EVAPORATOR DEFROSTING: WHEN AND WHY

The refrigeration evaporator is a container that provides room for the evaporating refrigerant. The refrigerant receives heat by conduction through the walls of the container. The efficiency of the evaporator depends on several related factors:

- its size
- the type of refrigerant in it, and its velocity and turbulence
- the amount of oil in the refrigerant
- the material from which the unit is constructed
- the difference in temperature between the evaporator and its surroundings
- exposure to surroundings
- the condition of the evaporator surface.

The evaporator surface needs to be kept clean. It should be free of scale, dirt, film or similar matter. If it is clean, the evaporator transfers heat to the refrigerant rapidly and easily. Otherwise, these elements act as insulation, which slows heat transfer.

Scale and other foreign matter collect over relatively long periods of time. They can be removed at intervals if they become a problem. Yet another element—frost—can constantly affect evaporator efficiency if the coil temperature is 32°F or less.

Frost is frozen water vapor. Its snowy crystals form when water vapor strikes an evaporator surface at 32°F or below. Frozen water becomes ice. Ice forms when frost melts into water and the water freezes. If this occurs frequently, an evaporator soon resembles a block of ice.

The colder the evaporator, the more water vapor will freeze out of the air. Always try to keep the evaporator temperature as high as possible, while maintaining the desired room or fixture temperature. This means keeping a minimum or low-temperature difference (TD) between the entering air and the evaporator.

A low TD is about 8 to 10°F. Four conditions help achieve a low TD:

- a large evaporator surface
- a fully active evaporator
- a rapid circulation of air
- a clean, frost-free surface.

These conditions for a given temperature promote slow frost buildup, high-suction pressure, high capacity, and efficiency. Less water vapor is removed from the air as frost. Humidity remains high. Foods lose less moisture and weight, and they keep their best appearance.

However, this ideal situation may not always exist. An evaporator may have a small surface area. It may not be fully active. Air circulation may be low or restricted. Heavy frost may clog air passages and act as insulation. If these things occur, the temperature difference between the entering air and the evaporator...
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will be high. Likewise, the temperature of the refrigerated space will be high. For almost any given refrigerator temperature, these conditions have the following negative effects:

- lower suction pressure
- higher cost of producing the refrigeration effect
- reduced humidity in the space, with loss of moisture from the stored food products.

There is a way to eliminate these conditions in an evaporator that operates at 32°F or below. It is to provide some means of automatic, periodic, frost removal, or "defrosting."

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A design and application engineer generally determines the heat transfer surface area of the evaporator and the air velocities over this surface. The refrigeration service technician controls the activity of the evaporator through the selection and adjustment of the expansion valve. The service technician also controls the problem of coil frosting through the application and adjustment of one of the available defrost methods.

There are many variations and refinements in defrost methods. To analyze the value and application of these variations, you must understand the concepts of the basic defrost methods. This chapter describes commonly used methods of defrosting commercial evaporators. It also covers the factors that the technician must consider in order to determine the method, or variation or combination of methods, most suitable for a particular application.

There is no perfect or ideal method of evaporator defrosting. No one method applies to any and all types of installations. This does not mean, however, that each installation requires a different defrosting method. If characteristics and conditions are the same, different systems can use similar defrosting methods and equipment. On the other hand, there may be differences in equipment, in design temperatures, or in the products being refrigerated. Numerous operating conditions can exist, which would require a variation in the defrosting method.

There are several methods of defrosting evaporators exposed to air. Most result in the evaporator temperature rising above the melting point of water (32°F). Exceptions to these methods will also be explored in this chapter. The five following evaporator defrosting methods are commonly used:

- manual frost removal
- manual equipment shutdown defrost
- off-cycle defrost
- timed shutdown defrost
- supplementary heat defrost.

MANUAL FROST REMOVAL

Evaporators in old refrigeration systems were usually made of iron pipe. They were connected to condensing units that operated continuously. Frost would accumulate until it affected system capacity. The pipe coils were brushed with a stiff wire brush, or the ice was removed with a chipping hammer or other edged tool. This was a slow and expensive process. Actually, this inefficient method of defrosting is
still found today in some ice cream dispensing (dipping) cabinets. These cabinets have evaporator coils fastened to the interior liner. They make the liner a secondary evaporator surface. Frost that builds up on the liner must be scraped off. The equipment is not usually shut down during this process. Needless to say, this method of removing frost left much to be desired. It sparked research and development of other methods as industry technology advanced.

MANUAL SHUTDOWN DEFROST

Plate evaporators are designed to be exposed to surrounding air. You find them in cafeterias where food products are displayed directly on cold plates. They are used in packaging machinery applications. These plate-type evaporators operated at a high TD and below 32°F. They accumulate a coating of frost over time. Generally, this equipment is simply turned off at the end of the business day. Food on display is moved to other storage locations. The evaporators then warm up to the surrounding (ambient) temperature and defrosting occurs. Figure 1 shows this cycle.

Figure 1. Manual shutdown defrost

This frost removal method was satisfactory in some applications. But more sophisticated, automatic refrigeration equipment was developed, which demanded defrosting methods that were also automatic. Then came the refinement of the forced-air, fin-tube evaporator for below-freezing applications. This development made automatic defrosting an absolute necessity.

The refrigeration industry answered this challenge. It developed defrost arrangements that used the forced-air evaporator and provided automatic frost removal.
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OFF-CYCLE DEFROST

Pressure-Operated Method

When storage temperatures are above freezing, especially above 35°F, heat in the refrigerated area itself can be used to defrost evaporators. The system’s low-pressure control on the condensing unit can indirectly control refrigerated space temperature, as shown in Figure 2. The low-pressure control’s “cut-in” setting is adjusted to a pressure that exists when the coil is free of frost, and the produced water from the melted frost has drained away. With this method, the temperature of the refrigerated space is indirectly controlled by the saturation pressure of the refrigerant in the evaporator. It corresponds to the temperature of the evaporator.

For example, assume that the design temperature of the refrigerated space is 40°F. The selected evaporator has the capacity to give a 16°F TD between its surface and the entering air. The temperature of the evaporator will be 24°F (40-16=24).

The refrigerant used is R-134a. At 24°F, it has a saturation pressure of about 21 pounds per square inch gauge (psig). Thus, if suction pressure of the refrigerant is 21 psig, the refrigerating temperature of the evaporator will be 24°F. The temperature of the refrigerated space can be controlled through a pressure control-set the cut-in point of the low-pressure control at 24 psig and the cut-out point at 18 psig. This results in an average refrigerating pressure of 21 psig (24 + 18 = 42/2=21), which corresponds to 24°F.
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However, the primary reason for using this method is frost removal. The cut-in point (24 psig) corresponds to only 27°F, which will not melt the frost. For frost melting, the low-pressure control cut-in must correspond to an evaporator temperature above 32°F. For R-134a, this is a suction pressure of 28 psig. Yet some parts of an evaporator do not warm up as quickly as others. This is especially true of the lower tubes. By the time these areas warm up to 32°F, others may be at 35°F. Obviously, for complete defrosting, all of the evaporator must be warm enough to melt the frost. The temperature of the warmest part will determine the evaporator refrigerant pressure. In this example, it is 35°F. For R-134a, the pressure that corresponds to 35°F is 30 psig, so the low-pressure control cut-in point must be no lower than 30 psig for complete frost removal. In most cases, it should be 32 psig or higher.

All frost or ice is usually melted by the time the control cuts in at 32 psig. At this point, the condensing unit starts. However, an expansion valve normally does not open at once when the compressor starts. There may be a pressure drop of 6 to 8 psig in the evaporator before the valve opens. This depends on valve design, superheat setting, etc. Thus, the evaporator in this example will not produce much refrigeration effect until its pressure decreases to about 24 psig (32-8), which is illustrated in Figure 3. At about this pressure, the expansion valve begins feeding refrigerant properly. It continues to provide refrigeration effect until the suction pressure again drops to 18 psig. This is the cut-out setting of the pressure control.

![Figure 3. Pressure-operated defrost example (R-134a)](image-url)

Given the characteristics of the average system, the final cut-in point setting still provides an average operating suction pressure of 21 psig. The average refrigerating temperature of the evaporator is 24 °F. With a 16°F TD, This gives a design refrigerated space temperature of 40°F.
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The pressure-operated defrost method is one way for a system to function normally during a condensing unit ON cycle, while also providing complete defrosting during its OFF cycle.

Note the following factors regarding pressure-operated defrosting:

• This method is generally limited to applications where the temperature is kept at a minimum of 35°F.

• The pressure differentials required for temperatures below 35°F make it nearly impossible to achieve complete defrosting between running cycles. Thus, this method cannot be used in systems with operating temperatures below 35°F.

• This method is unable to control air temperatures properly in unheated stores, or when the ambient temperature at the location of the condensing unit is as low or lower than the temperature in the refrigerated space. In unheated stores, the load could be so low that the air temperature in the refrigerated space is above normal. Yet it is not high enough to warm the evaporator to the point at which pressure closes the low-pressure control contacts and activates the condensing unit.

• If the condensing unit is in a location colder than the evaporator, refrigerant will migrate through the suction line. It condenses in the colder compressor crankcase. This prevents the evaporator pressure from rising to the cut-in point of the low-pressure control. Thus, the condensing unit will not start.

Actually, under these last two conditions, the pressure-operated defrost method would work—however; the refrigeration requirements of the application would not be satisfactorily met.

Variations of Off-Cycle Defrost

The HVAC/R industry has developed many combinations of OFF-cycle defrost methods. Some are proprietary in nature and others have widely used approaches. The general goal of these variations over the years was to have an effective automatic defrost and still allow for varying load conditions. Low-pressure controls were tried in which cut-in and cut-out points were controlled by different sets of links and bellows. Each bellows might be connected to a remote bulb temperature sensor, or one of the bellows might be temperature-operated and the other pressure-operated, connected to the suction side of the system. Cut-in action of the latter bellows would be the function of the bellows connected to the low-pressure side.

The pressure-operated defrost, temperature-operated defrost, and the variations described above all give the same basic result. Each provided OFF-cycle defrosting of the evaporator after every compressor running period.

Temperature-Operated Defrost

The temperature-operated defrost method replaces the low-pressure control with a temperature control. The control device is usually a remote bulb-type thermostat. The bulb is attached to the evaporator at the point most suitable for the evaporator used and the temperatures required. This gives direct control of the cut-in and cut-out points based on the temperature of the evaporator. With the pressure-operated defrost method; this control is indirect and based on pressure.

Refer back to the installation described above. Assume that you substitute temperature control for low-pressure control. The remote bulb could be attached near the upper part of the evaporator. The temperature control could be set to cut in at 34°F and cut out at 22°F. Since the control operates directly
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from temperature, it gives better control of temperature with variations in load. However, this may cause a sizable increase in compressor running time. The remote bulb location must be selected with great care in order to ensure a complete defrost every time, as well as good temperature control during the ON cycle.

Unlike the pressure method, the temperature method does not ensure a complete defrost. Nevertheless, the method is becoming more popular. An occasional manual shutdown defrost may be required. Such a need would occur in hot weather or when other highload conditions exist.

The temperature method has an advantage in refrigerators in cold locations, because it forces compressor operation from the temperature directly. However, it does not prevent compressor slugging caused by refrigerant condensed in the compressor crankcase in cold basements.

TIMED SHUTDOWN DEFROST

In many installations, the compressor can be shut down for an extended period of time. This can be down once or perhaps several times in a 24-hour period. These are installations in which the air temperature might be below 35°F but not lower that about 25°F. A switch actuated by a time clock can control this defrost method, as shown in Figure 4. The defrost timer is set to stop the compressor at a selected time. It is set to start it again after enough time for a complete defrost has elapsed.

Figure 4. Timed shutdown defrost
Installations vary a great deal. You may have to experiment to get the right cut-out and cut-in times. Recommendations of the equipment manufacturer may be helpful. Conditions also may vary, such as seasonally, so you may have to readjust the defrost time. This need for seasonal adjustment led to the development of the methods described here.

The defrost system can be time-initiated, and either pressure- or temperature-terminated. Both offer automatic adjustment to variable frost conditions. Each method responds to varying conditions in such a way as to provide the minimum OFF time and temperature rise needed for a complete defrost.

PRESSURE-TERMINATED TIMED DEFROST

Figure 5 shows the time-pressure system. This method of defrosting is usually controlled by a defrost timer combined with a low-pressure control. The timer stops the compressor at a predetermined time. The evaporator starts to defrost. However, the time switch can be closed again only by the action of the low-pressure control bellows, which is usually set to a pressure corresponding to 43°F.

Defrosting is not done during each unit OFF cycle. Thus, the pressure and temperature of the evaporator must rise higher than during an OFF-cycle defrost. The controls must give additional time for all of the heavy frost accumulation to melt.
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TEMPERATURE-TERMINATED TIMED DEFROST

The time-temperature method is similar to the time-pressure method. The difference is that a temperature control terminates the defrost period. In most current applications, the temperature control may be adjustable or preset. It may respond to coil tube temperature, coil fin temperature, air off the coil, or air return to the coil. It also may be located at any point in the air circulation path. This extreme flexibility has led to misunderstandings and there have been service adjustment errors. Therefore, it is very important to obtain and to follow the recommendations of equipment manufacturers. Find out where and how to measure the temperature to ensure a properly set defrost termination temperature.

The thermostats usually used are "close-on-rise" types. They have fairly wide differentials. The defrost timer has a small solenoid energized by the termination thermostat circuit. The solenoid armature closes the defrost timer switch contacts to start the condensing unit. At the same time, it opens the termination thermostat circuit. As the system refrigerants, the thermostat responds to the decreasing temperature. At the preset cut-out temperature, it opens its contacts. The termination circuit is thus reset. It now stands by for the next defrost period.

Temperature-activated arrangements ensure a more positive termination of the defrost period than pressure-activated arrangements, especially in installations where the compressor is in a cold location and suction pressure is kept low by the vapor condensing in the compressor. However, the time-temperature method does not protect the compressor against damage caused by slugging (as a result of refrigerant condensing in the crankcase). Such installations are to be avoided whenever possible. If the compressor must be located where temperatures could drop below the refrigerated space temperature, a compressor crankcase heater should be installed to prevent the refrigerant from condensing in the crankcase.

SUPPLEMENTARY HEAT DEFROST

Some refrigerated products may have to be kept below about 29°F. In such cases, evaporators must be defrosted as quickly as possible. You cannot depend on the heat in the ambient air that is circulated over the evaporator surface. Such systems need additional heat from another source. This is called supplementary heat.

There are many methods designed for quick defrost with minimal temperature change in either product or ambient temperature. Heat sources include:

- water
- brine sprays
- electric resistance
- high-side vapor

WATER DEFROST

Water can be directed defrosting medium. It may come from the mains, or it may be pumped from a reservoir and then returned to it. If necessary, the water may be reheated in the reservoir. As commonly used, the liquid-line valve, either the manual or the electric solenoid type, is closed. The low side is pumped down so that the evaporator is free of liquid refrigerant before defrosting starts. The compressor and the evaporator fans are stopped. In some installations, louvers are shut to enclose the evaporator coil.
A valve is then opened, as shown in Figure 6. Water goes to a spray head above the evaporator. The water washes over the evaporator and melts the frost. It is then caught in a drain pan and led away to the drain.

The valve in the water line shown in Figure 6 is a "stop and waste" valve. It allows water in the line and the spray head connections to drain out. This keeps it from freezing during normal refrigerating operation. The thermal contact between the water and the evaporator is excellent. The temperature of ordinary tap water is sufficient for rapid defrost. Figure 7 illustrates an automatic water defrost cycle, including the refrigerant pump-down and the stopping of the compressor and the fans. Two solenoid valves are used instead of the manual "stop and waste" valve.
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With the water defrost method, you must be careful to ensure that all of the water and drain lines in the refrigerated space are entirely drained of water after the defrost cycle. If they are not, they will probably freeze during the normal refrigerating cycle. Damage may result.

BRINE SPRAY DEFROST

In large installations, brine spray may be used in a manner similar to water defrost. The brine is returned to a reservoir and recirculated. The brine may be reheated in the reservoir. However, a large reservoir may have enough heat holdover without added heat, as shown in Figure 8.

Figure 7. Water defrost (automatic)
Water from the melted ice and frost mixing with the brine weakens it. Use "concentrators" to evaporate the excess water. This keeps the freezing point of the brine below the evaporator temperature. Carryover of the spray into the refrigerator may be undesirable during defrosting. If so, install duct baffles or louvers that can be closed during defrosting.

This type of system is usually manually operated. However, it can be arranged with timers, electrically operated valves, etc., for automatic defrost control.

**ELECTRIC DEFROST**

Electric defrost is illustrated in Figure 9. It has been popular since it was introduced over a quarter of a century ago. Heater manufacturers have solved problems and now produce reliable and long-lived heaters. The method is clean and quiet. It can be built to handle many types of evaporators. These range from small frozen-food chests to large multideck, low-temperature display fixtures. Unit coolers have
heaters built in or around their evaporators. Part of the resistance is built into drain pans and the drain line. This prevents refreezing and ensures adequate drainage.

Automatic control of the direct electric method is easily done with a timer. It can be supplemented, if desired, by a thermostatic or pressure control. Some systems with electric heaters use separate limit switches. They are thermostats that open the circuit to the electric heaters if the evaporator gets too hot.

Generally, evaporator fans on unit coolers in freezer boxes are turned off during the defrost period. Start-up after defrost is often delayed until the evaporator coils are below 32°F. In some unit coolers, baffles are closed to keep heat from getting into the refrigerated spaces. Evaporator fans in open display fixtures usually continue to operate during defrost. This allows warming of the flues and ducts of the air-circulating system.

The electric heaters may be of higher wattage than many common timers can handle. If so, use heavy-duty contactors, actuated by the timer contacts, to open and close the heater circuits.
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VAPOR DEFROST

A better understanding of the vapor defrost (hot gas) method can be gained by briefly reviewing what becomes of the heat in the air and the food in a refrigerated space. The refrigerant in the evaporator is the only cooling medium. As a result, all of the heat load must pass into the refrigerant and out through the suction line. There it picks up some additional heat from the surrounding air. The refrigerant gas, now warmed somewhat, goes to the compressor, where it is compressed and discharged into the condenser.

Work is done on the gas to compress it. Work is a form of energy. Since energy cannot be created or destroyed, that work must be accounted for. The work energy is turned into heat energy in the compressed gas. Therefore, it is added to the heat in the gas (vapor) that came from the refrigerated space. The hot gas that leaves the compressor contains heat from the refrigerated space, heat that was picked up in the suction line, and the heat of compression. The heat picked up in the suction line is usually rather small in normal-temperature installations. The heat of compression, however, may be 25% of the total heat of the compressor discharge gas.

The heat in the gas from the compressor raises its temperature. R-134a at the inlet to the condenser may be 90 to 120°F, depending on conditions. The function of the condenser is to remove this heat from the hot discharge gas from the compressor. In this process, the gas is changed back to a liquid at about room temperature for air-cooled machines, and a little above the inlet water temperature for water-cooled machines.

Instead of letting the hot gas flow into the condenser, some system designs intercept and divert it. It is sent through a bypass line to the evaporator at a point just beyond the expansion valve. In other words, the high-temperature gas from the hot gas line is fed into the evaporator. For many installations, this gas has enough heat to defrost the evaporator entirely. This is known as "hot gas" defrosting. Figure 10 illustrates the manual control method.
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The hot gas system transfers heat from the discharge gas to the evaporator metal and to frost on the evaporator exterior. First sensible heat is transferred, then latent heat. For a short period of time, the evaporator being defrosted acts like a condenser, and the hot gas changes to liquid refrigerant. Figure 11 shows the automatic operation.

Figure 10. Hot gas defrost (manual valve)
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However, this liquid refrigerant must move through the system. The only place it has to go is into the
suction line—and from there to the compressor. But some refrigeration compressors are made to pump
vapor only. Pumping the liquid formed in a hot gas defrost system could seriously damage these types of
compressors. In fact, they could be completely ruined.

The concept of using the “free” heat in compressed gas from the compressor was attractive to the
designers who set out to solve the problem of returning liquid refrigerant to the compressor. A few of the
methods devised have stood the test of time. They are now found in hundreds of successful installations.
Basically, a method was needed to change the liquid refrigerant, which was flowing from the defrosting evaporator, back to a gas before it reached the compressor.

One method uses an orifice at the inlet of the hot gas bypass to the evaporator. It limits flow so that the
liquid can be warmed enough in the suction line to become vapor again.

Another method provided an accumulator located at the outlet of the evaporator. Here the liquid collects
and is slowly boiled into vapor by the action of the compressor.

Other systems use equipment called "re-evaporators," as shown in Figure 12. Three variations of the re-evaporators follow:
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- Warm room air is forced through a finned coil by a fan. The coil becomes part of the suction line.
- A tank of fluid is heated by means of electric heaters. During defrost, the heat is given up to a loop of suction line, which also passes through the tank.
- A variety of combined methods make use of re-evaporators to change the liquid refrigerant back to a gas before it reaches the compressor.

Several methods are proprietary, and cannot be explored in this chapter.

Using hot gas to defrost the evaporator cured one problem, but introduced another. Suction pressure rose as the hot gas entered the evaporator. It could reach a point that caused compressor motors to overload and shut down—even on overload devices. This has been overcome by using a suction pressure throttling valve. It is set to permit a maximum suction pressure and motor load.

Hot gas defrost systems work well, but have limitations. At the beginning of the defrost period, the gas contains all the heat from the refrigerated space and the suction line, as well as the heat of compression. It imparts some of its heat to the evaporator. Most of this goes into the ice and frost and causes them to
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melt. This heat, therefore, is lost in the water down the drain. Some heat is again picked up in the suction line and from the heat of compression. As defrosting continues, however, the hot gas becomes cooler — it is losing its heat to the evaporator. It is kept partly supplied by the heat of compression, but at a reduced rate, and by some heat from the suction line. But the total heat available for defrosting slowly diminishes. This limits the defrosting action of the hot gas method. An evaporator may have collected a lot of ice. If so, the amount of heat in the hot gas may not last long enough for a complete defrost.

Hot gas defrosting is most effective at the beginning of the defrost period. Therefore, it is desirable, if possible, to defrost often (more than once a day). This takes advantage of several initial supplies of heat in the hot gas. Also, with less time between defrosts, less ice forms on the evaporator.

With any hot gas system, take care to avoid pressure drop and cooling of the gas due to long runs of the hot gas and the bypass lines. A long run, however, may be necessary, so it must be of ample size, and perhaps insulated against heat loss.

REVERSE-CYCLE GAS DEFROST

In the hot gas defrost method just described, a bypass line runs from the compressor discharge to a point just beyond the expansion valve. This method is the so-called “three-pipe” system and is subject to the limitations noted previously for avoiding pressure drop and cooling of the hot gas. The reverse-cycle gas defrost system can also provide a defrost. The reverse-cycle method overcomes the main problem with the three-pipe system, which is the limited heat available for defrost.

Reverse-cycle defrost is as old as mechanical refrigeration itself. A system of valves is arranged so that the evaporator acts as the condenser and the condenser acts as the evaporator. In early ammonia warehouse installations, various sections of the many evaporators could be manually reversed by the plant operator. This gave very satisfactory results. Now, electrically operated four-way valves can provide the reversing action. They also can be operated with a time clock, so that defrost is automatic at desired intervals. Figures 13 and 14 show normal and defrost cycles.
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Figure 13. Reverse-cycle gas defrost (normal cycle)
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As supermarkets grew in size, distances from evaporators to condensing units increased. Three-pipe hot gas systems fell into disfavor because of their tendency to run out of heat. A true reverse-cycle gas defrost system was developed. It operated successfully. It allowed open, low-temperature fixtures in food stores the advantage of a quick defrost with a vapor. However, these systems required a specially built condensing unit to handle the product of the gas defrost liquid refrigerant.

In time, central refrigeration systems for supermarkets evolved. This equipment meets all or most of the refrigeration needs of a complete food store. Various fixtures are arranged and piped much like the early warehouses previously mentioned. The arrangement made reverse-cycle gas defrost very practical. One or more evaporators are defrosted while others continue to refrigerate. This provides a continuous supply of heat to the defrosting coils.

Basically, the refrigerant condensed by the defrosting evaporator is fed to the refrigerating evaporators. They provide the necessary "re-evaporator" action, which prevents liquid return to the compressor.
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CONCLUSION

This chapter has shown that there are many basic methods of defrosting evaporators. There are not only several shutdown methods, but also several methods that use heat sources other than the air inside the refrigerated space. Supplementary heat is used in the water defrost, electric defrost, and hot gas defrost methods. In addition to the basic methods described in this chapter, there are other variations and combinations, most of which are aimed at speed and automation.

It is beyond the scope of this chapter to detail every possible variation and combination. The information given offers a fuller understanding of defrosting principles, the common methods used, and suggestions of sources of available heat.

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