

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 watts are pumped through temperature differentials from freezer to room temperature in excess of 55 K, 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 -18°C freezer and 32°C ambient:

Thermoelectric	Approximately 0.09 W/W
Absorption	Approximately 0.44 W/W
Vapor-compression	Approximately 1.39 W/W

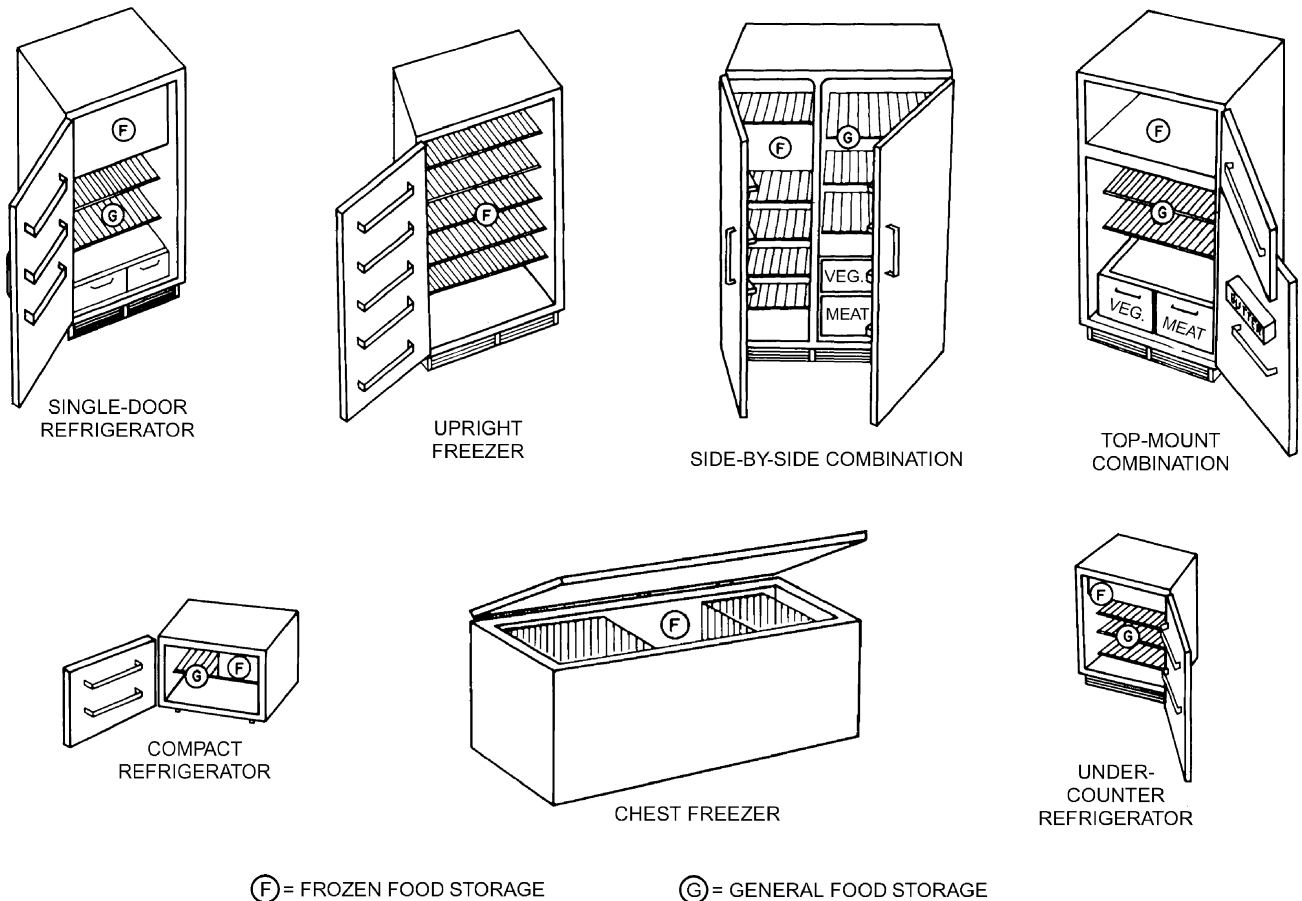


Fig. 1 Common Configurations of Contemporary Household Refrigerators and Freezers

An absorption system may operate from **gas** at a lower cost per unit of energy, but the initial cost, size, and mass 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 0 and 4°C 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 -18°C and always below -13°C 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 43°C 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 -1°C . 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 0°C 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 2 to 3 kg per 24 h. An ice production rate of about 2 kg per 24 h, coupled with an ice storage container capacity of 3 to 5 kg, 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 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 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 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 32°C room, no external surface temperature on the cabinet should be more than 3 K 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, W/(m·K)	Wall Thickness, mm			
		For Threshold of External Sweating in 32°C at 75% rh		Common Practice	
		−18°C	3°C	−18°C	3°C
Mineral or glass fiber, air filled	0.032 to 0.040	50 to 70	33 to 44	75 to 90	60 to 70
Foam-in-place urethane foam, heavy gas filled	0.019	32	22	48	40
Foamed slab urethane foam, heavy gas filled	0.023	38	25	50	38

Table 2 Cabinet Materials and Manufacturing Methods

Component	Material	Common Thickness, mm	Manufacturing Method	Finish
Outer cabinet assembly			Welded assembly	
Wrapper and top	Low-carbon cold-rolled steel	0.61 to 0.91	Roll form and bend	Organic finish (polyester, alkyd, acrylic, etc.)
Back	Low-carbon cold-rolled steel	0.56 to 0.84	Draw and stamp	
Bottom	Low-carbon cold-rolled steel	0.41 to 0.64	Draw and stamp	
Inner cabinet liner	Enameling iron	0.61 to 0.91	Bend and weld	Vitreous enamel
	Low-carbon cold-rolled steel	0.61 to 0.91	Bend and weld	Organic finish
	Aluminum	0.61 to 0.91	Bend and weld	Anodized or organic finish
	Plastic	1.3 to 5.1	Injection molded or vacuum formed	None
Inner door liner	Plastic	1.9 to 2.4	Vacuum formed or injection molded	None
Breaker strips	Plastic	1.9 to 2.4	Extruded or injection molded	None

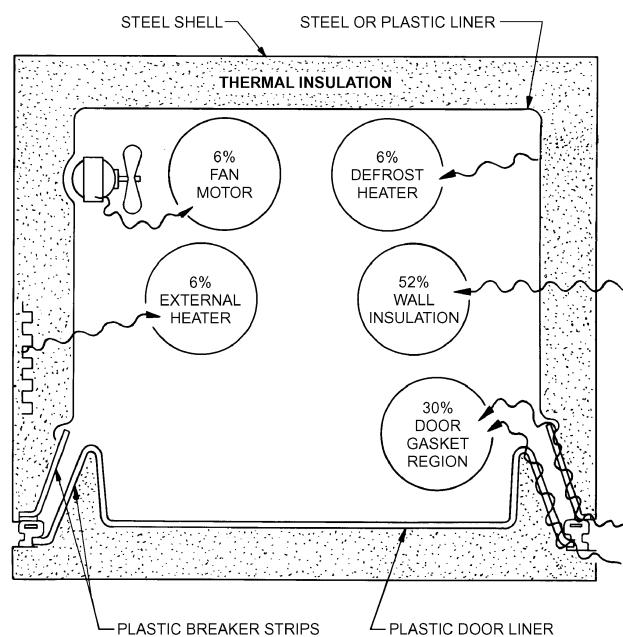


Fig. 2 Cabinet Cross Section Showing Typical Contributions to Total Basic Heat Load

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 67 N (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 7 to 9 kg 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 mass of the lid acts to compress the gasket, although most of the mass 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

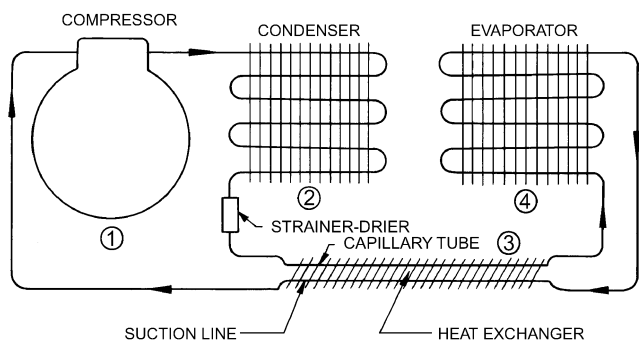


Fig. 3 Refrigeration Circuit

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 250 g 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 0°C. 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 6 mm 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 mass of liquid passes through a capillary more readily than the same mass 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](#)).

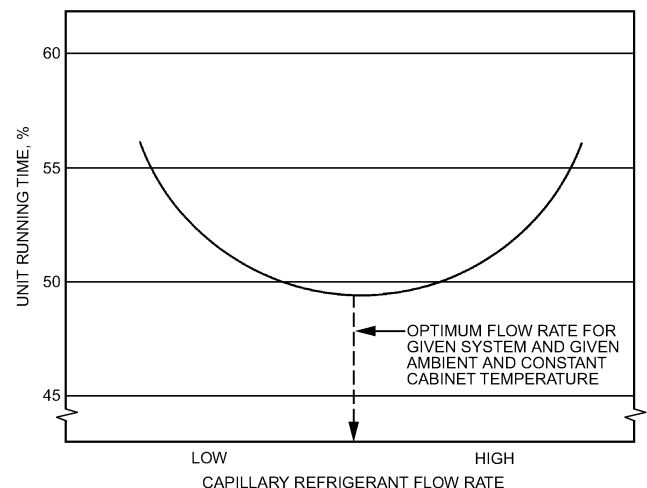


Fig. 4 Typical Effect of Capillary Tube Selection on Unit Running Time

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 (900 mm 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 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 90 W to about 600 W when measured at the usual rating conditions of -23°C evaporator, 54°C condenser, 32°C ambient, with the suction gas superheated to 32°C and the liquid subcooled to 32°C .

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 120°C when tested in a 43°C 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 300 W.

Temperature Control System

The temperature control thermostat is generally an electro-mechanical switch actuated by a temperature-sensitive power

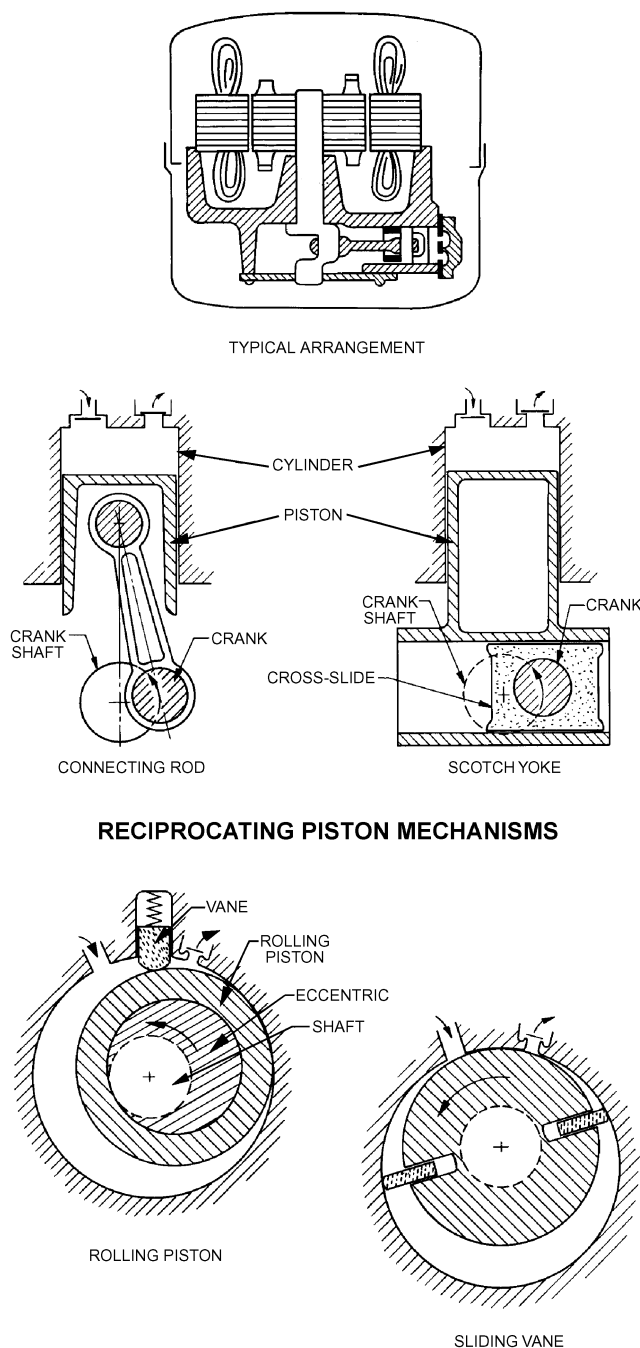


Fig. 5 Refrigerator Compressors

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 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 21 to 43°C accurate to within 0.5 K 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 -18 and 21°C. At least one test room should be capable of maintaining a desired relative humidity within a tolerance of $\pm 2\%$ 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 43°C ambient temperature to pull down from a stabilized warm condition to design temperatures within an acceptable period.

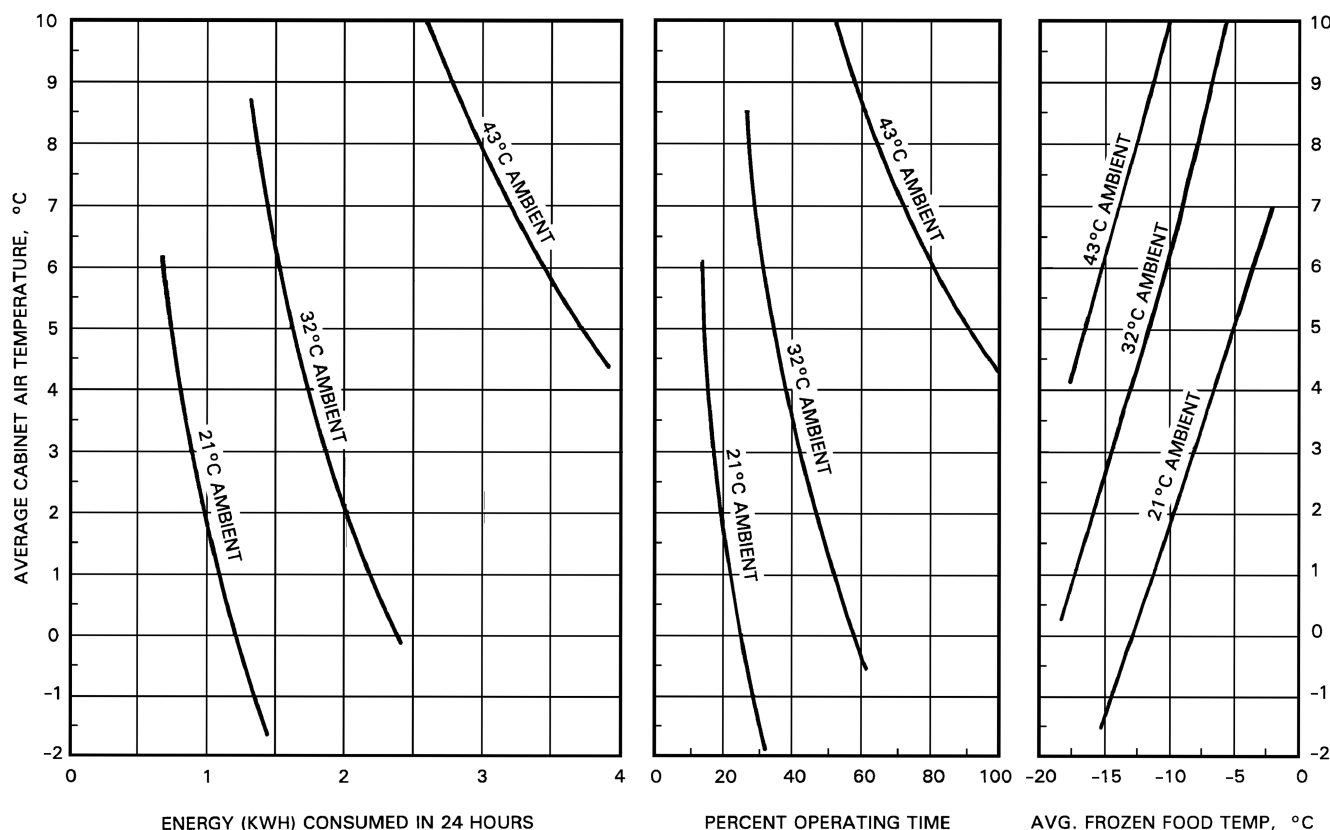


Fig. 6 Sample Plot of Simulated Load Test Results

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 21, 32, and 43°C 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 32°C 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 32°C 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 32°C, 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 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 32°C 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 centimetres onto a concrete floor, the impact experienced in a freight car coupling at 4.5 m/s, and jiggling equivalent to a trip of several thousand kilometres 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 150 mm 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 60°C ambient temperature, and then in a -18°C 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 13°C 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 32°C 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 0.9 kg 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.

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