

CHAPTER 48

HOUSEHOLD REFRIGERATORS AND FREEZERS

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THIS chapter covers design and construction of full-sized household refrigerators and freezers, the most common of which are illustrated in Figure 1. Some of these small refrigerators (Bansal and Martin 2000) use absorption systems, special forms of compressors, and, in some cases, **thermoelectric (Peltier effect)** refrigeration. Applications for water/ammonia **absorption** systems have developed for recreational vehicles, picnic coolers, and hotel room refrigerators, where noise is an issue.

Although there are various technologies for household refrigerators and freezers, this chapter only covers the **vapor-compression** cycle in detail, because it is a universally used system. In these applications, heat (usually ranging from 200 to 1400 Btu/h) is pumped through temperature differentials (from less than 50 to over 160°F) from evaporator to condenser. Other **electrically powered** systems compare unfavorably to vapor-compression systems in terms of manufacturing and operating costs. Typical coefficients of performance 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 5.63 Btu/watt-hour

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. Note, however, that if the electricity comes from an ineffi-

cient thermal power station, emissions from an absorption refrigerator (burning fossil fuel directly) will be of the same order as those from the power station running an equivalent vapor-compression unit. 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.

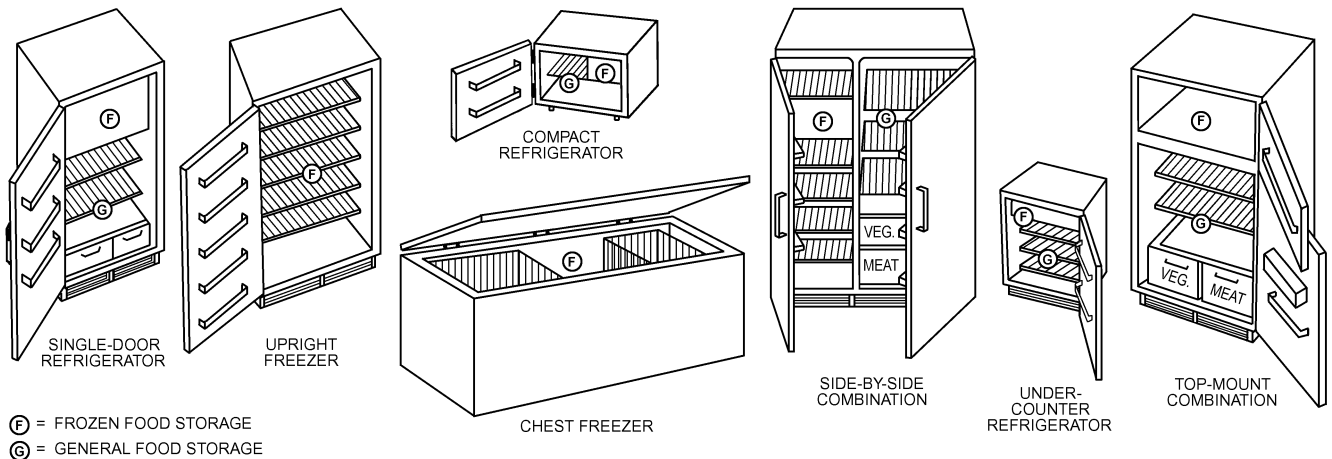
PRIMARY FUNCTIONS

Providing food storage space at reduced temperature is the primary function of a refrigerator or freezer, with ice making an essential secondary function in some markets. 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 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 detailed in Chapters 9 through 29.

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.

The preparation of this chapter is assigned to TC 8.9, Residential Refrigerators and Food Freezers.



Note: A special cabinet (not shown) called an **all-refrigerator** has no frozen food storage or even ice making capacity. Also not shown is a **bottom freezer** cabinet, which is like the top-mount freezer except that the freezer compartment is on the bottom.

Fig. 1 Common Configurations of Contemporary Household Refrigerators and Freezers

Table 1 General Requirements for Various Test Standards

Cabinet Type or Parameters	Requirement	AS/NZS	ISO	U.S. DOE <sup>a</sup>	JIS Method C <sup>b</sup>	CNS/KS	GOST
Testing Parameters	Ambient $T_A$	89.6 ± 0.9°F	77/89.6 ± 0.9°F	90 ± 1°F	77°F ± 1.8°F	86 ± 1.8°F	77/89.6 ± 0.9°F
	Relative Humidity	N/A	45 to 75%	N/A	75 ± 5%	75 ± 5%	N/A
All-Refrigerator	Fresh Food	37.4 ± 0.9°F	41°F	38°F	37.4 ± 0.9°F	37.4 ± 0.9°F	41°F
Refrigerator-Freezers <sup>c</sup>	Fresh Food	37.4 ± 0.9°F	41°F	45°F	37.4 ± 0.9°F	37.4 ± 0.9°F	41°F
	Freezer	5 ± 0.9°F	★ 21°F ★★ 10.4°F ★★★ -0.4°F	5°F	★ 21°F ★★ 10.4°F ★★★ -0.4°F	10.4/5°F	★ 21°F ★★ 10.4°F ★★★ -0.4°F
Freezers	Freezer	5 ± 0.9°F	-0.4°F	0°F	-0.4 ± 0.9°F	-0.4 ± 0.9°F	-0.4°F
Freezer Compartment	Loading of Test Packages	Unloaded	Loaded <sup>d</sup>	Sometimes <sup>e</sup>	Sometimes <sup>e</sup>	Unloaded	Loaded <sup>d</sup>
All Compartments	Door Openings	No	No	No	Yes	No	No
	Antisweat heaters	Always on	When needed	Average on and off	Always on	Always on	—
	Volume for labels/MEPS <sup>f</sup>	Gross	Storage (for EU)	Storage	Storage	Storage	Storage <sup>g</sup>
Energy Measurement Period		Lesser of 1 kWh or 16 h operation <sup>h</sup>	≥24 h	3 < $t$ < 24 h, 2 or more cycles	24 h of testing	24 h of testing	24 < $t$ < 48 h <sup>h</sup>

Source: Bansal 2003.

<sup>a</sup>Mexican and Canadian requirements are equivalent to U.S. DOE/AHAM.

<sup>b</sup>In previous Method A, 73% of consumption was weighted at an ambient of 59°F and 27% at 86°F.

<sup>c</sup>Per ISO, one-, two-, and three-star compartments are defined by their respective storage temperature being not higher than 21, 10.4, and -0.4°F. However, star ratings do not apply to AS/NZS, CNS, and U.S. DOE.

<sup>d</sup>Freezer temperature defined by warmest test package temperature that is below -0.4°F.

<sup>e</sup>Freezer temperature taken to be air temperature (contrary to ISO). Frost-free (forced-air) freezer compartments are generally unloaded. However, separate freezers in U.S. DOE are always loaded (to 75% of the available space) regardless of defrost type.

<sup>f</sup>Minimum energy performance standards.

<sup>g</sup>Freezer and fresh food compartment volumes are stated separately on the energy label.

<sup>h</sup>Note that test period for cyclic and frost-free models consists of a whole number of compressor and defrost cycles, respectively. Test must have at least one defrost cycle.

Abbreviations: AS/NZS: Australian/New Zealand Standard, ISO: International Organization for Standardization, U.S. DOE: American National Standards Institute, JIS C: Japanese International Standard (Method C), CNS/KS: Chinese National Standard/Korean Standard, GOST: Russian Committee of Standardization.

Overall system efficiency is important both because rising energy costs drive operating costs upward and because government energy standards dictate consumption limits. The challenge for the designer to control noise and vibration has been complicated by the need for fans for forced-air circulation and compressors with higher efficiencies and capacities. 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 and Test Procedures

In many countries (see, e.g., the Collaborative Labeling and Appliance Standards Program at [www.CLASOnline.org](http://www.CLASOnline.org)), regulators set efficiency standards for residential appliances. Periodically, these standards are reviewed and revised to promote the incorporation of emerging energy-saving technologies. 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. In the United States, this is done under the U.S. Department of Energy's (DOE) National Appliance Energy Conservation Act (NAECA).

Different test procedures are used around the world (Bansal 2003) to determine energy consumption of household refrigerators (see Table 1). Most tests measure energy consumption at a food compartment internal temperature of 37°F and an ambient temperature of either 89.6 or 86°F. Exceptions are the International Organization for Standardization (ISO) and U.S. DOE tests, which specify food compartment temperatures of 41 and 45°F, respectively. In addition, ISO specifies two different ambient temperatures (77 and 89.6°F), depending on climate classification. However, the quoted energy consumption figures in ISO are usually based on the temperate climate classification of 77°F. Also, ISO is the only test procedure that specifies food loading in the freezer compartment of frost-free refrigerator-freezers, but with closed doors. The Chinese National Standard (CNS) requires the relative humidity of the ambient air to be 75 ± 5%, whereas the ISO specifies between 45 and

75%. Australian/New Zealand Standard (AS/NZS), Japanese Institute of Standards (JIS) and the U.S. DOE do not prescribe any humidity requirements. JIS Method A, the predecessor of JIS Method C (Banse 2000) shown in Table 1, was the only procedure that prescribed door openings of both compartments, but without loading of any food packs in either of the compartments. It required tests at a second test ambient of 59°F and weighted the two results, assuming 100 days at 86°F (27%) and 265 days at 59°F (73%), to evaluate the annual energy consumption. JIS Method C (Banse 2000), however, is compatible with ISO. The new procedure prescribes ambient and food compartment temperatures of 77 and 41°F, respectively, and the door opening frequency to be 25 times (25 minutes/day) and 8 times (25 minutes/day) for the food compartment and the freezer doors, respectively.

Maximum energy consumption varies with cabinet volume and by product class. The latest U.S. minimum energy performance standard (MEPS) level, introduced in 2001, set energy reductions at 30% below the 1993 MEPS levels, resulting in over six and a half quads of energy savings. In Australia and New Zealand, energy reductions from 1999 to 2005 MEPS levels vary from 25 to 50%, depending on product category. Other countries have other reductions on other timetables.

### SAFETY REQUIREMENTS

Product safety standards are mandated in virtually all countries. These standards are designed to protect users from electrical shock, fire dangers, and other hazards under normal and some abnormal conditions. Product safety areas typically include motors, hazardous moving parts, earthing 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. Flammability of refrigerants and foam-

blowing agents are additional safety concerns that need to be considered. Most countries use IEC *Standard* 60335-2-24 or local variations. In the United States and Canada, however, products must comply with the joint Underwriters Laboratories/Canadian Standards UL *Standard* 250 CAN/CSA *Standard* C22.2. The United States, Canada, and Mexico are working to harmonize safety requirements for North America, based on IEC *Standard* 60335-2-24, with national differences as necessary.

### 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 compressor's hermetic motor will not be damaged by failure of a minor external component, unusual voltage extremes, or voltage interruptions.

### CABINETS

Good cabinet design achieves the optimum balance of

- Maximum food storage volume for floor area occupied by cabinet
- Maximum utility, performance, convenience, and reliability
- Minimum heat gain
- Minimum cost to 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 external cabinet dimensions, by using thinner but more effective insulation and reducing the space occupied by the compressor and condensing unit.

Methods of computing storage volume and shelf area are described in various countries' standards [e.g., Association of Home Appliance Manufacturers (AHAM) *Standard* HRF-1 for the United States].

### Special-Purpose Compartments

Special-purpose compartments provide a more suitable environment for storing specific foods. For example, some refrigerators have a meat storage compartment that can maintain storage temperatures just above freezing and may include independent temperature adjustment. 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 or bins, located in 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 or automatic means, most units other than "all refrigerators" provide ice. For **manual** operation, ice trays are usually 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 in the United States. Almost all U.S. 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. Freezing rate is primarily a function of system design. Most ice makers are in no-frost refrigerators, and 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, ice production is usually limited by design to 4 to 6 lb per 24 h. A 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** ejection of 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 overflow. 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 cooling air temperature and rate and direction of airflow.
2. **Ejecting** ice from the mold must be reliable. 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 occurs during freezing 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.

### 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 independent of use) 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 heat passing through the cabinet walls.

**Foam Insulation.** Polyurethane foam insulation has been used in refrigerator-freezer applications for over 40 years, originally using CFC-11 [an ozone-depleting substance (ODS)] as the blowing agent. Because of this ozone damage, the Montreal Protocol began curtailing its use in 1994. Most U.S. manufacturers of refrigerators and freezers then converted to HCFC-141b as a blowing agent as an interim solution, while those in many other parts of the world moved straight to cyclopentane as a blowing agent. Use of HCFC-141b was

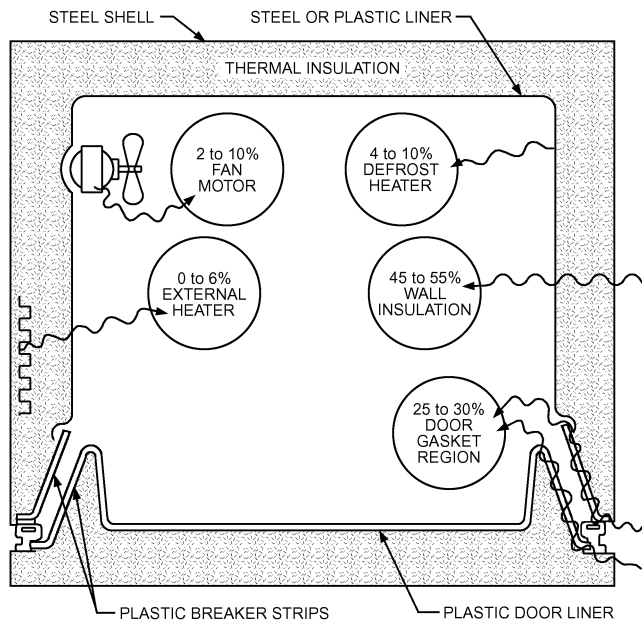


Fig. 2 Cabinet Cross Section Showing Typical Contributions to Total Basic Heat Load

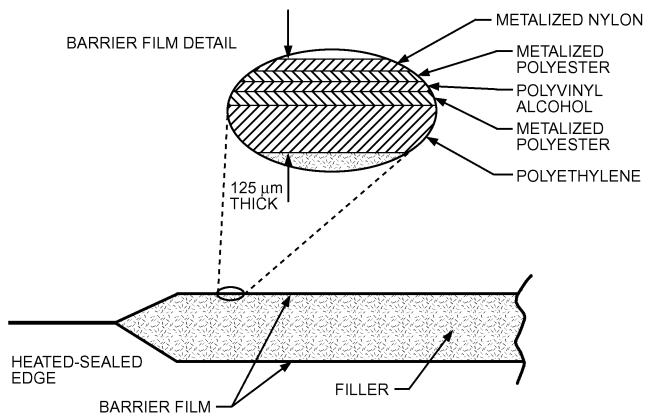


Fig. 3 Example Cross Section of Vacuum Insulation Panel

phased out in 2003 in the United States, and in most of the world. There are three alternatives to HCFC-141b:

- **Cyclopentane-blown foams** have the lowest foam material cost impact, require high capital cost for safety in foam process equipment, increase refrigerator energy use by about 4% compared to HCFC-141b, and can be difficult and expensive to implement in locations with very tight volatile organic compound restrictions.
- **HFC-134a-blown foams** have the next lowest foam material cost impact, require high-pressure-rated metering and mixing equipment, and increase refrigerator energy use by 8 to 10% compared to HCFC-141b.
- **HFC-245fa-blown foams** have the highest foam material cost impact, increase refrigerator energy use by 0 to 2% compared to HCFC-141b, require some revision to existing foam equipment, and retain insulating characteristics best over time.

**Vacuum Insulation.** Recently, flat vacuum-insulated panels have been developed to (Figure 3) inhibit heat conduction and provide highly effective insulation values down to  $0.0277 \text{ Btu}\cdot\text{in}/\text{h}\cdot\text{ft}^2\cdot^\circ\text{F}$ . A vacuum-insulated panel consists of a low-thermal-conductance fill and an impermeable skin. Fine mineral powders

such as silicas, fiberglass, open-cell foam, and silica aerogel have all been used as fillers. The fill has sufficient compressive strength to support atmospheric pressure and can act as a radiation barrier. The skin must be highly impermeable, to maintain the necessary vacuum level over a long period of time. Getter materials are sometimes included to absorb small amounts of cumulative vapor leakage. The barrier skin provides a heat conduction path from the warm to the cool side of the panel, commonly referred to as the **edge effect**, which must be minimized if a high overall insulation value is to be maintained. Metalized plastic films are sufficiently impermeable while causing minimal edge effect. They have a finite permeability, so air gradually diffuses into the panel, degrading performance over time and limiting the useful life. There is also a risk of puncture and immediate loss of vacuum. Depending on how the vacuum panel is applied, the drastic reduction in insulation value from loss of vacuum may result in condensation on the outside wall of the cabinet, in addition to reduced energy efficiency. In commercial practice, vacuum-panel insulation is one of the least cost-effective options for improving efficiency, but, where thicker walls cannot be tolerated, they are a useful option for reaching specified minimum efficiency levels.

External sweating can be avoided by keeping exterior surfaces warmer than the ambient dew point. 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  $90^\circ\text{F}$  room, no external surface temperature on the cabinet should be more than  $5$  or  $6^\circ\text{F}$  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 condenser tubing under the front flange of the cabinet outer shell or by locating low-wattage wires or ribbon heaters 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 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 dripage.

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 practicable. 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 as specified in safety standards is not exceeded; in the United States, this is specified in 16CFR1750.

Structural supports, if necessary 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 periodic automatic defrosting, ice makers, lights, timers, fan motors used for air circulation, and heaters used to prevent undesirable internal cabinet sweating or frost build-up or to maintain the required temperature in a compartment.

### Structure and Materials

The external shell of the cabinet is usually a single fabricated steel structure that supports the inner food compartment liner, door, and refrigeration system. Space between the inner and outer

cabinet walls is usually filled with 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. 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, when provided, is usually from incandescent lamps controlled by mechanically operated switches actuated by opening the refrigerator door(s) or chest freezer lid.

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 condenser tubing directly to the shell of the cabinet to prevent external sweating. Both designs influence 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. Cabinet design must be compatible with the method of installation chosen. In addition, forced-air systems frequently require ductwork in the cabinet or insulation spaces.

The overall structure of the cabinet must be strong enough to withstand shipping (and thus 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 kitchens. Shelves must be designed not to deflect excessively under the heaviest anticipated load. Standards typically require that refrigerator doors and associated hardware 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 its 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 simple disassembly of the cabinet for service or repairs.

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. 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 (HIPS) 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 good bearing qualities of nylon and acetal are used to advantage in applications such 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 (e.g., ice cubes, 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 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/or 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 does 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 tends 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 vapor-tight exterior cabinet is equally important with foam insulation.

### Door Latching and Entrapment

Door latching is accomplished by mechanical or magnetic latches that compress relatively soft compression gaskets made of vinyl compounds. Gaskets with embedded magnetic materials 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.

Safety standards mandate that appliances with any space large enough for a child to get into must be able to be opened from the inside. Doors or lids often must be removed when an appliance is discarded, as well.

Standards also typically mandate that any key-operated lock require two independent movements to actuate the lock, or be of a type that automatically ejects the key when unlocked. Some standards (e.g., IEC *Standard* 60335-2-24, UL *Standard* 250) also mandate safety warning markings.

### 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 appliance's useful life. The components of the system must provide optimum overall performance and reliability at minimum cost. In addition, all safety requirements of the appropriate

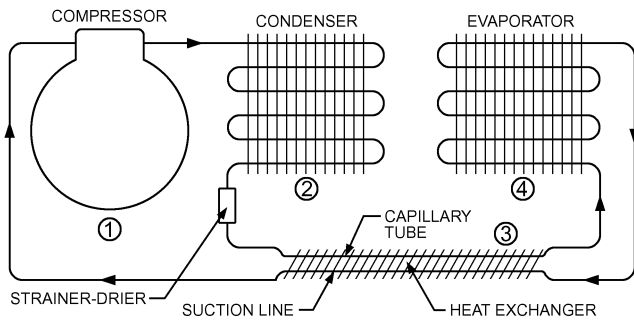


Fig. 4 Refrigeration Circuit

safety standard (e.g., IEC Standard 60335-2-24, UL Standard 250) must be met. The fully halogenated refrigerant R-12 was used in household refrigerators for many years. However, because of its strong ozone depletion property, appliance manufacturers have replaced R-12 with environmentally acceptable R-134a or isobutane.

Design of refrigerating systems for refrigerators and freezers has improved because of new refrigerants and oils, wider use of aluminum, and smaller and more efficient motors, fans, and compressors. These refinements have kept the vapor-compression system in the best competitive position for household application.

### Refrigerating Circuit

Figure 4 shows a common refrigerant circuit for a vapor-compression refrigerating system. In the refrigeration cycle,

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 heat is rejected to the ambient air.
3. 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 compressor shell. A portion of the capillary tube is usually soldered to the suction line to form a heat exchange. Cooling 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 0.3 lb or less are common. A thermostat (or cold control) cycles the compressor to provide the desired temperatures in the refrigerator. During the off cycle, the capillary tube allows 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 bonded aluminum sheets or aluminum tubing, either with integral extruded fins or with extended surfaces mechanically attached to the tubing. Evaporators in cold-wall appliances are typically steel, copper, or aluminum. 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.** Manufacturers still make a few models that use manual defrost, 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 energy for defrosting provided mainly by heat leakage (typically 10 to 20 W) into the fresh food compartment, though usually assisted by an electric heater, which is turned on when the compressor is turned off. The cold control senses the temperature of the fresh food compartment evaporator and cycles the compressor on when the evaporator surface is about 37°F. The freezer evaporator requires infrequent manual defrosting. This system is also commonly used in all-refrigerator units (see Figure 1 note).

**Frost-Free Systems (Automatic Defrost).** Most combination refrigerator-freezers and 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 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 by hot refrigerant gas, and the defrosting period is short, 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 traditional 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 radiant heating elements positioned to heat 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 is located in an air duct remote from the fresh food space, with air circulated continuously by a small fan.

The **frost-free** evaporator is usually a forced-air fin-and-tube arrangement designed to minimize frost accumulation, which tends to be relatively rapid in a single-evaporator system. The coil is usually arranged for airflow parallel to the fins' long dimension.

Fins may be more widely spaced at the air inlet to provide for preferential frost collection and to minimize its air restriction effects. All surfaces must be heated adequately during defrost to ensure complete defrosting, and provision must be made for draining and evaporating the defrost water outside the food storage spaces. Some more efficient designs of new evaporators types (Bansal et al. 2001) are now commonly used in the industry. They are made of aluminum with continuous rectangular fins; fin layers are press-fitted onto the serpentine bent evaporator tube. These evaporators work in counter/parallel/cross flow configuration.

**Freezers.** Evaporators for chest freezers usually consist of tubing that is in good thermal contact with the exterior of the food compartment liner. Tubing is generally concentrated near the top of the liner, with wider spacing near the bottom to take advantage of natural convection of air inside. Most non-frost-free upright food freezers have refrigerated shelves and/or surfaces, sometimes concentrated at the top of the food compartment. These may be connected in series with an accumulator at the exit end. Frost-free freezers and refrigerator-freezers usually use a fin-and-tube evaporator and an air-circulating fan.

## 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 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 common natural-draft arrangement, 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. Bansal and Chin (2003) provide an in-depth analysis of both these types of condensers.

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 entrance and exit of air. This makes the cooling air system largely independent of the location of the refrigerator and allows built-in applications.

In hot and humid climates, defrosted water may not evaporate easily (Bansal and Xie 1999). Part of the condenser may be located under the defrost water evaporating pan to promote water evaporation.

For **compressor cooling**, the condenser may also incorporate a section where partially condensed refrigerant is routed to an oil-cooling loop in the compressor. Here, 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.

Condenser performance may be evaluated directly on calorimeter test equipment similar to that used for compressors. However, final condenser design 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) refrigerant holding capacity that prevents excessive pressures during pulldown or in the event of a restricted or plugged capillary tube; (3) good refrigerant drainage to minimize refrigerant trapping in the bottom of loops in low ambients, 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; (5) a configuration that provides adequate evaporation of defrost water; and (6) an adequate safety factor against bursting.

## Fans

Advancements in small motor technology and electronic controls make high-efficiency fans advantageous. High-efficiency fan motors are typically dc and variable speed over a broad speed range. Energy improvements are approximately two times that of conventional ac shaded-pole fan motors.

## 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, mass flow is 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 5 shows the typical effect of capillary refrigerant flow rate on system performance. Because of

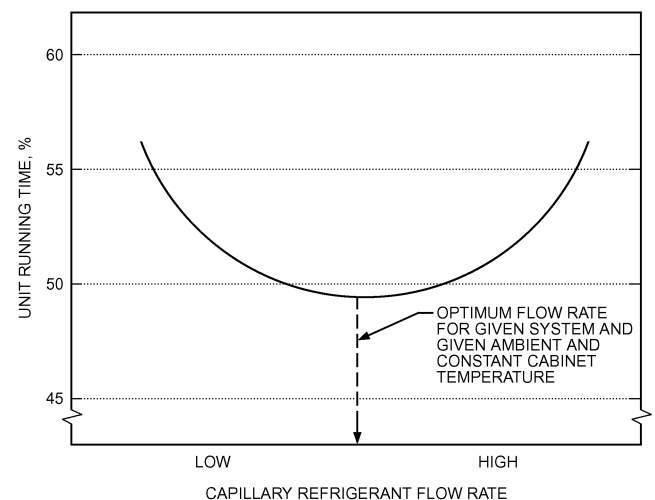


Fig. 5 Typical Effect of Capillary Tube Selection on Unit Running Time

these shortcomings and the difficulty of maintaining a match between the capillary restriction and the output of variable-pump-rate compressors, electronically controlled expansion valves are now used.

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 refrigerating capacity and efficiency. Another advantage is that 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 4](#)). There are a number of studies available in the literature (e.g., Bansal and Xu 2002; Dirik et al. 1994; Mezavila and Melo 1996; Wolf and Pate 2002) on design and modeling of capillary tubes.

**Selection.** Optimum metering action can be obtained by variations in either the diameter or the length of the tube. Factors such as the physical location of system components and 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 44](#).

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 capillary selection 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.

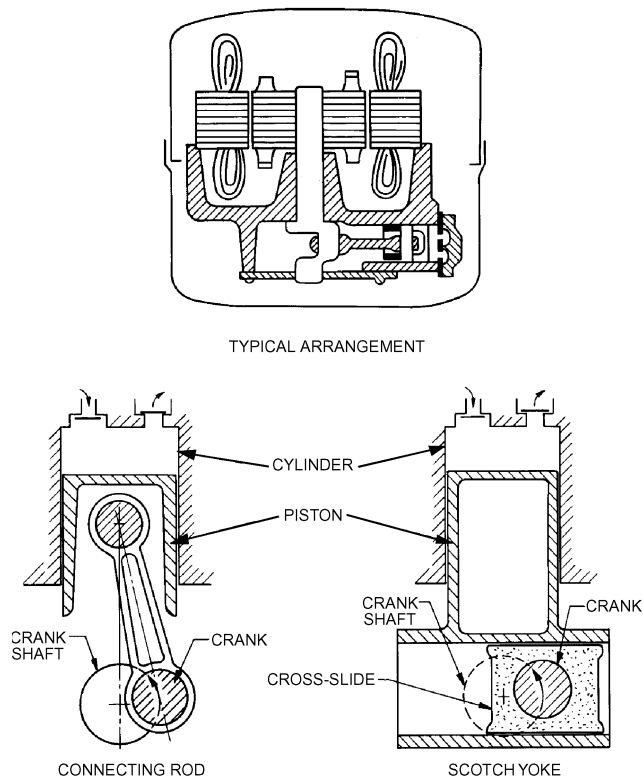
## Compressor

Although a more detailed description of compressors can be found in Chapter 34 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*, a brief discussion of the small compressors used in household refrigerators and freezers is included here.

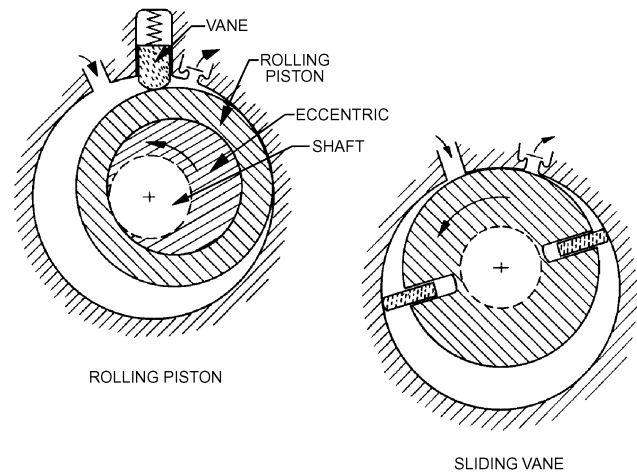
These products use positive-displacement compressors in which the entire motor-compressor is hermetically sealed in a welded steel shell. Capacities range from about 300 to about 2000 Btu/h measured at the ASHRAE rating conditions of  $-10^{\circ}\text{F}$  evaporator,  $130^{\circ}\text{F}$  condenser, and  $90^{\circ}\text{F}$  ambient, with suction gas superheated to  $90^{\circ}\text{F}$  and liquid subcooled to  $90^{\circ}\text{F}$ , or CECOMAF rating conditions of  $-10^{\circ}\text{F}$  evaporator,  $131^{\circ}\text{F}$  condenser, and  $89.6^{\circ}\text{F}$  ambient, with suction gas superheated to  $89.6^{\circ}\text{F}$  and liquid subcooled to  $131^{\circ}\text{F}$ .

Design emphasizes ease of manufacturing, reliability, low cost, quiet operation, and efficiency. [Figure 6](#) 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.

Most of these compressors are directly driven by two-pole (3450 rpm on 60 Hz, 2850 on 50 Hz) squirrel cage induction motors, although some four-pole (1750 rpm on 60 Hz, 1450 on 50 Hz) 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  $250^{\circ}\text{F}$  when tested in a  $110^{\circ}\text{F}$  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



RECIPROCATING PISTON MECHANISMS



ROTARY MECHANISMS

Fig. 6 Refrigerator Compressors

loads from start-up and pulldown of a warm refrigerator and for loads 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, positive temperature coefficient (PTC) device, or electronic switching device disconnects the start winding. A run capacitor is often used for greater motor efficiency. Motor overload protection is provided by an automatically 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.

### Temperature Control System

Temperature is often controlled by a thermostat consisting of an electromechanical switch actuated by a temperature-insensitive power element that has a condensable gas charge, which operates a bellows 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 carried through the switch. The thermostat is usually equipped with a shaft and knob for adjusting the operating temperature. **Electronic temperature controls**, some using microprocessors, are becoming more common. They allow better temperature performance by reacting faster to temperature and load changes in the appliance, and do not have the constraint of requiring the sensor to be colder than the thermostat body or the phial tube connecting them. In some cases, both compartment controls use thermistor sensing devices that relay electronic signals to the microprocessor. Electronic temperature sensors provide real-time information to the control system that can be customized to optimize energy performance and temperature management. Electronic control systems provide a higher degree of independence in temperature adjustments for the two main compartments. Electronics also enable the engineer to use variable-speed fans and motorized dampers to further optimize temperature and energy performance.

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

In a combination refrigerator-freezer with a split air system, location of the sensor(s) depends on whether an automatic damper control is used to regulate airflow to the fresh food compartment. When an auxiliary control is used, the sensor is usually located where it can sense the temperature of air leaving the evaporator. In manual-damper-controlled systems, the sensor is usually placed in the cold airstream to the fresh food compartment. Sensor 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 sensor 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. Some combination refrigerator-freezers manage the temperature with a sensor for each compartment. These may manage the compressor, an automatic damper, variable-speed fans, or a combination of these. Such controls are almost certainly microprocessor-based.

### System Design and Balance

A principal design consideration is selecting components that will operate together to give the optimum system performance and efficiency when total cost is considered. Normally, a range of

combinations of values for these components meets the performance requirements, and the lowest cost for the required efficiency is only obtained through 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 total cost and efficiency, and most 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 component selection requires performance testing of the system installed in the cabinet. These tests also determine 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 made on the complete refrigerator. The interaction between components is further addressed in [Chapter 43](#). This experimental procedure assumes knowledge (equations or graphs) of the performance characteristics of the various components, including cabinet heat leakage 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 (unless the latter is already in the compressor as supplied). 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 45](#).

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.

### 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 for the U.S. and Canadian market, and ISO *Standard* 7371 describes conditions for many other markets. For some markets, ISO requires rooms to operate down to 50°F and up to 109°F. In-house testing may require a wider window than this. AHAM *Standard* HRF-1 requires test room temperatures from 70 to 109°F for North American markets accurate to within 0.9°F of the desired value. The temperature gradient and air circulation in 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 down to 0°F for things such as plastic liner stress-crack testing. At

least one test room should be able to maintain a desired relative humidity within a tolerance of  $\pm 2\%$  up to 85% rh.

All instruments should be calibrated at regular intervals. 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 in the United States (see [Table 1](#) for other standards). It specifies 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. This test is also a part of AS/NZS *Standard* 4474.1, but not of ISO regulations.

**Simulated Load Test (Refrigerators) or Storage Load Test (Freezers).** This test determines thermal performance under varying ambient conditions, as well as 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. Cabinet doors remain closed during the test. The freezer compartment is loaded with filled frozen packages. Heavy usage testing, although not generally in standards, is also almost always done by manufacturers (to their own procedures). This is typically testing with lots of door openings in high temperature and high humidity to see whether the defrosting system copes and recovers. AS/NZS *Standard* 4474.1 has neither a load test nor the compressor operating time test, and it tests at 50, 90, and 109°F (not 70, 90, and 110°F). Each test point may take 8 h or more to ensure steady-state condition and accuracy of data.

Freezers are tested similarly, but in a 90°F ambient. Under actual operating conditions in the home, with frequent door openings and ice making, 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  $75 \pm 2\%$ , 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 moisture sealing of the cabinet in preventing moisture from getting into the insulation space and degrading refrigerator performance and life. Secondly, it determines the rate of frost build-up on refrigerated surfaces, expected frequency of defrosting, and 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 21 days with a rigid schedule of door openings over the first 16 h of each day: 96 openings per

day for a general refrigerated compartment, and 24 per day for a freezer compartment and for food freezers.

**Current Leakage Test.** IEC *Standard* 60335-1 (not available in AHAM *Standard* HRF-1) allows testing on a component-by-component basis, determining the electrical current leakage through the entire electrical insulating system under severe operating conditions to eliminate the possibility of a shock hazard.

**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, vibration, and 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 high and low temperature extremes that may be experienced. This test determines the cabinet's ability, 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, to determine performance under unusually low temperatures.

**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; 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 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. Without formal procedures for this purpose, test procedures are usually improvised.

**Energy Consumption Tests.** Many countries use procedures relevant to their local conditions (see [Table 1](#) for reference) to determine a refrigerator's energy consumption.

### Materials Testing

The materials used in a refrigerator or freezer should meet certain test specifications [e.g., U.S. Food and Drug Administration (FDA) requirements]. Metals, paints, and surface finishes may be tested according to procedures specified by the American Society for Testing and Materials (ASTM) and others. Plastics may be tested according to procedures formulated by the Society of the Plastics Industry (SPI) appliance committee. In addition, the following tests on materials, as applied in the final product, are assuming importance in the refrigeration industry (*Federal Specification A-A-2011*).

**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 cabinet exterior surfaces and 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 over 8 days. 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 hit 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 product's life; 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 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.

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