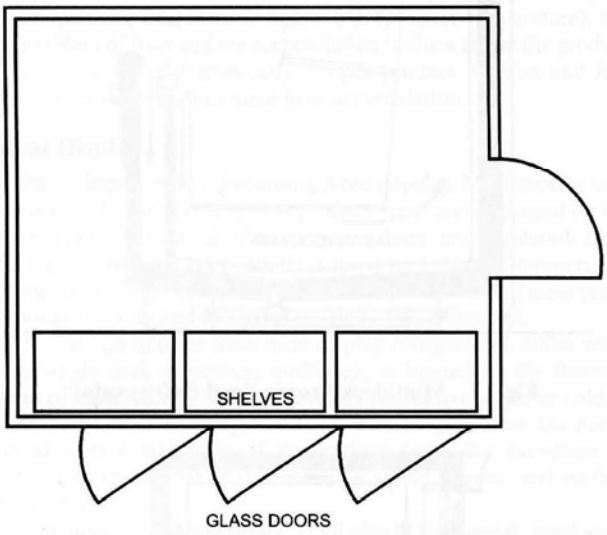


Fig. 12 Typical Walk-In Cooler Installation

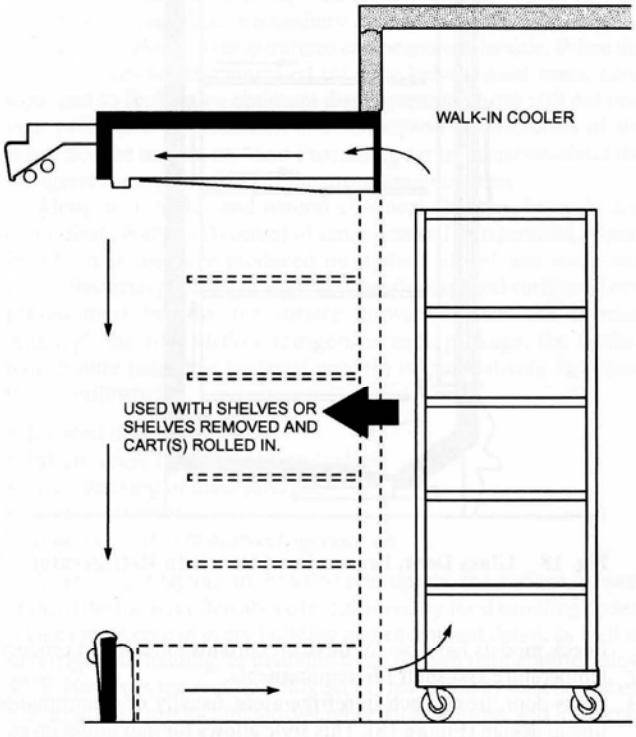


Fig. 13 Vertical Rear-Load Dairy (or Produce) Refrigerator with Roll-In Capability

Produce Display

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

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

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

Frozen Food and Ice Cream Display

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

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

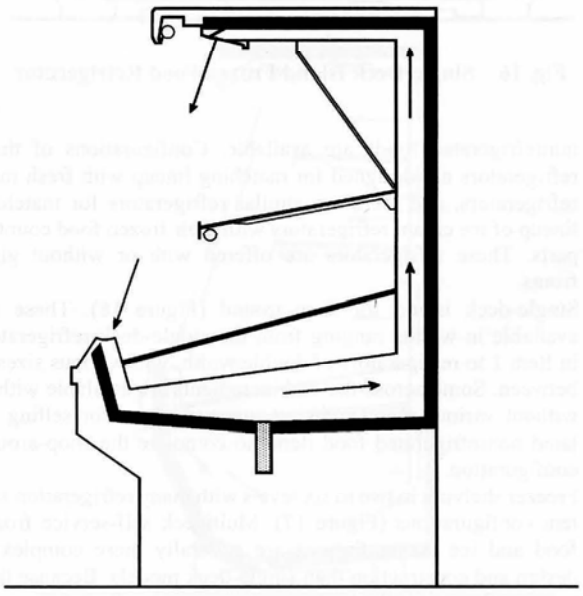


Fig. 14 Multideck Produce Refrigerator

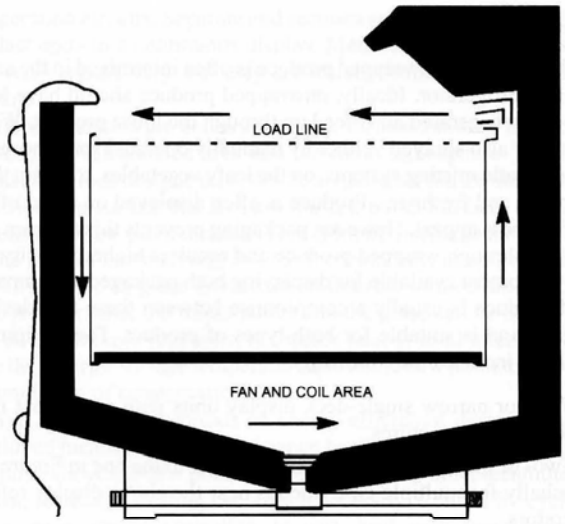


Fig. 15 Single-Deck Well-Type Frozen Food Refrigerator

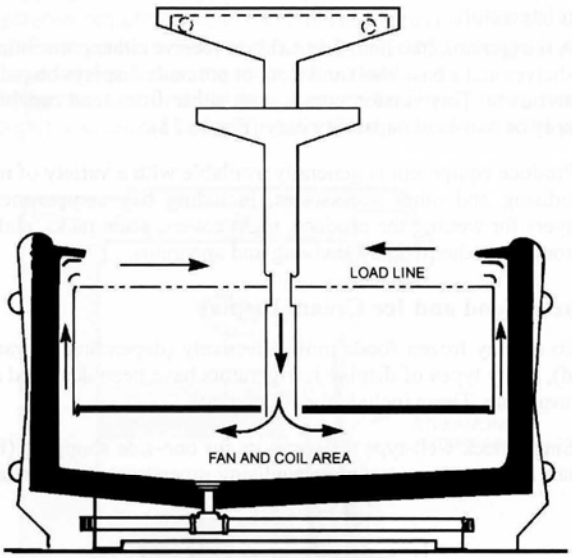


Fig. 16 Single-Deck Island Frozen Food Refrigerator

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

2. Single-deck island for shop-around (Figure 16). These are available in widths ranging from the single-deck refrigerators in Item 1 to refrigerators of double width, with various sizes in between. Some across-the-end increments are available with or without various merchandising superstructures for selling related nonrefrigerated food items to complete the shop-around configuration.
3. Freezer shelving in two to six levels with many refrigeration system configurations (Figure 17). Multideck self-service frozen food and ice cream fixtures are generally more complex in design and construction than single-deck models. Because they have wide, vertical display compartments, they are more affected by ambient conditions in the store. Generally, open multideck models have two or three air curtains to maintain product temperature and shelf life requirements.
4. Glass door, front reach-in refrigerators, usually of a continuous lineup design (Figure 18). This style allows for maximum inventory volume and variety in minimum floor space. These advantages must be balanced against the barrier produced by the doors

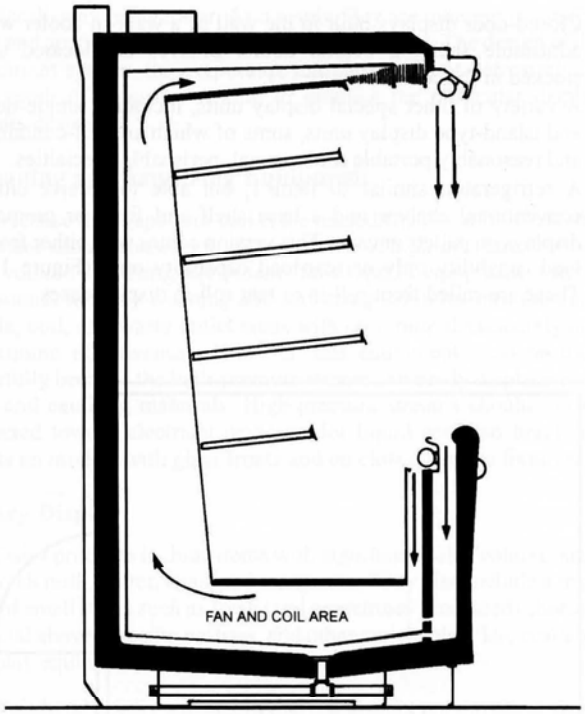


Fig. 17 Multideck Frozen Food Refrigerator

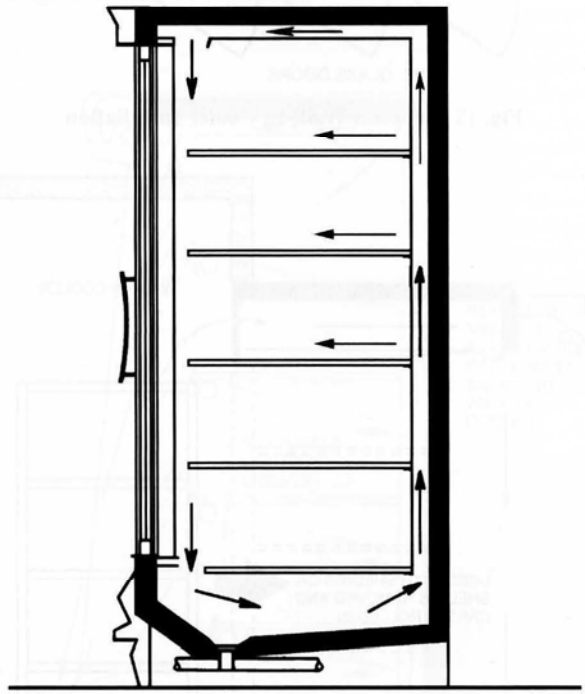


Fig. 18 Glass Door, Frozen Food Reach-In Refrigerator

and the greater labor requirement in restocking. The front-to-back interior dimension of these cabinets is usually about 24 in. Greater attention must be given to the back product to provide the desired rotation. While these refrigerators generally consume less energy in their operation than open multideck low-temperature refrigerators, specific comparisons by model should be made to determine original and operating costs.

5. Spot merchandising refrigerators, usually self-contained and sometimes arranged for quick change from nonfreezing to freezing temperature to allow for promotional items of either type (e.g., fresh asparagus or ice cream).
6. Versions of most of the above items for ice cream, usually with modified defrost heaters and other changes necessary for the approximately 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.

Meat Display

Prepackaged meat is becoming more popular. Most meat is sold in packaged form. Some of this product is cut and packaged on the store premises. Control of temperature, time, and sanitation from the truck to the checkout counter is important. Surface temperature on the meat in excess of 40°F shortens the salable life of meat products significantly and increases the rate of discoloration.

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

Sanitation is also important. If all else is kept equal, good sanitation can as much as double the salable life of meat in a display refrigerator. In this chapter, sanitation includes the control of the time during which meat is exposed to temperatures above 40°F. If meat has been handled in a sanitary manner until it is placed in the display case, elevated temperatures can be more tolerable. When the meat surfaces are contaminated by dirty knives, meat saws, table tops, and so forth, even optimum display temperatures will not prevent premature discoloration and subsequent deterioration of the meat. See the section on Meat Processing for information about the refrigeration requirements of the meat wrapping area.

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

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

Where these factors are handled improperly, the surface temperature of the meat is often above that allowed by food handling codes. It takes great care in every building and equipment detail, as well as in refrigerator loading, to maintain meat surface temperature below 40°F. However, the required diligence is rewarded by excellent shelf life, improved product integrity, higher sales volume, and less scrap or spoilage.

The surface temperature rises during defrost. Tests have compared matched samples of meat—one goes through normal defrost, and the other is removed from the refrigerator during its defrosting cycles. Although defrosting characteristics of refrigerators vary, such tests have shown that the effects on shelf life of properly handled defrosts are negligible. Tests for a given installation can easily be run to prove the effects of defrosting on shelf life for that specific set of conditions.

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

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

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

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

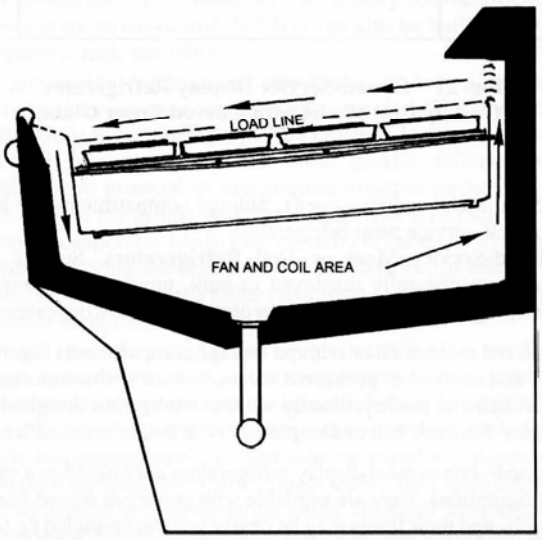


Fig. 19 Single-Deck Meat Display Refrigerator

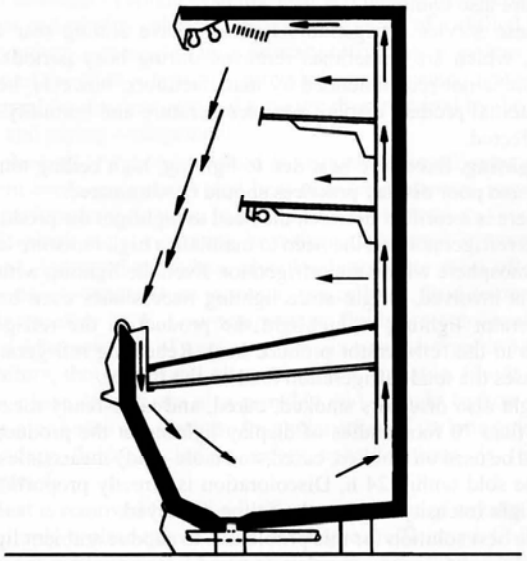


Fig. 20 Multideck Meat Refrigerator

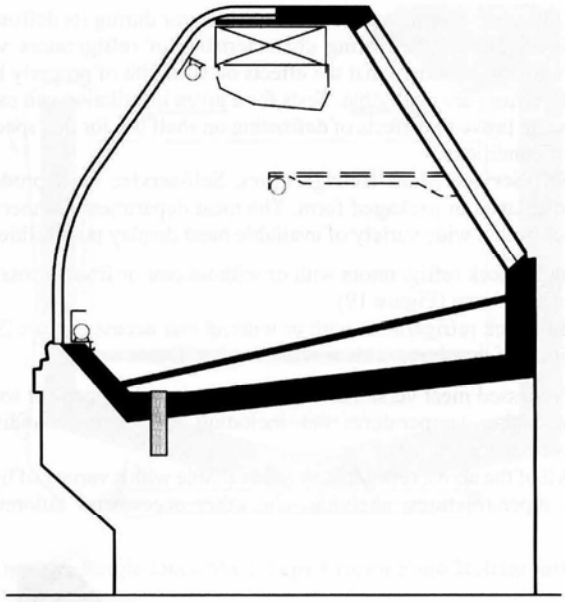


Fig. 21 Closed-Service Display Refrigerator (Gravity Coil Model with Curved Front Glass)

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

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

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

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

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

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

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

Light also discolors smoked, cured, and table-ready meats. No more than 70 footcandles of display lighting at the product level should be used on smoked, cured, and table-ready meats unless they will be sold within 24 h. Discoloration is directly proportional to both light intensity and length of time displayed.

The best solution for this problem is to subdue ambient lighting around the refrigerators so that minimal lighting within the refrigerator is not dominated. As mentioned in the section on Display Case Cooling Load and Heat Sources, fluorescent lamps with electronic ballasts or ballasts located out of the refrigerated space have been used to reduce heat load in the case. Meat and deli refrigerators usually maintain a long shelf life when the air temperature in the refrigerator is between 35 and 37°F. At the same time, the velocity of the refrigerated air over the product should be minimized. High relative humidity and a stable temperature should be maintained in the product zone for maximum shelf life. Use of an evaporator pressure control is often recommended for refrigeration control. A minimum temperature difference (TD) thermostat is used as a backup for times when the load is small. This control method minimizes product dehydration.

MEAT PROCESSING

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

The wrapping room should not be too dry, but condensation on the meat, which provides a medium for bacterial growth, should be avoided by maintaining a dew point temperature within a few degrees of the sensible temperature. Fan-coil units should be selected with a maximum of 10°F 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 the personnel, but not low enough for meat storage. Thus, meat should be held in that room only for the cutting and packaging operation; then, as soon as possible, it should be moved to a packaged product storage cooler held at 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, while the second compartment is refrigerated at 45 to 55°F and used as a cutting and packaging room. Best results are attained when the meat is cut and wrapped to minimize exposure to temperatures above 28 to 32°F.

STORAGE REFRIGERATORS

Wrapped Meat Storage

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

A second option is a pass-through, reach-in cabinet. This cabinet has both front and rear insulated glass doors and is located between the wrapping room and the display refrigerators. After wrapping, the meats are passed into the cabinet for temporary storage at 28 and 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 into which the trays of meat can be slid. This method of storage also offers visible inventory control. This method provides convenient access to both the wrapping room and the display cases.

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

Walk-In Storage Coolers

Each category of displayed food product that requires refrigeration for preservation is usually backed up by storage in the back room. This storage usually consists of refrigerated rooms with sectional walls and ceilings equipped with the necessary storage racks for a particular food product. Walk-in coolers are required for the storage of meat, some fresh produce, dairy products, frozen food, and ice cream. Medium and large stores have separate produce and dairy coolers usually in the 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 the refrigeration load, allowance must be made for the extra service load.

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

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

For optimum humidity control, unit coolers should be selected at about a 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.

REFRIGERATORS AND SYSTEMS

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

Temperature controls also vary greatly, from a produce preparation room (which may operate with a wet coil) requiring no defrost to the ice cream case requiring induced heat to defrost the coil periodically. Electronic sensor control is the most accurate and can also provide a temperature alarm to prevent food loss. Defrost methods include (1) off-time defrost, (2) gas defrost, (3) electric defrost, and (4) defrost using ambient air induced into the refrigerator.

Various Refrigeration System Design Solutions

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

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

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

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

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

Secondary Coolant Systems

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

Selection of secondary fluid is critical to the efficiency of the system because viscosity and heat-transfer properties impact system performance directly. In most cases, the secondary fluid is in a single-phase state, removing heat through a sensible temperature change. Inhibited propylene glycol solutions are most often used for medium-temperature systems, typically at fluid temperatures not lower than 15°F. Low-temperature fluids are commonly composed of a solution of various potassium-based organic salts and inhibitors, though several alternatives are available. Fluids involving a phase change are also possible and include carbon dioxide and water-based ice slurries. An explanation of various options for secondary fluids, including safety considerations, is found in Chapter 4.

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

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

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

There are several advantages to secondary coolant systems. Because the primary refrigeration system is mostly contained in the machine room, the amount of refrigerant required can be reduced by as much as 80-90%. Since most piping joints are factory installed, this combined with a lower charge results in significantly lower refrigerant leakage rates which reduce any environmental impacts associated with the primary refrigerant. The compressors and evaporator are close-coupled, so suction line pressure losses and heat gains are minimized, enhancing system performance. Secondary coolant systems are inherently less complex than direct expansion types, requiring fewer and less-complicated valves and control devices. Less-expensive nonmetallic piping systems and components can also be utilized since the system operating pressure is low, typically less than 60 psig. Service of the refrigeration is basically limited to the machine room area. Because a fluid loop is used, thermal storage may be applied to reduce peak power demands and take advantage of lower off-peak utility rates. Ambient or free cooling may be applied in areas with colder climates. Secondary systems also can use primary refrigerants not typically suitable for direct expansion systems, including ammonia and hydrocarbons.

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

Two defrost methods, time-off and warm fluid, are most commonly applied to secondary systems. Time-off defrost can be used in some medium-temperature applications. However, the most effective method is warm fluid defrost, which is used for all low-temperature applications and in selected medium-temperature cases where product temperatures are critical or time-off defrost is not practical. Fluid for defrost is typically heated using refrigerant discharge gas, but system efficiency can be increased by a heat exchange with liquid refrigerant. Temperatures of warm fluid vary and must be optimized for the coil application; however, typical values are 50 to 60°F for medium 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.

Liquid-Cooled Self-Contained Systems

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

As with other systems, there are advantages and disadvantages. As much as 80% less refrigerant charge is needed. There is less potential for refrigerant loss by leakage. Initial equipment costs may be lower. Refrigerators can be performance-tested before they are shipped from the factory, and installations may be less labor-intensive.

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

Load Versus Ratings

Food store refrigerator manufacturers publish case load ratings to match the proper condensing unit with the fixture load. For single-compressor applications only, the ratings can be stated, for selection convenience, as the capacity the condensing unit must deliver at an arbitrary suction pressure (evaporator temperature). In general, manufacturers of display refrigerators use ASHRAE *Standards* 72 and 117, which specify standard methods of testing open and closed refrigerators for food stores. These standards establish refrigeration load requirements at rated ambient conditions of 75°F and 55% rh in the sales area. Similar display refrigerators vary between manufacturers, so manufacturers' recommendations must be followed to achieve proper results in both efficiency and product integrity.

Multiplexed Systems

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

Electronically or mechanically actuated pilot-operated evaporator pressure regulator (EPR) valves control evaporator pressures in multiplexed systems. These valves cause little or no measurable pressure drop when they are in the full-open position. Another design uses liquid or discharge pressure to open and close the EPR valves, so the pressure drop is negligible. Another design has no pilot valve but typically requires a minimum of 1 psi pressure drop for operation.

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

One solution to excessively high superheat is to run the suction line and liquid line tightly together from the fixture refrigerant line outlet, with the pair insulated together for a distance of 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). Most manufacturers produce suction line to liquid line heat exchangers installed in the display fixture. This technique converts a loss into a gain by allowing the suction gas to pick up heat

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

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

COMPRESSOR CONFIGURATIONS

Matching Refrigerator Requirements with Compressor Capacity

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

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

Typical Parallel Compressor Energy Efficiency

A typical supermarket includes one or more medium-temperature parallel systems for meat, deli, dairy, and produce refrigerators and the medium-temperature walk-in coolers. The system may have a separate compressor for the meat or deli refrigerators, or all units may have a single compressor. Energy efficiency ratios typically run from 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 the frozen food units and as low as 3.5 to 4.0 Btu/h per watt for the ice cream units. Cutting and preparation rooms are most economically placed on a single unit because the refrigeration EER is at 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 22).

Capacity Control of Parallel Systems

This system must be designed to maintain proper refrigerator temperatures under peak summer load. During the remainder of the year, store conditions can be easily maintained at a more ideal condition, and refrigeration load will be lower. In the past, refrigeration systems were operated at 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, today's technology permits the condensing temperature to follow the ambient down to about 70°F or less. When proper liquid-line piping practices are observed, the expansion valves feed the evaporators properly under these low condensing temperatures. Therefore, at partial load, the system has excessive capacity to perform adequately.

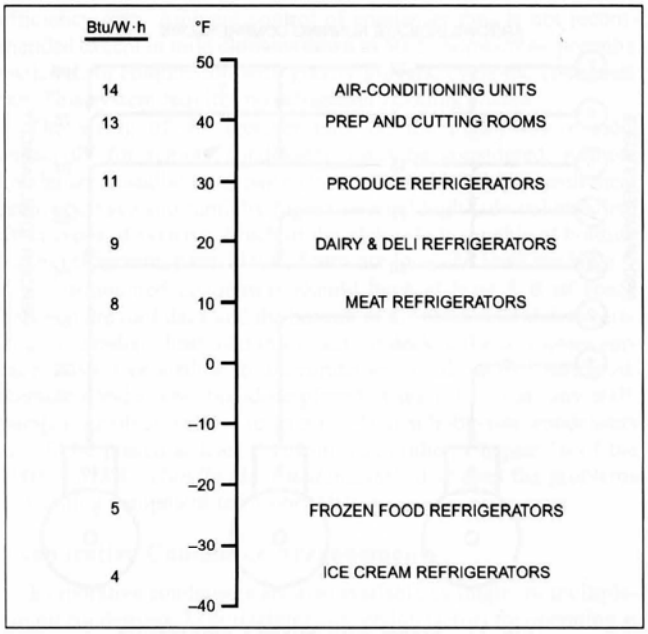


Fig. 22 Typical Single-Stage Compressor Efficiency

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. Newer, solid-state control devices can cycle units; the run time for each compressor motor can be equalized while the system remains at one economical pressure range. Satellite compressors can be controlled accurately with one control that also monitors other components, such as oil pressure and alarm functions. Rack capacity can also be varied by compressor cylinder unloading.

Staging Unequally Sized Compressors

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

Screw Compressor Central Plant Units

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

Use of the Economizer Port on Screw Compressors

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

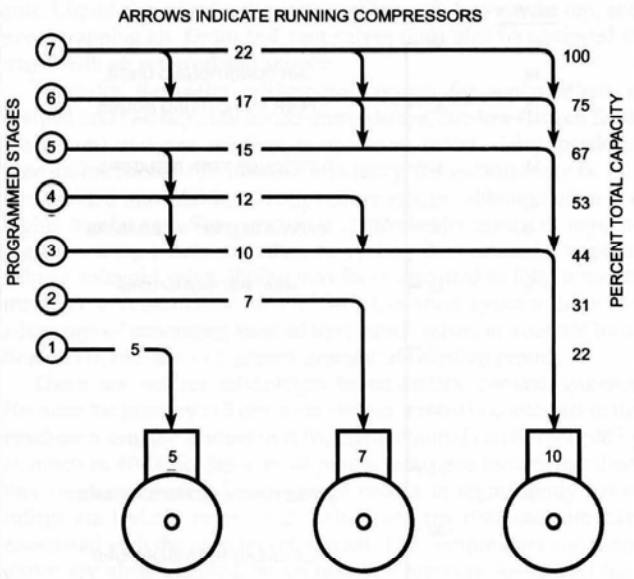


Fig. 23 Stages with Mixed Compressors

the sizing of the screw compressors is very important to a successful refrigeration installation.

Factory-Assembled Equipment

Factory assembly of the necessary compressor systems with either a direct air-cooled condenser or any style of remote condenser is common practice. Both single and parallel systems can be housed, 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 supermarkets have elected to purchase the compressor equipment installed in a housing to reduce real estate costs for the building. The time requirements for installation of piping and wiring may also be reduced with prefabrication. Most of the rooms are modular and prewired and include some refrigeration piping. Their fabrication in a factory setting should offer good quality control of the assembly. They are usually put into operation quickly upon arrival at the site.

Subcooling Liquid Refrigerant

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

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

Heat Recovery

Heat recovery may be an important feature of virtually every compressor system, parallel or single. A heat recovery coil is simply a second condenser coil placed in the air handler. If the store needs heat, this coil is energized and run in series with the regular condenser (see Figure 25). The heat recovery coil can be sized for a 30 to 50°F TD depending on the capacity in cool weather. Lower head pressures in parallel systems permit little heat recovery. However, when heat is required in the store, simple controls create a higher head pressure for heat recovery. Compared with the cost of auxiliary gas or electric heat, the higher energy consumption of the compressor system may be compensated for by the value of the heat gained.

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

CONDENSING METHODS

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

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

Air-Cooled Machine Room

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

A complete air-cooled condensing unit located indoors requires ample, well-distributed ventilation. Ventilation requirements vary depending on maximum summer conditions and evaporator temperature, but 750 to 1000 cfm per condensing unit horsepower has given proper results. Exhaust fans should be spaced for an even distribution of air (Figure 24).

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 24), 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 24). Because air recirculation is needed around the condensers for proper winter control, the intake air should not be baffled to flow only through the condensers.

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

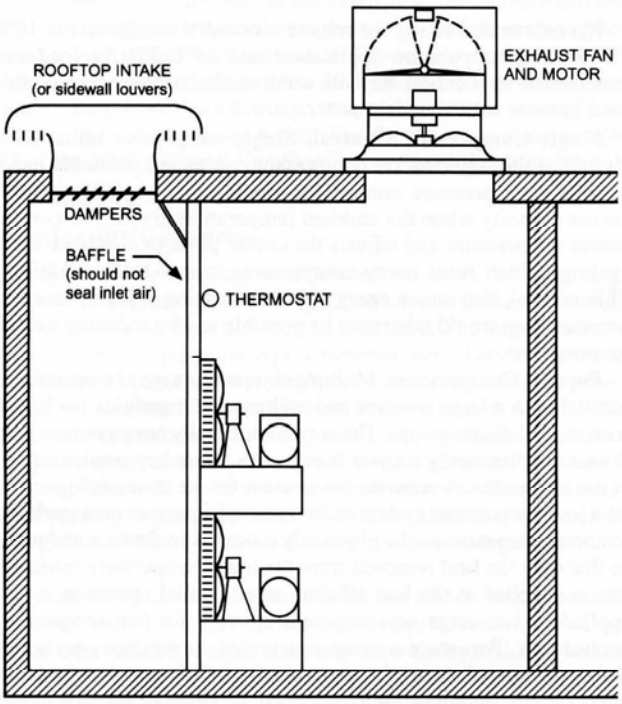


Fig. 24 Typical Air-Cooled Machine Room Layout

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

Condenser Sizing

To minimize energy consumption, condensers should be more generously sized than they are for typical air-conditioning applications. Typical condenser selection is based on the temperature difference between the air entering the condenser and the saturated condensing temperature. Generally accepted TDs for refrigeration condenser sizing are 15°F for medium-temperature systems and 10°F for low-temperature systems.

Remote Air-Cooled Condenser

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

Pressure must be controlled on most outdoor condensers. Fan cycle controls work well down to 50°F on condensers with single compressors or with parallel groups of compressors. Below 50°F, condenser flooding (with the refrigerant) can be used alone or with fan controls. Flooding requires a larger refrigerant charge and larger liquid receiver. In contrast, split condensers with solenoid valves in the hot-gas lines and bleedoff in the liquid return lines can reduce the condenser surface during cold weather. Natural subcooling can be integrated into the design to save energy.

Fans are controlled by pressure controls, liquid-line thermostats, or a combination of both. Ambient control of condenser fans is commonly used; however, it may not give the degree of condensing temperature control required in systems designed for high-efficiency gain. Ambient control of condenser fans is not recommended except in mild climates down to 50°F. Sometimes, pressure switches, in conjunction with gravity louvers, cycle the condenser fan. This system requires no refrigerant flooding charge.

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

Roof-mounted condensers should have at least 3 ft of space between the roof deck and the bottom of the condenser slab to minimize the radiant heat load from the roof deck to the condenser surface. Also, free airflow to the condenser should not be restricted. Remote condensers should be placed at least 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 2001 *ASHRAE Handbook—Fundamentals* discusses the problems of locating equipment for proper airflow.

Evaporative Condenser Arrangements

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

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

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

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

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

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

Cooling Tower Arrangements

Few supermarkets use water-cooled condensing units because the trend is toward air cooling. Nearly all water-cooled condensing units are installed with a water-saving cooling tower because of the high cost of water and sewage disposal.

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

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

Condensing Units

Air-Cooled Condensing Unit. Single-unit compressors with air-cooled condenser systems can be mounted in racks up to three high to save space. These units may have condensers sized so that the TD is in the 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.

Water-Cooled Condensing Unit. Water-cooled units range in size from 0.5 to 30 hp and are best for hot, dry climates. A city water-cooled condensing unit is usually no longer economical due to the high cost of water and sewer fees. Cooling towers, which cool the water for all compressors, are used instead. Closed water systems are also used in areas that can use an evaporative water cooler.

Remote Condenser-Compressor Unit. Remote units operate efficiently with minimum condenser maintenance. Evaporative condensers are also used in some areas. Sizes range from 0.5 to 30 hp.

Recommended sizing for remote air-cooled condensers is 10°F TD for low-temperature application and 15°F TD for medium-temperature application. Remote water-cooled condensers are often used in areas with abundant water.

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

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

Remote Air-Cooled Condenser and Heat Recovery Coil. Remote air-cooled condensers are popular for use with parallel compressors. The condenser coil TD is in the range of 10°F for low-temperature and 15°F for medium-temperature applications. For energy conservation, generous sizing of the condenser with a lower TD is recommended. Figure 25 illustrates a basic parallel system with an air-cooled condenser and heat recovery coil.

Evaporative Condenser. Evaporative condensers have a coil, in which refrigerant is condensed or closed-loop circulating water is cooled, and a means of supplying air and water over its external surfaces. Heat is transferred from the condensing refrigerant inside the

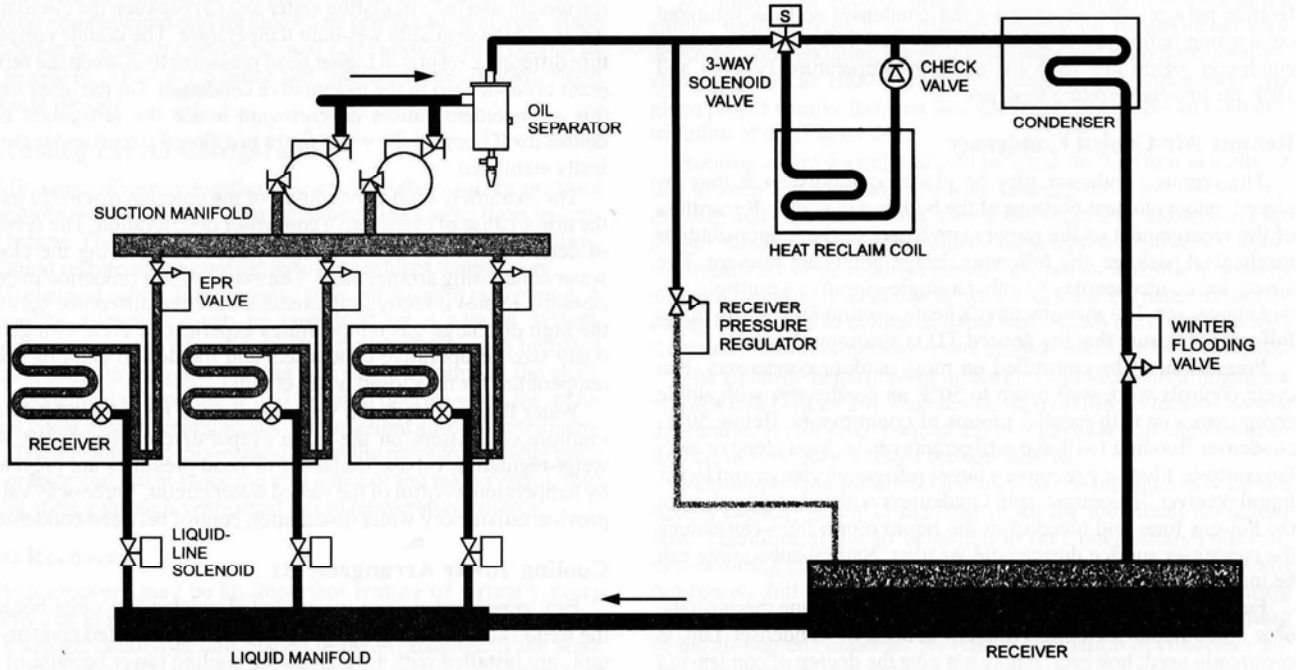


Fig. 25 Basic Parallel System with Remote Air-Cooled Condenser and Heat Recovery

coil or the water in the loop to the external wetted surface and then into the moving airstream principally by evaporation. In areas where the wet-bulb temperature is about 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; one evaporative condenser can be installed for the entire store. Chapter 35 of the 2000 *ASHRAE Handbook—Systems and Equipment* gives more details.

Condensing Unit Noise

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

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

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

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

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

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

See Chapter 46 of the 1999 *ASHRAE Handbook—Applications* for information on outdoor sound criteria, equipment sound levels, sound control for outdoor equipment, and vibration isolation.

METHODS OF DEFROST

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

Gas Defrost

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

Air Defrost

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

Electric Defrost

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

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

Condensing Unit Off-Time

This method simply shuts off the unit and allows it to remain off until the evaporator reaches a temperature that permits defrosting and gives ample time for condensate drainage. Because this method obtains its heat from the air circulating in the display fixture, it is slow and limited to open fixtures operating at temperatures of 34°F or above. Methods of defrost control include (1) suction pressure control (no time clock required); (2) time clock initiation and termination; (3) time clock initiation and suction pressure termination; (4) time clock initiation and temperature termination; and (5) demand defrost or proportional defrost.

Suction Pressure Control. This control is adjusted for a cut-in pressure high enough to allow defrosting during the off cycle. This method is usually used in fixtures maintaining temperatures from 36 to 43°F. Air is circulated over the coil, melting the frost on the coil. This provides some cooling effect to the product during defrost. If an excessive heat or humidity load occurs, the evaporator frost becomes ice. When the evaporator pressure is lowered to the cutout point of the control, the control initiates a defrost cycle to clear the evaporator.

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

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

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

Initiation and Termination

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

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

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

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

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

REFRIGERANT LINES

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

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

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

REFRIGERANTS

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

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

The concern about ozone depletion has lead to regulations by the U.S. Environmental Protection Agency to minimize emissions of the refrigerants. Intentional venting of all refrigerants, including the substitutes, is prohibited. Additional regulations apply to chlorine-containing refrigerants such as R-22. When systems containing more than 50 lb of refrigerant leak more than 35% of the charge per year, equipment repairs are required. Certain servicing and record keeping practices are also required. Future regulations have been proposed to extend these regulations to the hydrofluorocarbon substitutes and to tighten the leak repair requirements. These developments should be monitored.

INTERACTION BETWEEN REFRIGERATION AND AIR CONDITIONING

Open display equipment often extracts enough heat from the store's ambient air to reduce the air temperature in the customer aisles to as much as 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 cases back to the store air handler. Lack of attention to this element can substantially reduce sales in these areas.

Heat Reclamation

Heat reclaim condensers and related controls operate as alternates to or in series with the normal refrigeration condensers. They can be used in winter to return most of the refrigeration and compressor heat to the store. They may also be used in mild spring and fall weather when some heating is needed to overcome the cooling effect of the refrigeration system itself. Another use is for cooling coil reheat when needed for humidity control in spring, summer, and fall. Excess humidity in the store must be avoided because it can increase the display case refrigeration load as much as 20% at the same dry-bulb temperature. Also, heat reclamation can be used to heat water for store use. The section on Supermarkets in Chapter 2 of the 1999 *ASHRAE Handbook—Applications* has more detailed information on the interrelation of the store environment and the refrigeration equipment.

Environmental Equipment and Control

Major components of common store environmental equipment include (1) central air handler with fresh makeup air mixing box, (2) air-cooling coils, (3) heat recovery coils, (4) supplemental heat equipment, (5) connecting ducts, and (6) termination units such as air diffusers and return grilles.

Environmental control is the heart of energy management. Control panels designed for the unique heating, cooling, and humidity control requirements for food stores provide several stages of heating (up to eight) and cooling (up to three), plus a dehumidification

stage. When high humidity exists in the store, cooling is activated to remove moisture. The controller receives input from temperature and dew point sensors that are located in the sales area.

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

Following are rules for good air distribution in food stores:

Air Circulation. Operate 100% of the time the store is open at a volumetric flow of 0.6 to 1 cfm per square foot of sales area. Air supply and return grilles should be located so they do not disturb the air in open display cases and negatively affect case performance.

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

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

Return Air. Locate return air registers as low as possible. With low registers, return air temperature may be 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 case ventilated bases and through trenches.

REFERENCES

ASHRAE. 1983. Method of testing open refrigerators for food stores. ASHRAE *Standard* 72-1983.

ASHRAE. 1992. Methods of testing closed refrigeration. ANSI/ASHRAE *Standard* 117-1992.

ASHRAE.1992. Number designation and safety classification of refrigerants. ANSI/ASHRAE *Standard* 34-1992.

Arthur D. Little, Inc. 1996. Energy savings potential for commercial refrigeration equipment—Final Report, prepared for the U.S. Department of Energy.

Faramarzi, R. 1999. Efficient display case refrigeration. *ASHRAE Journal* (November):46.

Faramarzi, R. and K. Kemp. 1999. Testing the old with the new. *Engineered Systems* (May):52.

Faramarzi, R. 2000. Analyzing air curtain performance in a refrigerated display case. Seminar, ASHRAE Annual Meeting (June). Minneapolis.

Faramarzi, R. 2001. Effects of improper product loading on the performance of an open vertical meat display case. Seminar, ASHRAE Annual Meeting (June). Cincinnati.

Faramarzi, R., B. Coburn, and R. Sarhadian. 2001. Anti-sweat heaters in refrigerated display cases. *ASHRAE Journal* (June):64.

FDA. 1995. *Food Code.* Food and Drug Administration, U.S. Department of Health and Human Services, Washington, D.C.

Food Marketing Institute, Inc. 2000. *Key industry facts.* http://www.fmi.org/facts_figs/keyfacts/stores.html.

Gas Research Institute. 2000. *Investigation of relative humidity impacts on the performance and energy use of refrigerated display cases.* Chicago, IL.

Howell, R.H. 1993a. Effects of store relative humidity on refrigerated display case performance. *ASHRAE Transactions* 99(1).

Howell, R.H. 1993b. Calculation of humidity effects on energy requirements of refrigerated display cases. *ASHRAE Transactions* 99(1).

Komor, P., C. Fong, and J. Nelson. June 1998. Delivering energy services to supermarkets and grocery stores. E Source. Boulder, CO.

CHAPTER 48

FOOD SERVICE AND GENERAL COMMERCIAL REFRIGERATION EQUIPMENT

Reach-In and Specialty Cabinets 48.1
Roll-In Cabinets 48.3
Food Freezers 48.3
Blast Chillers and Blast Freezers 48.3
Walk-In Coolers/Freezers 48.4

FOOD service requires refrigerators that meet a variety of needs. This chapter covers refrigerators available for restaurants, fast-food restaurants, cafeterias, commissaries, hospitals, schools, convenience stores, and other specialized applications.

Many of the refrigeration products used in food service applications are self-contained, and the corresponding refrigeration systems are conventional. Some systems, however, do use ice for fish, salad pans, or specialized preservation and/or display. Chapters 47, 49, and 50 have further information on some of these products.

Generally, electrical and sanitary requirements of refrigerators are covered by criteria, standards, and inspections of Underwriters Laboratories (UL), NSF International, and the U.S. Public Health Service.

Frame construction is usually of metal. Occasionally, wood is used in minor amounts, but it is rarely visible in the final assembly. Nonmetallic materials are used increasingly for interior liners, decoration, finish, trim, thermal break strips, and gaskets.

Stainless steel is the most common sheet metal used for these refrigerators. Other sheet metals used are aluminum and carbon steel, either hot- or cold-rolled. Stainless steel usually has a grained or polished finish when exposed in final assembly. Aluminum is generally unfinished, although it may occasionally be lacquered or coated with some other organic finish. Carbon steel may be black; plated; aluminized; or coated with either high-solids powder paint, enamel, or another special finish.

Insulation is usually one of the following: (1) foam polyurethane poured in place, (2) slab polyurethane, (3) slab polystyrene, or (4) glass fiber batts. Foam polyurethane is advantageous because it conforms to various cavity shapes and provides added structural integrity through adherence bonding to cabinet liners.

REACH-IN AND SPECIALTY CABINETS

The **reach-in refrigerator** or freezer is an upright, box-shaped cabinet with straight vertical front(s) and hinged or sliding doors (Figure 1). It is usually about 2.5 to 3 ft deep and 6 ft high and ranges in width from about 3 to 10 ft. Capacities range from about 20 to 90 ft^3. Undercounter models 3 ft high with the same dimensions are also available. These capacities and dimensions are standard from most manufacturers.

The typical reach-in cabinet (Figure 1) is available in many styles and combinations, depending on its intended application. Other shapes, sizes, and capacities are available on a custom basis from some manufacturers (Figure 2).

There are many varied adaptations of refrigerated spaces for storing perishable food items. Reach-ins, by definition, are medium- or low-temperature refrigerators small enough to be moved into a building. This definition also includes refrigerators and freezers built for special purposes, such as mobile cabinets or refrigerators on wheels and display refrigerators for such products as beverages, pies, cakes, and bakery goods. The latter cabinets usually have glass doors. Candy refrigerators are also specialized in size, shape, and temperature.

Refrigerated vending machines satisfy the general definition of reach-ins, but they also receive coins and dispense products

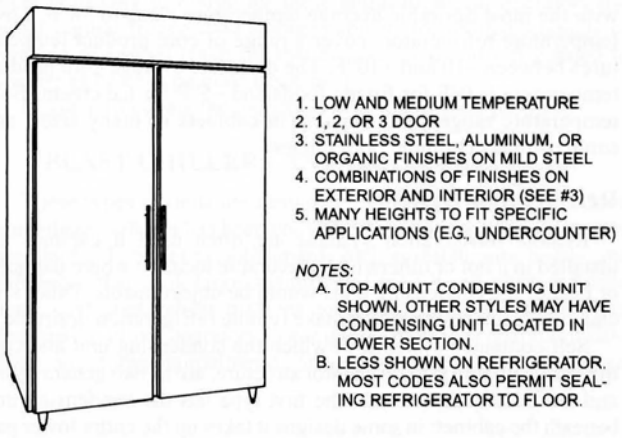


Fig. 1 Reach-In Food Storage Cabinet Features

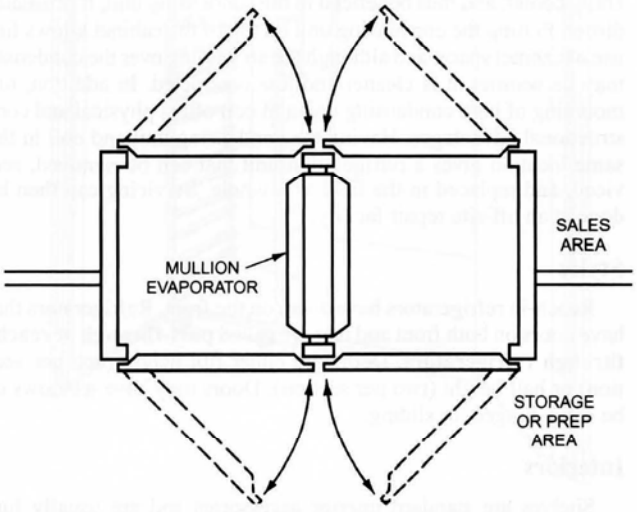


Fig. 2 Pass-Through Styles Facilitate Some Handling Situations

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

individually. Generally, the full product load of a vending machine is not accessible to the customer. Beverage-dispensing units dispense a measured portion into a cup rather than in a bottle or can.

Types of Construction

Reach-in refrigerators are available in two basic types of construction. The older style is a wood frame substructure clad with a metal interior and exterior. The newer style is a welded assembly of exterior panels with insulation and liner inserts.

Materials used on exteriors and interiors are stainless steel, painted steel, aluminum-coated steel, aluminum, and vinyl-clad steel with wood grain or other patterns. The requirements are for a material that (1) matches or blends with that used on nearby equipment; (2) is easy to keep clean; (3) is not discolored or etched by commonly used cleaning materials; (4) is strong enough to resist denting, scratching, and abrasion; and (5) provides the necessary frame strength. The material chosen by an individual purchaser depends a great deal on layout and budget.

Temperature Ranges

Reach-in refrigerators are available for medium- or low-temperature ranges. The medium-temperature range has a maximum of 41°F and a minimum of 33°F core product temperature, with the most desirable average temperature close to 38°F. Low-temperature refrigerators cover a range of core product temperatures between –10 and +10°F. The desirable average core product temperature is 0°F for frozen foods and –5°F for ice cream. Both temperature ranges are available in cabinets of many sizes, and some cabinets combine both ranges.

Refrigeration Systems

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. Other special circumstances may also make remote refrigeration desirable.

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

There is no advantage to locating a self-contained condensing unit beneath the refrigerator; although the air near the floor is generally cooler, and thus beneficial to the condensing unit, it is usually dirtier. Putting the condensing unit on top of the cabinet allows full use of cabinet space, and although the air passing over the condenser may be warmer, it is cleaner and less obstructed. In addition, top mounting of both condensing unit and coil offers physical and constructional advantages. Having the condensing unit and coil in the same location gives a refrigeration unit that can be removed, serviced, and replaced in the field as a whole. Servicing can then be done at an off-site repair facility.

Styles

Reach-in refrigerators have doors on the front. Refrigerators that have doors on both front and rear are called **pass-through** or **reach-through refrigerators**. Doors are either full height (one per section) or half height (two per section). Doors may have windows or be solid, hinged, or sliding.

Interiors

Shelves are standard interior accessories and are usually furnished three or four per full-height section. Generally, various types of shelf standards are used to provide vertical shelf adjustment.

Modifications and Adaptations

Food Service. These applications often require extra shelves or tray slides, pan slides, or other interior accessories to increase food-holding capacity or make operation more efficient. Because certain stored foods create a corrosive atmosphere in the enclosure, the evaporator coil may have special coatings or fin materials to prevent oxidation. As use of foods prepared off-premises increases, on-site storage cabinets are becoming more specialized; there is growing pressure for designs that consider new food shapes, as well as in-and-out handling and storage.

Beverage Service. If reach-ins are required, standard cabinets are used except when glass doors and special interior racks are needed for chilled product display.

Meal Factories. These applications, which include airline or central feeding commissaries, require rugged, heavy-duty equipment, often fitted for bulk in-and-out handling.

Retail Bakeries. Special requirements of bakeries are the dough retarder refrigerator and the bakery freezer, which permit the baker to spread the work load over the entire week and to offer a greater variety of products. The recommended temperature for a dough retarder is 36 to 40°F. The relative humidity should be in excess of 80% to prevent crusting or other undesirable effects. In the freezer, the temperature should be held at 0°F. All cabinets or wheeled racks should be equipped with racks to hold 18 by 26 in. bun pans, which are standard throughout the baking industry.

Retail Stores. Stores use reach-ins for many different nonfood items. Drugstores often have refrigerators with special drawers for storage of biological compounds. (See the section on Nonfood Installations.)

Retail Florists. Florists use reach-in refrigerators for displaying and storing flowers. Although a few floral refrigerator designs are considered conventional in the trade, the majority are custom built. The display refrigerator located in the sales area at the front of the shop may include a picture window display front and have one or more display access doors, either swinging or sliding. A variety of open refrigerators may also be used.

For the general assortment of flowers in a refrigerator, most retail florists have found best results at temperatures from 40 to 45°F. The refrigeration coil and condensing unit should be selected to maintain a high relative humidity. Some florists favor a gravity cooling coil because the circulating air velocity is low. Others, however, choose forced-air cooling coils, which develop a positive but gentle airflow through the refrigerator. The forced-air coil has an advantage when the in-and-out service is especially heavy because it provides quick temperature recovery during these peak conditions.

Nonfood Installations. A variety of applications use a wide range of reach-ins, some standard except for accessory or temperature modifications and some completely special. Examples are (1) biological and pharmaceutical cabinets; (2) blood bank refrigerators; (3) low- and ultralow-temperature cabinets for bone, tissue, and red-cell storage; and (4) specially shaped refrigerators to hold column chromatography and other test apparatus.

Blood bank refrigerators for whole blood storage are usually standard models, ranging in size from under 20 to 45 ft^3, with the following modifications:

- Temperature is controlled at 37 to 41°F.
- Special shelves and/or racks are sometimes used.
- A temperature recorder with a 24 h or 7 day chart is furnished.
- An audible and/or visual alarm system is supplied to warn of unsafe blood temperature variation.
- Sometimes an additional alarm system is provided to warn of power failure.

Biological, laboratory, and mortuary refrigerators involve the same technology as refrigerators for food preservation. Most

biological serums and vaccines require refrigeration for proper preservation and to retain highest potency. In hospitals and laboratories, refrigerator temperatures should be 34 to 38°F. The refrigerator should provide low humidity and should not freeze. Storage in mortuary refrigerators is usually short-term, normally 12 to 24 h at 34 to 38°F. Refrigeration is provided by a standard air- or water-cooled condensing unit with a forced-air cooling coil.

Items in biological and laboratory refrigerators are kept in specially designed stainless steel drawers sized for convenient storage, labeled for quick and safe identification, and perforated for proper air circulation.

Mortuary refrigerators are built in various sizes and arrangements, the most common being two- and four-cadaver self-contained models. The two-cadaver cabinet has two individual storage compartments, one above the other. The condensing unit compartment is above and indented into the upper front of the cabinet; also ventilation grills are on the front and top of this section. The four-cadaver cabinet is equivalent to two two-cadaver cabinets set together; the storage compartments are two cabinets wide by two cabinets high, with the compressor compartment above. Six- and eight-cadaver cabinets are built along the same lines. The two-cadaver refrigerator is approximately 38 in. wide by 94 in. deep by 77 in. high and is shipped completely assembled.

Each compartment contains a mortuary rack consisting of a carriage supporting a stainless steel tray. The carriage is telescoping, equipped with roller bearings so that it slides out through the door opening and is self-supporting even when extended. The tray is removable. Some specifications call for a thermometer to be mounted on the exterior front of the cabinet to show the inside temperature.

ROLL-IN CABINETS

These cabinets are very similar in style and appearance to reach-in cabinets. Roll-ins (Figure 3) are usually part of a food-handling or other special-purpose system (Figure 4). Pans, trays, or other specially sized and/or shaped receptacles are used to serve a specific system need, such as the following:

- Food-handling for schools, hospitals, cafeterias, and other institutional facilities
- Meal manufacturing
- Bakery processing
- Pharmaceutical products
- Body parts preservation (e.g., blood)

The roll-in differs from the reach-in in the following ways:

- The inside floor is at about the same level as the surrounding room floor, so wheeled racks of product can be rolled directly from the surrounding room into the cabinet interior.
- Cabinet doors are full height, with drag gaskets at the bottom.
- Cabinet interiors have no shelves or other similar accessories.

The racks that roll in and out of these cabinets are generally fitted with slides to handle 18 by 26 in. pans, although some newer systems call for either 12 by 20 in. or 12 by 18 in. steam table pans. Racks designed for special applications are available, but usually custom designed.

Manufacturers and contractors offer various methods of insulating the floor area. This is important if the roll-in is to hold frozen food.

FOOD FREEZERS

Some hospitals, schools, commissaries, and other mass-feeding operations use on-premises freezing to level work loads and operate kitchens efficiently on normal schedules. Industrial freezing equipment is usually too large for these applications, so operators use either regular frozen food storage cabinets for limited amounts of freezing or special reach-ins that are designed and refrigerated to operate as batch-type blast freezers.

Chapter 15 covers the industrial freezing of food products.

BLAST CHILLERS AND BLAST FREEZERS

These types of units are designed to rapidly chill or freeze food immediately after it has been cooked. Blast chillers and freezers are used by food-service establishments such as restaurants, hotels, and cafeterias, that cook large quantities of food items, chill or freeze them, and later reheat portions to be served. Blast chillers are designed to allow operators to comply with food preparation, handling, and storage guidelines on preventing the growth of dangerous



Fig. 3 Open and Enclosed Roll-In Racks

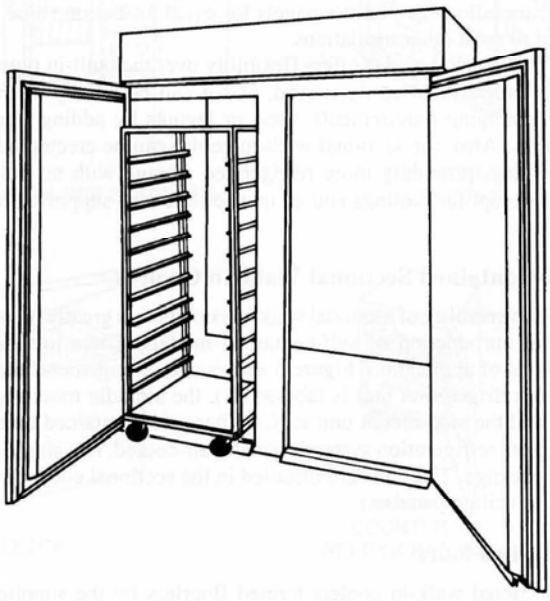


Fig. 4 Roll-In Cabinet —Usually Part of a Food-Handling or Other Special-Purpose System

bacteria. These guidelines mandate that food be cooked to a minimum core temperature of 160°F and held there for at least 2 minutes. The food is then immediately cooled to between 33 and 38°F within 2 to 4 hours. This not only prevents bacteria growth, but also helps preserve the appearance, flavor, texture, and nutritional value of the food item. Once cooled, refrigerated food must be stored at a temperature range of 33 to 38°F for a period not to exceed 5 days. Frozen food must be maintained below 0°F and can be kept for 8 weeks or longer.

Blast chillers for refrigerated food, and blast freezers for frozen food, are available in reach-in and roll-in models in a variety of sizes and capacities. They are designed to operate both as blast chillers and as storage refrigerators or freezers. Most blast chillers will automatically change over to storage mode when the blast-chill cycle is completed. Many of today's models are equipped with sophisticated microprocessor control systems that allow the operator not only to program the chill cycle, but also to obtain readouts, printouts, and alarms that document and monitor the entire process. Built-in food probes are commonly used to take readings and allow the control system to make adjustments if necessary.

WALK-IN COOLERS/FREEZERS

This type of commercial refrigerator is a factory-made, prefabricated, sectional version of the built-in, large-capacity cooling room. It closely matches the reach-in type in meeting a wide variety of applications.

Its function is to store foods and other perishable products in larger quantities and for longer periods than the reach-in refrigerator. Good refrigeration practice dictates that dissimilar unpackaged foods be stored in separate rooms because they require different temperatures and humidity and because odors from some foods are absorbed by others. Large food operations may have three rooms: one for fruits and vegetables, one for meats and poultry, and one for dairy products. A fourth room, at 0°F, may be added for frozen foods. Smaller food operations that use appropriate food packaging may require only two rooms; one for medium-temperature refrigeration and one for frozen storage.

Foam plastic materials have improved thermal insulation in both self-contained and remotely refrigerated sectional coolers. Polyurethane foam-in-place insulation between two skins of metal makes a light, water-resistant panel. Additionally, the foam is a very efficient insulator, allowing slimmer panels for equal insulation value compared to most other insulations.

The sectional cooler offers flexibility over the built-in type. It is easily erected and easily moved, and it can be readily altered to meet changing requirements, uses, or layouts by adding standard sections. Also, the sectional walk-in cooler can be erected outside a building, providing more refrigerated storage with no building costs except for footings and an inexpensive roof supported by the cooler.

Self-Contained Sectional Walk-In Coolers

The versatility of sectional walk-in coolers was greatly increased by the introduction of self-contained models. There are various methods of application. Figure 5 shows one arrangement; the top-mount refrigeration unit is labeled (A), the straddle mount unit is (B), and the side-mount unit is (C). These self-contained units use complete refrigeration systems, usually air-cooled, in a single compact package. The units are installed in the sectional cooler/freezer wall or ceiling panels.

Walk-In Floors

Sectional walk-in coolers termed floorless by the supplier are furnished with floor splines to fasten to the existing floor to form a base for the wall sections. Models with an insulated floor are also available.

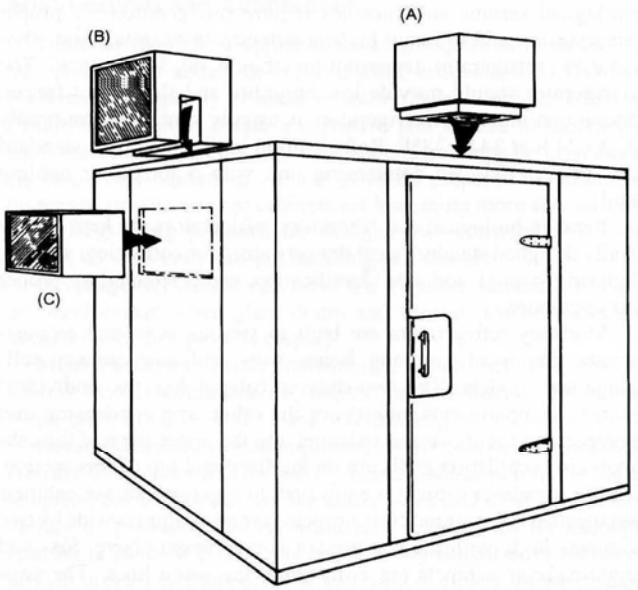


Fig. 5 Refrigeration Equipment Added to Make a Walk-In Cooler Self-Contained

A medium-temperature (above-freezing) cooler can be erected on an uninsulated concrete floor on the ground. Generally, floor losses are considered small.

Level entry is becoming more important as the use of hand trucks and electric trucks increases. The advantage and convenience of level entry afforded by a floorless cooler can also be obtained by recessing a sectional insulated floor.

Design Characteristics

The factory-made walk-in cooler consists of standard top, bottom, wall, door, and corner sections, which are shipped to the user and erected on the site. The frames are filled with insulation and are covered on the inside and outside with metal. The edges of these frames are usually of tongue-and-groove construction and either fitted with a gasket material or provided with suitable caulking material to ensure a tight vapor seal when assembled. These sections are assembled on the site with either lag screws or hooks operated from inside the cooler.

Exterior and interior surfaces may be painted and are made of one or more of the following:

- Galvanized steel
- Aluminum
- Aluminum-coated steel
- Stainless steel
- Vinyl-clad steel

Coolers may be used to hold sides or quarters of beef, lamb carcasses, crates of vegetables, and other bulky items. Food operations now rarely use such items. If they do, the items are broken down, trimmed, or otherwise processed before entering refrigerated storage. The modern cooler is not a storage room for large items, but a temporary place for quantities of small, partially or totally processed products.

The food cooler, therefore, is likely to be equipped with sturdy, adjustable shelving about 18 in. deep and arranged in tiers, three or four high, around the inside walls. Alternatively, the cooler is often provided with rolling racks that are actually shelving on wheels. These racks are rolled directly into and out of the cooler.

CHAPTER 49

HOUSEHOLD REFRIGERATORS AND FREEZERS

Primary Functions 49.2
Performance Characteristics 49.2
Safety Requirements 49.2
Durability and Service 49.2
Cabinets 49.2
Refrigerating Systems 49.5
Evaluation 49.9

THIS chapter covers the design and construction of full-sized household refrigerators and freezers, the most common of which are illustrated in Figure 1. Small portable and secondary refrigerators are not specifically addressed here. Some of these small refrigerators use absorption systems, special forms of compressors, and, in some cases, **thermoelectric** refrigeration. Applications for water-ammonia **absorption** systems have developed for recreational vehicles, picnic coolers, and hotel room refrigerators, where noise is an issue.

The preparation of this chapter is assigned to TC 7.1, Residential Refrigerators and Food Freezers.

The section on Refrigerating Systems only covers the **vapor-compression** cycle, which is almost universally used for full-sized household refrigerators and freezers. In these applications, where several hundred Btu/h are pumped through temperature differentials from freezer to room temperature in excess of 100°F, other **electrically powered** systems compare unfavorably to vapor-compression systems in terms of manufacturing and operating costs. Typical operating efficiencies of the three most practical refrigeration systems are as follows for a 0°F freezer and 90°F ambient:

Thermoelectric	Approximately 0.3 Btu/watt-hour
Absorption	Approximately 1.5 Btu/watt-hour
Vapor-compression	Approximately 4.75 Btu/watt-hour

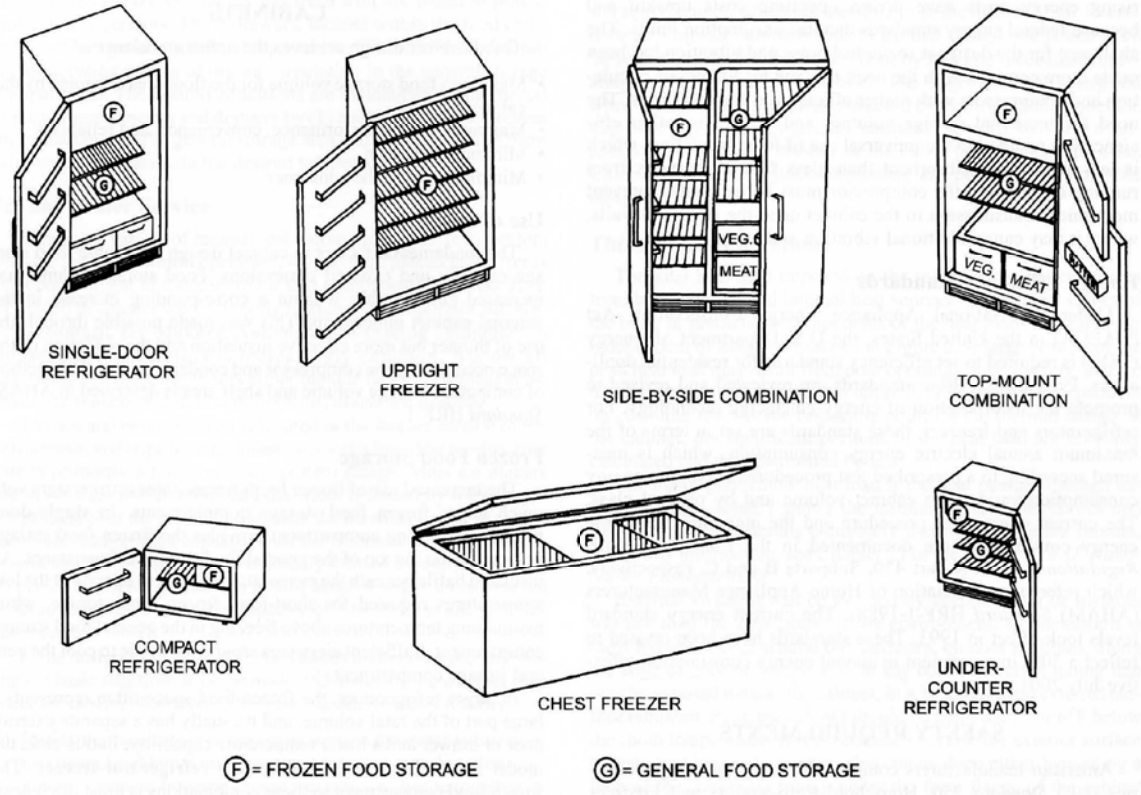


Fig. 1 Common Configurations of Contemporary Household Refrigerators and Freezers

An absorption system may operate from **gas** at a lower cost per unit of energy, but the initial cost, size, and weight have made it unattractive to use gas systems for major appliances where electric power is available. Because of its simplicity, thermoelectric refrigeration could replace other systems if (1) an economical thermoelectric material were developed and (2) design issues such as the need for a direct current (dc) power supply and an effective means for transferring heat from the module were addressed.

PRIMARY FUNCTIONS

Providing food storage space at reduced temperature is the primary function of a refrigerator or freezer, with ice making an essential secondary function. To preserve fresh food, a general storage temperature between 32 and 39°F is desirable. Higher or lower temperatures or a humid atmosphere are more suitable for storing certain foods; the section on Cabinets discusses special-purpose storage compartments designed to provide these conditions. Food freezers and combination refrigerator-freezers used for long-term storage are designed to hold temperatures near 0°F and always below 8°F during steady-state operation. In single-door refrigerators, the frozen food space is usually warmer than this and is not intended for long-term storage. Optimum conditions for food preservation are addressed in more detail in Chapters 8 through 28.

PERFORMANCE CHARACTERISTICS

A refrigerator or freezer must maintain desired temperatures and have reserve capacity to cool to these temperatures when started on a hot summer day. Most models cool down within hours in a 110°F ambient at rated voltage.

Overall system efficiency has become important both because rising energy costs have driven operating costs upward and because federal energy standards dictate consumption limits. The challenge for the designer to control noise and vibration has been made more complex with the need for fans for forced-air circulation and compressors with higher efficiencies and capacities. The need for increased storage volumes and better insulation efficiency has resulted in the universal use of foam insulation, which is less acoustically absorbent than glass fiber. Vibrations from running or stopping the compressor must be isolated to prevent mechanical transmission to the cabinet or to the floor and walls, where it may cause additional vibration and noise.

Energy Efficiency Standards

Under the National Appliance Energy Conservation Act (NAECA) in the United States, the U.S. Department of Energy (DOE) is required to set efficiency standards for residential appliances. Periodically, these standards are reviewed and revised to promote the incorporation of energy-enhancing technology. For refrigerators and freezers, these standards are set in terms of the maximum annual electric energy consumption, which is measured according to a prescribed test procedure. Maximum energy consumption varies with cabinet volume and by product class. The current energy test procedure and the maximum allowable energy consumption are documented in the *Code of Federal Regulations* (10 CFR Part 430, Subparts B and C, respectively, which reference Association of Home Appliance Manufacturers (AHAM) *Standard* HRF-1-1988). The current energy standard levels took effect in 1993. These standards have been revised to reflect a 30% improvement in annual energy consumption effective July 2001.

SAFETY REQUIREMENTS

American manufacturers comply with Underwriters Laboratories (UL) *Standard* 250, Household Refrigerators and Freezers, which protects the user from electrical shock, fire dangers, and other hazards under normal and some abnormal conditions. Product safety areas include motors, hazardous moving parts, grounding and bonding, stability (cabinet tipping), door-opening force, door-hinge strength, shelf strength, component restraint (shelves and pans), glass strength, cabinet and unit leakage current, leakage current from surfaces wetted by normal cleaning, high-voltage breakdown, ground continuity, testing and inspection of polymeric parts, and uninsulated live electrical parts accessible with an articulated probe.

DURABILITY AND SERVICE

Refrigerators and freezers are expected to last 15 to 20 years. The appliance therefore incorporates several design features that allow it to protect itself over this period. Motor overload protectors are normally incorporated, and an attempt is made to design fail-safe circuits so that the hermetic motor of the compressor will not be damaged by failure of a minor external component, unusual voltage extremes, or voltage interruptions.

Customer-operated devices must withstand frequent use. For example, a refrigerator door may be opened and shut over 300,000 times in its lifetime. To protect the customer against the cost of premature failure, most manufacturers will replace faulty parts within one year and repair or replace a faulty hermetic system within five years or longer at no charge for materials. Beyond these warranties, the terms vary among manufacturers; warranties are sometimes combined with an extended service contract.

In designing refrigerators and freezers, provisions must be made for economical and effective servicing if damage or malfunction occurs in the field.

CABINETS

Good cabinet design achieves the optimum balance of

- Maximum food storage volume for the floor area occupied by the cabinet
- Maximum utility, performance, convenience, and reliability
- Minimum heat gain
- Minimum cost to the consumer

Use of Space

The fundamental factors in cabinet design are usable food storage capacity and external dimensions. Food storage volume has increased considerably without a corresponding increase in the external cabinet dimensions. This was made possible through the use of thinner but more effective insulation and the reduction of the space occupied by the compressor and condensing unit. The method of computing storage volume and shelf area is described in AHAM *Standard* HRF-1.

Frozen Food Storage

The increased use of frozen foods necessitates refrigerators with much larger frozen food storage compartments. In **single-door models**, a freezing compartment provides the frozen food storage volume across the top of the general food storage compartment. An insulated baffle beneath the evaporator allows it to operate at the low temperatures required for short-term frozen food storage, while maintaining temperatures above freezing in the general food storage compartment. Sufficient air passes around the baffle to cool the general storage compartment.

In larger refrigerators, the frozen food space often represents a large part of the total volume, and it usually has a separate exterior door or drawer and a lower temperature capability; in this case, the model is classified as a **combination refrigerator-freezer**. The frozen food compartment in these combinations is most often positioned across the top, but on the largest models, side-by-side

arrangements are not uncommon. Bottom-mounted freezer models also exist in the market.

Two-door cabinets are sometimes built with two separate inner liners housed in a single outer shell. Others use only a single liner divided into two sections by an insulated panel that separates the frozen food storage from the fresh food storage. This panel may be integral with the liner or installed as a separate piece. Located beneath the evaporator, it allows the unit to operate at the low temperatures required for short-term frozen food storage, while maintaining temperatures above freezing in the general food storage compartment. The insulation must be sufficiently thick to prevent excessive amounts of condensation from forming on the fresh food side of the panel. Reduced heat transfer through the panel increases the demand for cool, dry air in the fresh food compartment. This dry air improves performance in high-humidity environments when doors are opened for normal usage.

Food freezers are offered in two forms: **upright** (vertical) and **chest**. Locks are often provided on the lids or doors as protection against accidental door opening or access by children. A power supply indicator light or a thermometer with an external dial may be provided to warn of high storage temperatures.

Special-Purpose Compartments

Special-purpose compartments provide a more suitable environment for storage of specific foods. For example, a warmer compartment for maintaining butter at spreading temperature is often found in the refrigerator door. Some refrigerators have a meat storage compartment that can maintain storage temperatures just above freezing and may include an independent temperature adjustment feature. Some models have a special compartment for fish, which is maintained at approximately 30°F. High-humidity compartments for storage of leafy vegetables and fresh fruit are found in practically all refrigerators. These drawers, located within the food compartment, are generally tight fitting to protect vulnerable foods from the desiccating effects of dry air circulating in the general storage compartment. The desired conditions are maintained in the special storage compartments and drawers by (1) enclosing them to prevent air exchange with the general storage area and (2) surrounding them with cold air to maintain the desired temperature.

Ice and Water Service

Through a variety of manual and automatic means, refrigerators provide ice. For **manual** operation, ice trays are placed in the freezing compartment in a stream of air that is substantially below 32°F or placed in contact with a directly refrigerated evaporator surface.

Automatic Ice Makers. Automatic ice-making equipment in household refrigerators is increasingly common. Almost all automatic defrost refrigerators either include factory-installed automatic ice makers or can accept field-installable ice makers.

The ice maker mechanism is located in the freezer section of the refrigerator and requires attachment to a water line. The ice-freezing rate is primarily a function of the system design. Most ice makers are in no-frost refrigerators, and the water is frozen by refrigerated air passing over the ice mold. Because the ice maker must share the available refrigeration capacity with the freezer and food compartments, the ice production rate is usually limited by design to 4 to 6 lb per 24 h. An ice production rate of about 4 lb per 24 h, coupled with an ice storage container capacity of 7 to 10 lb, is adequate for most users.

In the design of an ice maker, the various methods of accomplishing the basic functions must be evaluated to determine whether they meet the design objectives. The basic functions are as follows:

1. **Initiating** the ejection of the ice as soon as the water is frozen is necessary to obtain a satisfactory production rate. Ejection before complete freezing causes wet cubes to freeze together in the storage container and may cause the ice mold to overfill. One method is to initiate ejection in response to the temperature of a selected location in the mold that indicates complete freezing. Another successful method is to initiate ejection based on the time required to freeze the water under normal freezer temperatures. In either method, the temperature or time required may vary in different applications, depending on the cooling air temperature and the rate and direction of the airflow.
2. **Ejecting** the ice from the mold must be a reliable operation. In several designs, ejection is accomplished by freeing the ice from the mold with an electric heater and pushing it from the tray into an ice storage container. In other designs, water is frozen in a plastic tray by passing refrigerated air over the top so that the water freezes from the top down. The natural expansion that takes place during this freezing process causes the ice to partially freeze free from the tray. Through twisting and rotation of the tray, the ice can be completely freed and ejected into a container.
3. **Driving** the ice maker is done in most designs by a gear motor, which operates the ice ejection mechanism and may also be used to time the freezing cycle and the water-filling cycle and to operate the stopping means.
4. **Filling** the ice mold with a constant volume of water, regardless of the variation in line water pressure, is necessary to ensure uniform-sized ice cubes and prevent overfilling. This is done by timing a solenoid flow-control valve or by using a solenoid-operated, fixed-volume slug valve.
5. **Stopping** is necessary after the ice storage container is filled until some ice is used. This is accomplished by using a feeler-type ice level control or a weight control.

Ice service has become more convenient in some models that dispense ice through the door. In one design, the ice is ejected into a storage container, which is accessible from the outside of the freezer door as a tilt-out compartment. In another design, ice is delivered through a trap door in the freezer door by an auger mechanism operating in the ice storage container. The auger motor is energized when a push-button switch is contacted by placing a glass under the trap door. On some designs, an additional selector switch is available to actuate an ice crusher as the cubes pass through the door. Chilled water and/or juice dispensing are provided on yet other designs.

Thermal Considerations

The total heat load imposed on the refrigerating system comes from both external and internal heat sources. The relative values of the basic or predictable components of the heat load (those that are independent of usage) are shown in Figure 2. A large portion of the peak heat load may result from door openings, food loading, and ice making, which are variable and unpredictable quantities dependent on customer use. As the beginning point for the thermal design of the cabinet, the significant portions of the heat load are normally calculated and then confirmed by test.

The major predictable heat load is the heat passing through the cabinet walls. Table 1 shows the insulating values of fibrous and foam insulation materials commonly used to insulate the cabinet; for further information, see Chapter 23 of the 2001 *ASHRAE Handbook—Fundamentals*.

External sweating can be avoided by keeping exterior surfaces warmer than the dew point of the environment. Condensation is most likely to occur around the hardware, on door mullions, along the edge of door openings, and on any cold refrigerant tubing that may be exposed outside the cabinet. In a 90°F room, no external surface temperature on the cabinet should be more than 5 or 6°F below the room temperature. If it is necessary to raise the exterior surface temperature to avoid sweating, this can be done either by routing a loop of the condenser tubing under the front flange of the cabinet outer shell or by locating low-wattage wires or ribbon heaters

Table 1 Effect of Thermal Insulation on Cabinet Wall Thickness

Insulation	Thermal Conductivity, Btu·in/h·ft²·°F	Wall Thickness, in.			
		For Threshold of External Sweating in 90°F at 75% rh		Common Practice	
		0°F	38°F	0°F	38°F
Mineral or glass fiber, air-filled	0.22 to 0.28	2.0 to 2.7	1.3 to 1.75	3.0 to 3.5	2.3 to 2.75
Foam-in-place urethane foam, heavy gas-filled	0.13	1.25	0.85	1.9	1.6
Foamed slab urethane foam, heavy gas-filled	0.16	1.5	1.0	2.0	1.5

Table 2 Cabinet Materials and Manufacturing Methods

Component	Material	Common Thickness, in.	Manufacturing Method	Finish
Outer cabinet assembly			Welded assembly	
Wrapper and top	Low-carbon cold-rolled steel	0.024 to 0.036	Roll form and bend	Organic finish (polyester, alkyd, acrylic, etc.)
Back	Low-carbon cold-rolled steel	0.022 to 0.033	Draw and stamp	
Bottom	Low-carbon cold-rolled steel	0.016 to 0.025	Draw and stamp	
Inner cabinet liner	Enameling iron	0.024 to 0.036	Bend and weld	Vitreous enamel
	Low-carbon cold-rolled steel	0.024 to 0.036	Bend and weld	Organic finish
	Aluminum	0.024 to 0.036	Bend and weld	Anodized or organic finish
	Plastic	0.050 to 0.200	Injection molded or vacuum formed	None
Inner door liner	Plastic	0.075 to 0.095	Vacuum formed or injection molded	None
Breaker strips	Plastic	0.075 to 0.095	Extruded or injection molded	None

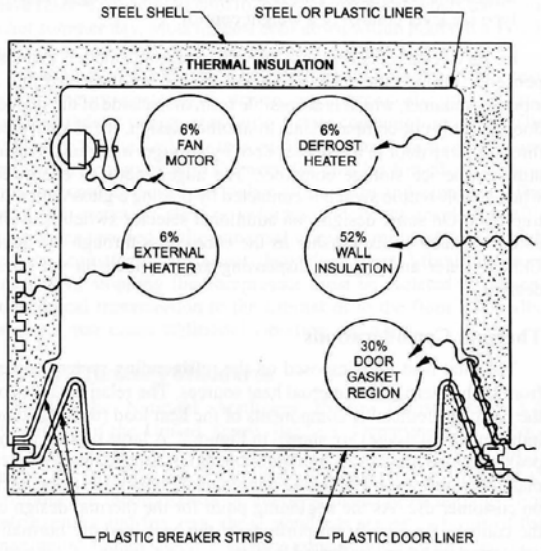


Fig. 2 Cabinet Cross Section Showing Typical Contributions to Total Basic Heat Load

behind the critical surfaces. Most refrigerators that incorporate electric heaters have power-saving electrical switches that allow the user to deenergize these electrical heaters when the environmental conditions do not require their use.

Temporary condensation on internal surfaces may occur with frequent door openings, so the interior of the general storage compartment must be designed to avoid objectionable accumulation or drippage.

Figure 2 shows the design features of the throat section where the door meets the face of the cabinet. On products with metal liners, thermal breaker strips prevent metal-to-metal contact between inner and outer panels. Because the air gap between the breaker strip and the door panel provides a low-resistance heat path to the door gasket, the clearance should be kept as small as possible and the breaker strip as wide as practical. When the inner liner is made of plastic rather than steel, there is no need for separate plastic breaker strips because they are an integral part of the liner.

Cabinet heat leakage can be reduced by using door gaskets with more air cavities to reduce conduction or by using internal secondary gaskets. Care must be taken so that the maximum door opening force of 15 lb (as specified in U.S. *Federal Register* Vol. 38, No. 242, Tuesday, December 18, 1973) is not exceeded.

Structural supports, used to support and position the food compartment liner from the outer shell of the cabinet, are usually constructed of a combination of steel and plastics to provide adequate strength with maximum thermal insulation.

Internal heat loads that must be overcome by the system's refrigerating capacity are generated by ice makers, lights, timers, fan motors used for air circulation, and heaters used to prevent undesirable internal cabinet sweating or frost buildup.

Structure and Materials

The external shell of the cabinet is usually a single fabricated steel structure that supports the inner food compartment liner, the door, and the refrigeration system. The space between the inner and outer walls of the cabinet is usually filled with foam slabs or foam-in-place insulation. In general, the door and breaker strip construction is similar to that shown in Figure 2, although breaker strips and food liners formed of a single plastic sheet are also common. The doors cover the whole front of the cabinet, and plastic sheets become the inner surface for the doors, so no separate door breaker strips are required. The door liners are usually formed to provide an array of small door shelves and racks. Cracks and crevices are avoided, and edges are rounded and smooth to facilitate cleaning. Interior lighting is from incandescent lamps controlled by mechanically operated switches actuated by opening the refrigerator door(s) or chest freezer lid. Table 2 summarizes the most common materials and manufacturing methods used in constructing refrigerator and freezer cabinets.

The cabinet design must provide for the special requirements of the refrigerating system. For example, it may be desirable to refrigerate the freezer section by attaching evaporator tubing directly to the food compartment liner. Also, it may be desirable, particularly with food freezers, to attach the condenser tubing directly to the shell of the cabinet to prevent external sweating. Both designs influence the cabinet heat leakage and the amount of insulation required.

The method of installing the refrigerating system into the cabinet is also important. Frequently, the system is installed in two or more component pieces and then assembled and processed in the cabinet. Unitary installation of a completed system directly into the cabinet allows the system to be tested and charged beforehand. The cabinet design must be compatible with the method of installation chosen. In addition, systems using forced air frequently require ductwork in the cabinet or insulation spaces.

The overall structure of the cabinet must be strong enough to withstand shipping, in which case it will be strong enough to withstand daily usage. However, additional support is typically provided in packaging material. Plastic food liners must withstand the thermal stresses they are exposed to during shipping and usage, and they must be unaffected by common contaminants encountered in a kitchen environment. Shelves must be designed not to deflect excessively under the heaviest anticipated load. Refrigerator doors and associated hardware must withstand a minimum of 300,000 door openings.

Foam-in-place insulation has had an important influence on cabinet design and assembly procedures. Not only does the foam's superior thermal conductivity allow wall thickness to be reduced, but the foam's rigidity and bonding action usually eliminate the need for structural supports. The foam is normally expanded directly into the insulation space, adhering to the food compartment liner and the outer shell. Unfortunately, this precludes disassembly of the cabinet for service or repairs. Alternative constructions that overcome this restriction use prefoamed slabs or expand the foam against an inner mold, which is later withdrawn and replaced with the food compartment liner. In either case, the liner is not bonded to the foam, and it can be easily removed if required. However, the foam no longer provides the structural tie between the liner and the outer shell.

Outer shells of refrigerator and freezer cabinets are now typically of prepainted steel, thus reducing the volatile emissions that accompany the finishing process and providing a consistently durable finish to enhance product appearance and avoid corrosion.

Use of Plastics. As much as 15 or 20 lb of plastic is incorporated in a typical refrigerator or freezer, and the use of plastic is increasing because of its

- Wide range of physical properties
- Good bearing qualities
- Electrical insulating ability
- Moisture and chemical resistance
- Low thermal conductivity
- Ease of cleaning
- Pleasing appearance with or without an applied finish
- Potential of multifunctional design in a single part
- Transparency, opacity, and colorability
- Ease of forming and molding
- Lower cost

A few examples illustrate the versatility of plastics. High-impact polystyrene and acrylonitrile butadiene styrene (ABS) plastics are used for inner door liners and food compartment liners. In these applications, no applied finish is necessary. These and similar thermoplastics such as polypropylene and polyethylene are also selected for evaporator doors, baffles, breaker strips, drawers, pans, and many small items. The phenolics are used for decorative door panels, terminal boards, and terminal covers and as a binder for the glass fiber insulation. The good bearing qualities of nylon and acetal are used to advantage in such applications as hinges, latches, and rollers for sliding shelves. Gaskets, both for the refrigerator and for the evaporator doors, are generally made of vinyl.

Many items (such as ice cubes and butter) readily absorb odors and tastes from materials to which they are exposed. Accordingly, manufacturers take particular care to avoid using any plastics or other materials that will impart an odor or taste in the interior of the cabinet.

Moisture Sealing

For the cabinet to retain its original insulating qualities, the insulation must be kept dry. Moisture may get into the insulation through leakage of water from the food compartment liner, through the defrost water disposal system, or, most commonly, through vapor leaks in the outer shell.

The outer shell is generally crimped, seam welded, or spot welded and carefully sealed against vapor transmission with mastics and hot-melt asphaltic or wax compounds at all joints and seams. In addition, door gaskets, breaker strips, and other parts should provide maximum barriers to vapor flow from the room air to the insulation. When refrigerant evaporator tubing is attached directly to the food compartment liner, as is generally done in chest freezers, moisture will not migrate from the insulation space, and special efforts must be made to vapor-seal this space.

Although urethane foam insulation tends to inhibit moisture migration, it does have a tendency to trap water when migrating vapor reaches a temperature below its dew point. The foam then becomes permanently wet, and its insulation value is decreased. For this reason, a vaportight exterior cabinet is equally important with foam insulation.

Door Latching

Latching of doors is accomplished by mechanical or magnetic latches that compress relatively soft compression gaskets made of vinyl compounds. Gaskets with magnetic materials embedded in the gasket are generally used. Chest freezers are sometimes designed so that the weight of the lid acts to compress the gasket, although most of the weight is counterbalanced by springs in the hinge mechanism.

In 1956, the Refrigerator Safety Act, Public Law 84-930, was enacted prohibiting shipment in interstate commerce of any household refrigerator that was not equipped with a device or system permitting the door to be opened from the inside. Although freezers are not included under PL 84-930, UL *Standard* 250 has adopted the requirements of PL 84-930 to prevent entrapment in freezers.

In addition, because freezers are sometimes located in areas that have public access, they are often equipped with key locks to prevent pilferage. UL requires that these key locks be the non-self-engaging type, and the key must be self-ejected from the slot when not in place to prevent entrapment caused by accidentally locking the door.

Cabinet Testing

Specific tests necessary to establish the adequacy of the cabinet as a separate entity include (1) structural tests, such as repeated twisting of the cabinet and door; (2) door slamming test; (3) tests for vapor-sealing of the cabinet insulation space; (4) odor and taste transfer tests; (5) physical and chemical tests of plastic materials; and (6) heat leakage tests. Cabinet testing is also discussed later in the section on Evaluation.

REFRIGERATING SYSTEMS

The vapor-compression refrigerating systems used with modern refrigerators vary considerably in capacity and complexity, depending on the refrigerating application. They are hermetically sealed and normally require no replenishment of refrigerant or oil during the useful life of the appliance. The components of the system must provide optimum overall performance and reliability at minimum

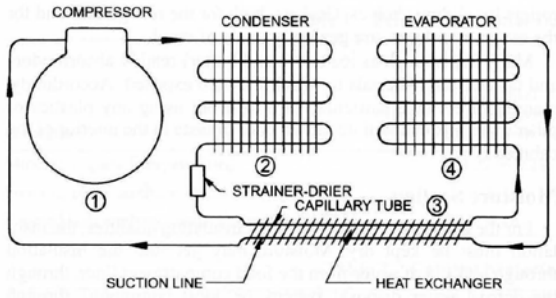


Fig. 3 Refrigeration Circuit

cost. In addition, all safety requirements of UL *Standard* 250 must be met. The fully halogenated refrigerant R-12 was used in household refrigerators for many years. However, due to its strong ozone depletion property, appliance manufacturers have replaced R-12 with environmentally acceptable R-134a or isobutane.

The design of refrigerating systems for refrigerators and freezers has improved due to new refrigerants and oils, wider use of aluminum, smaller and more efficient motors and compressors, universal use of capillary tubes, and simplified electrical components. These refinements have kept the vapor-compression system in the best competitive position for household application.

Refrigerating Circuit

Figure 3 shows the refrigerant circuit for a vapor-compression refrigerating system. The refrigeration cycle is as follows:

1. Electrical energy supplied to the motor drives a positive displacement compressor, which draws cold, low-pressure refrigerant vapor from the evaporator and compresses it.
2. The resulting high-pressure, high-temperature discharge gas then passes through the condenser, where it is condensed to a liquid while the heat is rejected to the ambient air.
3. The liquid refrigerant passes through a metering (pressure reducing) capillary tube to the evaporator, which is at low pressure.
4. The low-pressure, low-temperature liquid in the evaporator absorbs heat from its surroundings, evaporating to a gas, which is again withdrawn by the compressor.

Note that energy enters the system through the evaporator (heat load) and through the compressor (electrical input). Thermal energy is rejected to the ambient by the condenser and the compressor shell. A portion of the capillary tube is usually soldered to the suction line for heat exchange. Cooling the refrigerant in the capillary tube with the suction gas increases capacity and efficiency.

A strainer-drier is usually placed ahead of the capillary tube to remove foreign material and moisture. Refrigerant charges of 1/2 lb or less are common. A thermostat (or cold control) cycles the compressor to provide the desired temperatures within the refrigerator. During the off cycle, the capillary tube permits the pressures to equalize throughout the system.

Materials used in refrigeration circuits are selected for their (1) mechanical properties, (2) compatibility with the refrigerant and oil on the inside, and (3) resistance to oxidation and galvanic corrosion on the outside. Evaporators are usually made of aluminum tubing, either with integral extruded fins or with extended surfaces mechanically attached to the tubing. Condensers are usually made of steel tubing with an extended surface of steel sheet or wire. Steel tubing is used on the high-pressure side of the system, which is normally dry, and copper is used for suction tubing, where condensation can occur. Because of its ductility, corrosion resistance, and ease of brazing, copper is used for capillary tubes and often for small connecting tubing. Wherever aluminum tubing comes in contact with copper or iron, it must be protected against moisture to avoid electrolytic corrosion.

Defrosting

Manual Defrost. A few manufacturers still use the manual defrost method, in which the cooling effect is generated by natural convection of air over a refrigerated surface (evaporator) located at the top of the food compartment. The refrigerated surface forms some of the walls of a frozen food space, which usually extends across the width of the food compartment. Defrosting is typically accomplished by manually turning off the temperature control switch.

Cycle Defrosting (Partial Automatic Defrost). Combination refrigerator-freezers sometimes use two separate evaporators for the fresh food and freezer compartments. The fresh food compartment evaporator defrosts during each off cycle of the compressor, with the energy for defrosting provided mainly by the heat leakage into the fresh food compartment. The cold control senses the temperature of the fresh food compartment evaporator and cycles the compressor on when the evaporator surface is above 32°F. The freezer evaporator requires infrequent manual defrosting.

No-Frost Systems (Automatic Defrost). Most combination refrigerator-freezers and some upright food freezers are refrigerated by air that is fan-blown over a single evaporator concealed from view. Because the evaporator is colder than the freezer compartment, it collects practically all of the frost, and there is little or no permanent frost accumulation on the frozen food or on exposed portions of the freezer compartment. The evaporator is defrosted automatically by an electric heater located under the heat exchanger or hot refrigerant gas, and the defrosting period is short in order to limit food temperature rise. The resulting water is disposed of automatically by draining to the exterior, where it is evaporated in a pan located in the warm condenser compartment. A timer usually initiates defrosting at intervals of up to 24 h. If the timer operates only when the compressor runs, the accumulated time tends to reflect the probable frost load.

Adaptive Defrost. Developments in electronics have allowed the introduction of microprocessor-based control systems to some household refrigerators. An adaptive defrost function is usually included in the software. Various parameters are monitored so that the period between defrosts varies according to actual conditions of use. Adaptive defrost tends to reduce energy consumption and improve food preservation.

Forced Heat for Defrosting. All no-frost systems add heat to the evaporator to accelerate melting during the short defrosting cycle. The most common method uses a 300 to 1000 W electric heater. The typical defrost cycle is initiated by a timer, which stops the compressor and energizes the heater.

When the evaporator has melted all the frost, a defrost termination thermostat opens the heater circuit. In most cases, the compressor is not restarted until the evaporator has drained for a few minutes and the system pressures have stabilized; this reduces the applied load for restarting the compressor. Commonly used defrost heaters include metal-sheathed heating elements in thermal contact with evaporator fins and radiative heating elements positioned to radiate heat to the evaporator.

Evaporator

The **manual defrost** evaporator is usually a box with three or four sides refrigerated. Refrigerant may be carried in tubing brazed to the walls of the box, or the walls may be constructed from double sheets of metal that are brazed or metallurgically bonded together with integral passages for the refrigerant. In this construction, the walls are usually aluminum, and special attention is required to avoid (1) contamination of the surface with other metals that would

promote galvanic corrosion and (2) configurations that may be easily punctured during use.

The **cycle defrost** evaporator for the fresh food compartment is designed for natural defrost operation and is characterized by its low thermal capacity. It may be either a vertical plate, usually made from bonded sheet metal with integral refrigerant passages, or a serpentine coil with or without fins. In either case, the evaporator should be located near the top of the compartment and be arranged for good water drainage during the defrost cycle. In some designs, this cooling surface has been located in an air duct remote from the fresh food space, with air circulated continuously by a small fan.

The **no-frost** evaporator is usually a forced-air fin-and-tube arrangement designed to minimize the effect of frost accumulation, which tends to be relatively rapid in a single evaporator system. The coil is usually arranged for airflow parallel to the long dimension of the fins.

The fins may be more widely spaced at the air inlet to provide for preferential frost collection and to minimize the air restriction effects of the frost. All surfaces must be heated adequately during the defrost cycle to ensure complete defrosting, and provision must be made for draining and evaporating the defrost water outside the food storage spaces.

Freezers. Evaporators for chest freezers usually consist of tubing that is in good thermal contact with the exterior of the food compartment liner. The tubing is generally concentrated near the top of the liner, with wider spacing near the bottom to take advantage of natural convection of the air inside. Most upright food freezers usually have refrigerated shelves and a refrigerated surface at the top of the food compartment. These are commonly connected in series with an accumulator at the exit end. No-frost freezers usually incorporate a fin-and-tube evaporator and an air-circulating fan as used in the no-frost combination refrigerator-freezers.

Condenser

The condenser is the main heat-rejecting component in the refrigerating system. It may be cooled by natural draft on free-standing refrigerators and freezers or fan-cooled on larger models and on models designed for built-in applications.

The **natural-draft condenser** is located on the back wall of the cabinet and is cooled by natural air convection under the cabinet and up the back. The most common form of natural-draft condenser consists of a flat serpentine of steel tubing with steel cross wires welded on 1/4 in. centers on one or both sides perpendicular to the tubing. Tube-on-sheet construction may also be used.

The **hot wall condenser**, another natural-draft arrangement, is used principally with food freezers. It consists of condenser tubing attached to the inside surface of the cabinet shell. The shell thus acts as an extended surface for heat dissipation. With this construction, external sweating is seldom a problem.

The **forced-draft condenser** may be of fin-and-tube, folded banks of tube-and-wire, or tube-and-sheet construction. Various forms of condenser construction are used to minimize clogging caused by household dust and lint. The compact, fan-cooled condensers are usually designed for low airflow rates because of noise limitations. Air ducting is often arranged to use the front of the machine compartment for the entrance and exit of air. This makes the cooling air system largely independent of the location of the refrigerator and permits built-in applications.

A portion of the condenser may be located under the defrost water evaporating pan to promote water evaporation. The condenser may also incorporate a section for **compressor cooling**; from here the partially condensed refrigerant is routed to an oil-cooling loop in the compressor, where the liquid refrigerant, still at high pressure, absorbs heat and is reevaporated. The vapor is then routed through the balance of the condenser, to be condensed in the normal manner. In some designs, as noted previously, a portion of the condenser tubing is routed internally in contact with the outer case in place of anticondensation heaters.

Condenser performance may be evaluated directly on calorimeter test equipment similar to that used for compressors. However, the final design of the condenser must be determined by performance tests on the refrigerator under a variety of operating conditions.

Generally, the most important design requirements for a condenser include (1) sufficient heat dissipation at peak-load conditions, (2) storage volume that prevents excessive pressures during pulldown or in the event of a restricted or plugged capillary tube, (3) good refrigerant drainage to minimize the off-cycle losses and the time required to equalize system pressures, (4) an external surface that is easily cleaned or designed to avoid dust and lint accumulation, and (5) an adequate safety factor against bursting.

Capillary Tube

The most commonly used refrigerant metering device is the capillary tube, a small-bore tube connecting the outlet of the condenser to the inlet of the evaporator. The regulating effect of this simple control device is based on the principle that a given weight of liquid passes through a capillary more readily than the same weight of gas at the same pressure. Thus, if uncondensed refrigerant vapor enters the capillary, the mass flow will be reduced, giving the refrigerant more cooling time in the condenser. On the other hand, if liquid refrigerant tends to back up in the condenser, the condensing temperature and pressure rise, resulting in an increased mass flow of refrigerant. Under normal operating conditions, a capillary tube gives good performance and efficiency. Under extreme conditions, the capillary either passes considerable uncondensed gas or backs liquid refrigerant well up into the condenser. Figure 4 shows the typical effect of capillary refrigerant flow rate on system performance.

A capillary tube has the advantage of extreme simplicity and no moving parts. It also lends itself well to being soldered to the suction line for heat exchange purposes. This positioning prevents sweating of the otherwise cold suction line and increases the refrigerating capacity and efficiency. Another advantage is that the pressure equalizes throughout the system during the off cycle and reduces the starting torque required of the compressor motor. The capillary is the narrowest passage in the refrigerant system and the place where low temperature first occurs. For that reason, a combination strainer-drier is usually located directly ahead of the capillary to prevent it from being plugged by ice or any foreign material circulating through the system (see Figure 3).

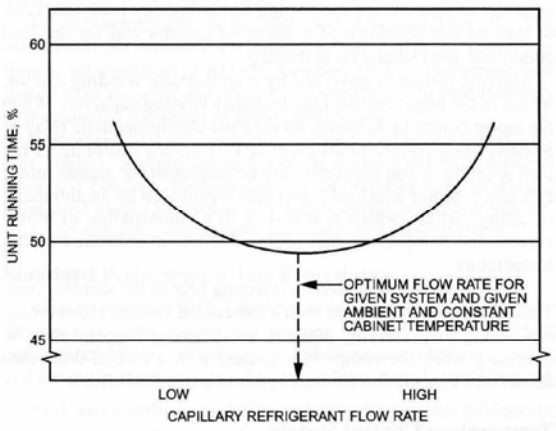


Fig. 4 Typical Effect of Capillary Tube Selection on Unit Running Time

Selection. Optimum metering action can be obtained by variations in either the diameter or the length of the tube. Such factors as the physical location of the system components and the heat exchanger length (36 in. or more is desirable) may help determine the optimum length and bore of the capillary tube for any given application.

Capillary tube selection is covered in detail in Chapter 45. Once a preliminary selection is made, an experimental unit can be equipped with three or more different capillaries that can be activated independently. System performance can then be evaluated by using in turn capillaries with slightly different flow characteristics.

Final selection of the capillary requires optimizing performance under both no-load and pulldown conditions, with maximum and minimum ambient and load conditions. The optimum refrigerant charge can also be determined during this process.

Compressor

Although a more detailed description of compressors can be found in Chapter 34 of the 2000 *ASHRAE Handbook—Systems and Equipment*, a brief discussion of the small compressors used in household refrigerators and freezers is included here.

These products use positive displacement compressors in which the entire motor-compressor is hermetically sealed in a welded steel shell. Capacities range from about 300 Btu/h to about 2000 Btu/h when measured at the usual rating conditions of −10°F evaporator, 130°F condenser, 90°F ambient, with the suction gas superheated to 90°F and the liquid subcooled to 90°F.

Design emphasizes ease of manufacturing, reliability, low cost, quiet operation, and efficiency. Figure 5 illustrates the two reciprocating piston compressor mechanisms and two types of rotary compressors that are used in virtually all conventional refrigerators and freezers; no one type is much less costly than the others. Rotary compressors are somewhat more compact than reciprocating compressors, but a greater number of close tolerances is involved in their manufacture.

These compressors are directly driven by two-pole, 3450 rpm squirrel cage induction motors, although some four-pole, 1750 rpm motors are also used. Field windings are insulated with special wire enamels and plastic slot and wedge insulation; all are chosen for their compatibility with the refrigerant and oil. During continuous runs at rated voltage, motor winding temperatures may be as high as 250°F when tested in a 110°F ambient temperature. In addition to maximum operating efficiency at normal running conditions, the motor must provide sufficient torque at the anticipated extremes of line voltage for starting and temporary peak loads due to start-up and pulldown of a warm refrigerator and for the load conditions associated with defrosting.

Starting torque is provided by a split-phase winding circuit, which in the larger motors may include a starting capacitor. When the motor comes up to speed, an external electromagnetic relay or positive temperature coefficient (PTC) device disconnects the start winding. A run capacitor may be employed for greater motor efficiency. Motor overload protection is provided by an automatic resetting switch, which is sensitive to a combination of motor current and compressor case temperature or to internal winding temperature.

The compressor is cooled by rejecting heat to the surroundings. This is easily accomplished with a fan-cooled system. However, an oil-cooling loop carrying partially condensed refrigerant may be necessary when the compressor is used with a natural-draft condenser and in some forced-draft systems above 1000 Btu/h.

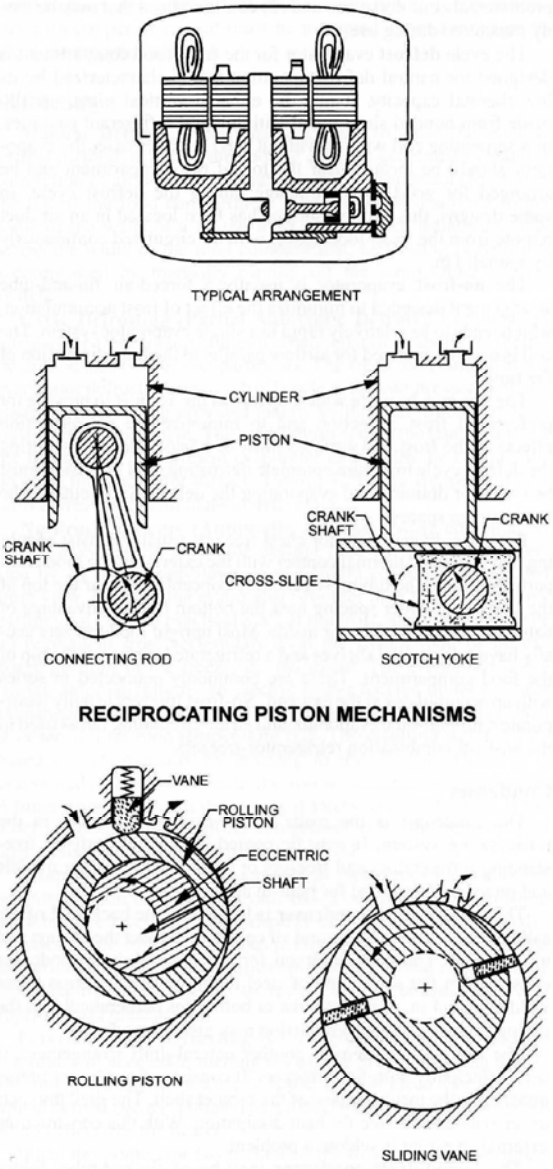


Fig. 5 Refrigerator Compressors

Temperature Control System

The temperature control thermostat is generally an electromechanical switch actuated by a temperature-sensitive power element that has a condensable gas charge, which operates a bellow or diaphragm. At operating temperature, this charge is in a two-phase state, and the temperature at the gas-liquid interface determines the pressure on the bellows. To maintain temperature control at the bulb end of the power element, the bulb must be the coldest point at all times.

The thermostat must have an electrical switch rating for the inductive load of the compressor and other electrical components that is carried through the switch. The thermostat is usually

equipped with a shaft and knob for adjusting the operating temperature.

In the simple gravity-cooled system, the sensing bulb of the thermostat is normally clamped to the evaporator. The location of the bulb and the degree of thermal contact are selected to produce both a suitable cycling frequency for the compressor and the desired refrigerator temperature. Small refrigerators sold in Europe are sometimes equipped with a manually operated push button to prevent the control from coming on until defrost temperatures are reached; afterward, normal cycling is resumed.

In a combination refrigerator-freezer with a split air system, the location of the thermostat sensing bulb depends on whether an automatic damper control is used to regulate the airflow to the fresh food compartment. When such an auxiliary control is used, the sensing bulb is usually located where it can sense the temperature of the air leaving the evaporator. In manual damper controlled systems, the sensing bulb is usually placed in the cold airstream to the fresh food compartment. The sensing bulb location is frequently related to the damper effect on the airstream. Depending on the design of this relationship, the damper may become the freezer temperature adjustment or it may serve the fresh food compartment, with the thermostat being the adjustment for the other compartment. The temperature-sensing bulb should be located to provide a large enough temperature differential to drive the switch mechanism, while avoiding (1) excessive cycle length; (2) short cycling time, which can cause compressor starting problems; and (3) annoyance to the user from frequent noise level changes.

In some refrigerators, microprocessor-based control systems have replaced the electromechanical thermostat switch; in some cases, both compartment controls use thermistor sensing devices that relay electronic signals to the microprocessor. Electronic control systems provide a higher degree of independence in temperature adjustments for the two main compartments.

System Design and Balance

A principal design consideration is the selection of components that will operate together to give the optimum system performance and efficiency when the total cost is considered. Normally, a range of combinations of values for these components meets the performance requirements, and the lowest cost is only obtained through a careful analysis or a series of tests—usually both. For instance, for a given cabinet configuration, food storage volume, and temperature, the following can be traded off against one another: (1) insulation thickness and overall shell dimensions, (2) insulation material, (3) system capacity, and (4) individual component performance (e.g., fan, compressor, and evaporator). Each of these variables affects the total cost, and most of them can be varied only in discrete steps.

The experimental procedure involves a series of tests. Calorimeter tests may be made on the compressor and condenser, separately or together, and on the compressor and condenser operating with the capillary tube and heat exchanger. Final selection of the components requires performance testing of the system installed in the cabinet. These tests also determine the refrigerant charge, airflows for the forced-draft condenser and evaporator, temperature control means and calibration, necessary motor protection, and so forth. The section on Evaluation covers the final evaluation tests to be made on the complete refrigerator. The interaction between components is further addressed in Chapter 44. This experimental procedure assumes knowledge (equations or graphs) of the performance characteristics of the various components, including the heat leakage of the cabinet and the heat load imposed by the customer. The analysis may be performed manually point by point. If enough component information exists, it can be entered into a computer simulation program capable of responding to various design conditions or statistical situations. Although the available information may not always be adequate for an accurate analysis, this procedure is often useful, although confirming tests must follow.

Processing and Assembly Procedures

All parts and assemblies that are to contain refrigerant are processed to avoid unwanted substances or remove them from the final sealed system and to charge the system with refrigerant and oil. Each component should be thoroughly cleaned and then stored in a clean, dry condition until assembly. The presence of free water in stored parts produces harmful compounds such as rust and aluminum hydroxide, which are not removed by the normal final assembly process. Procedures for dehydration, charging, and testing may be found in Chapter 46.

Assembly procedures are somewhat different, depending on whether the sealed refrigerant system is completed as a unit before being assembled to the cabinet, or components of the system are first brought together on the cabinet assembly line. With the unitary installation procedure, the system may be tested for its ability to refrigerate and then be stored or delivered to the cabinet assembly line.

EVALUATION

Once the unit is assembled, laboratory testing, supplemented by field-testing, is necessary to determine actual performance. The following aspects are considered in this section:

- Test facilities required
- Established test procedures published by standard, technical, and industry organizations
- Special performance testing
- Materials testing
- Life testing of components
- Field testing

Environmental Test Rooms

Controlled temperature and humidity test rooms are essential for performance testing refrigerators and freezers. AHAM *Standard* HRF-1 describes the environmental conditions to be maintained. The rooms should be capable of providing ambient temperatures ranging from 70 to 110°F accurate to within 1°F of the desired value. The temperature gradient and the air circulation within the room should also be maintained closely. To provide more flexibility in testing, it may be desirable to have an additional test room that can cover the range between 0 and 70°F. At least one test room should be capable of maintaining a desired relative humidity within a tolerance of ±2% up to 85% rh.

All instruments should be calibrated at regular intervals. The instruments for adequate performance testing of a refrigerator or freezer are described in AHAM *Standard* HRF-1. Instrumentation should have accuracy and response capabilities of sufficient quality to measure the dynamics of the systems tested.

Computerized data acquisition systems that record power, current, voltage, temperature, and pressure are used in testing refrigerators and freezers. Refrigerator test laboratories have developed automated means of control and data acquisition (with computerized data reduction output) and automated test programming.

Standard Performance Test Procedures

AHAM *Standard* HRF-1 describes tests for determining the performance of refrigerators and freezers. It specifies the standard ambient conditions, power supply, and means for selecting samples and measuring temperatures. Test procedures include the following:

No-Load Pulldown Test. This tests the ability of the refrigerator or freezer in a 110°F ambient temperature to pull down from a stabilized warm condition to design temperatures within an acceptable period.

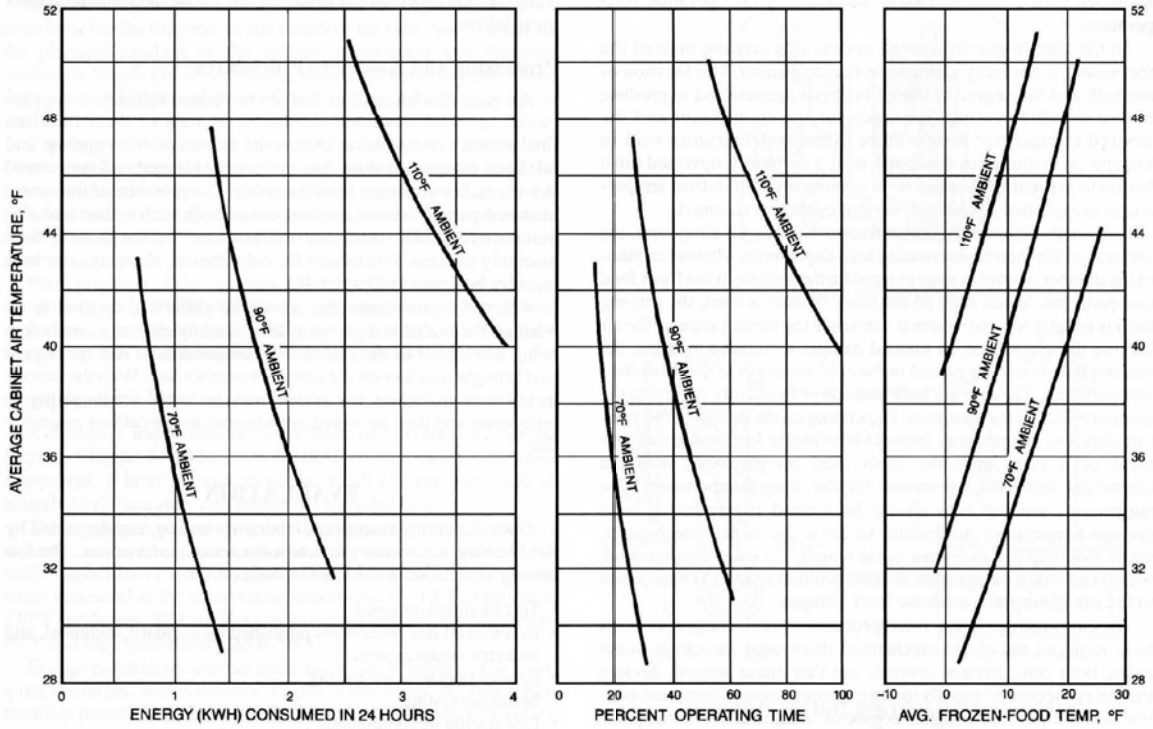


Fig. 6 Sample Plot of Simulated Load Test Results

Simulated Load Test (*Refrigerators*) or Storage Load Test (*Freezers*). This test determines the electrical energy (kWh) consumption rate per 24 h period, the percent operating time of the compressor motor, and temperatures at various locations within the cabinet at 70, 90, and 110°F ambient for a range of temperature control settings. The cabinet doors remain closed during the test. The freezer compartment is loaded with filled frozen packages. Each test point may take 8 h or more to ensure steady-state condition and accuracy of data. The data taken are usually plotted as shown in Figure 6 for a combination refrigerator-freezer with only a fresh food temperature control. If there is a separate control for freezer temperature, these graphs can carry additional curves for high and low freezer control settings.

Freezers are tested similarly, but in a 90°F ambient. Under actual operating conditions in the home, with frequent door openings and ice making, the performance may not be as favorable as that shown by this test. However, the test indicates general performance, which can serve as a basis for comparison.

Ice-Making Test. This test, performed in a 90°F ambient, determines the rate of making ice with the ice trays or other ice-making equipment furnished with the refrigerator.

External Surface Condensation Test. This test determines the extent of moisture condensation on the external surfaces of the cabinet in a 90°F, high-humidity ambient when the refrigerator or freezer is operated at normal cabinet temperatures. Although AHAM *Standard* HRF-1 calls for this test to be made at a relative humidity of 75 ± 2%, it is customary to determine the sweating characteristics through a wide range of relative humidity up to 85%. This test also determines the need for, and the effectiveness of, anticondensation heaters in the cabinet shell and door mullions.

Internal Moisture Accumulation Test. This dual-purpose test is also run under high-temperature, high-humidity conditions. First, it determines the effectiveness of the moisture sealing of the cabinet in preventing moisture from getting into the insulation space and degrading the performance and life of the refrigerator. Secondly, it determines the rate of frost buildup on refrigerated surfaces, the expected frequency of defrosting, and the effectiveness of any automatic defrosting features, including defrost water disposal.

This test is performed in ambient conditions of 90°F and 75% rh with the cabinet temperature control set for normal temperatures. The test extends over a 21 day period with a rigid schedule of door openings over the first 16 h of each day. The test calls for 96 door openings per day for a general refrigerated compartment and 24 per day for a freezer compartment and for food freezers.

Current Leakage Test. This test determines the electrical current leakage through the entire electrical insulating system under severe operating conditions. To eliminate the possibility of a shock hazard, a current leakage of 0.75 mA at rated line voltage, in accordance with UL *Standard* 250, is considered the industry maximum.

Handling and Storage Test. As with most other major appliances, it is during shipping and storage that a refrigerator is exposed to the most severe impact forces, to vibration, and to extremes of temperature. When packaged, it should withstand without damage a drop of several inches onto a concrete floor, the impact experienced in a freight car coupling at 10 mph, and jiggling equivalent to a trip of several thousand miles by rail or truck.

The widespread use of plastic parts makes it important to select materials that also withstand the high and low temperature extremes

that may be experienced. This test determines the ability of the cabinet, when packaged for shipment, to withstand handling and storage conditions in extreme temperatures. It involves raising the crated cabinet 6 in. off the floor and suddenly releasing it on one corner. This is done for each of the four corners. This procedure is carried out at stabilized temperature conditions—first in a 140°F ambient temperature, and then in a 0°F ambient. At the conclusion of the test, the cabinet is uncrated and operated, and all accessible parts are examined for damage.

Special Performance Testing

To ensure customer acceptance, several additional performance tests are customarily performed.

Usage Test. This is similar to the internal moisture accumulation test, except that additional performance data are taken during the test period, including (1) electrical energy consumption per 24 h period, (2) percent running time of the compressor motor, and (3) cabinet temperatures. These data give an indication of the reserve capacity of the refrigerating system and the temperature recovery characteristics of the cabinet.

Low Ambient Temperature Operation. It is customary to conduct a simulated load test and an ice-making test at ambient temperatures of 55°F and below. This test determines performance under unusually low temperature conditions.

Food Preservation Tests. This test determines the food-keeping characteristics of the general refrigerated compartment and is useful for evaluating the utility of special compartments such as vegetable crispers, meat keepers, high-humidity compartments, and butter keepers. This test is made by loading the various compartments with food, as recommended by the manufacturer, and periodically observing the condition of the food.

Noise Tests. The complexity and increased size of refrigerators have made it difficult to keep the sound level within acceptable limits. Thus, sound testing is important to ensure customer acceptance.

A meaningful evaluation of the sound characteristics may require a specially constructed room with a background sound level of 30 dB or less. The wall treatment may be reverberant, semireverberant, or anechoic; the reverberant construction is usually favored in making an instrument analysis. A listening panel is most commonly used for the final evaluation, and most manufacturers strive to correlate instrument readings with the panel's judgment.

High- and Low-Voltage Tests. The ability of the compressor to start and pull down the system after an ambient soak is tested with applied voltages that are at least 10% above and below the rated voltage. The starting torque is reduced at low voltage; the motor tends to overheat at high voltage.

Special Functions Tests. Refrigerators and freezers with special features and functions may require additional testing. In the absence of formal procedures for this purpose, test procedures are usually improvised as required.

Determining Energy Consumption. This is a special 90°F ambient, closed-door test using the test procedure for electric refrigerators, refrigerator-freezers, and freezers published by the DOE in the U.S. *Federal Register* (Vol. 54, No. 221, Friday, November 17, 1989). This test procedure specifies a statistical sampling plan, which must be followed to establish the estimated annual cost of energy for labeling under the U.S. Federal Trade Commission's Energyguide Program, as well as conformance with DOE energy standards. The DOE test procedure presently references AHAM *Standard* HRF-1 for methods of testing.

Materials Testing

The materials used in a refrigerator or freezer should meet certain test specifications. All materials in contact with foods must meet U.S. Food and Drug Administration requirements. Metals, paints, and surface finishes may be tested according to procedures specified by the American Society for Testing and Materials and others. Plastics may be tested according to procedures formulated by the Society of the Plastics Industry appliance committee. In addition, the following tests on materials, as applied in the final product, are assuming importance in the refrigeration industry [*Federal Specification* AA-R-00211H(GL)].

Odor and Taste Contamination. This test determines the intensity of odors and tastes imparted by the cabinet air to uncovered, unsalted butter stored in the cabinet at operating temperatures.

Stain Resistance. The degree of staining is determined by coating the cabinet exterior surfaces and the surface of plastic interior parts with a typical staining food (e.g., prepared cream salad mustard).

Environmental Cracking Resistance Test. This tests the cracking resistance of the plastic inner door liners and breaker strips at operating temperatures when coated with a 50/50 mixture of oleic acid and cottonseed oil. The cabinet door shelves are loaded with weights, and the doors are slammed on a prescribed schedule extending over an 8 day test period. The parts are then examined for cracks and crazing.

Breaker Strip Impact Test. This test determines the impact resistance of the breaker strips at operating temperatures when coated with a 50/50 mixture of oleic acid and cottonseed oil. The breaker strip is impacted by a 2 lb dart dropped from a prescribed height. The strip is then examined for cracks and crazing.

Component Life Testing

Various components of a refrigerator and freezer cabinet are subject to continual use by the consumer throughout the life of the product; they must be adequately tested to ensure their durability for at least a 10 year life. Some of these items are (1) hinges, (2) latch mechanism, (3) door gasket, (4) light and fan switches, and (5) door shelves. These components may be checked by an automatic mechanism, which opens and closes the door in a prescribed manner. A total of 300,000 cycles is generally accepted as the standard for design purposes. Door shelves should be loaded as they would be for normal home usage. Several other important characteristics may be checked during the same test: (1) retention of door seal, (2) rigidity of door assembly, (3) rigidity of cabinet shell, and (4) durability of inner door panels.

Life tests on the electrical and mechanical components of the refrigerating system may be made as required.

Field Testing

Additional information may be obtained from a program of field testing in which test models are placed in selected homes for observation. Because high temperature and high humidity are the most severe conditions encountered, the Gulf Coast of the United States is a popular field test area. Laboratory testing has limitations in the complete evaluation of a refrigerator design, and field testing can provide the final assurance of customer satisfaction.

Field testing is only as good as the degree of policing and the completeness and accuracy of reporting. However, if the testing is done properly, the data collected are important, not only in product evaluation, but also in providing criteria for more realistic and timely laboratory test procedures and acceptance standards.

REFERENCES

AHAM. 1988. Household refrigerators, combination refrigerator freezers, and household freezers. ANSI/AHAM *Standard* HRF-1-1988. Association of Home Appliance Manufacturers, Washington, D.C.

Code of Federal Regulations. 10 CFR, Part 430, Subparts B and C.

Federal Register. 1973. Vol. 38, No 242. Dated Tuesday, December 18, 1973.

Federal Register. 1989. Vol. 54, No. 221. Dated Friday, November 17, 1989, pp. 47916-47945.
Federal Specification. 1977. Refrigerators, mechanical, household (electrical, self-contained). AA-R-00211H(GL).
Refrigeration Safety Act. 1956. *Public Law* 84-930.
UL. 1994. Household refrigerators and freezers, 10th ed. *Standard* 250-93. Underwriters Laboratories, Northbrook, IL.