HT-SUR-0313A

Surveillant

Demand Defrost

Evaporator Control

Theory of Operation

Advanced Energy Saving Technology

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The **Surveillant** Evaporator Controller reduces the energy used by the evaporator coil in refrigeration systems through precise control of superheat, fan management, and demand defrosts. Surveillant was designed to be used in single and multiple evaporator installations, with a payback period of two years*, and a life expectancy that matches that of the system. Once the controller pays for itself, it continues to pay dividends for the life of the system.

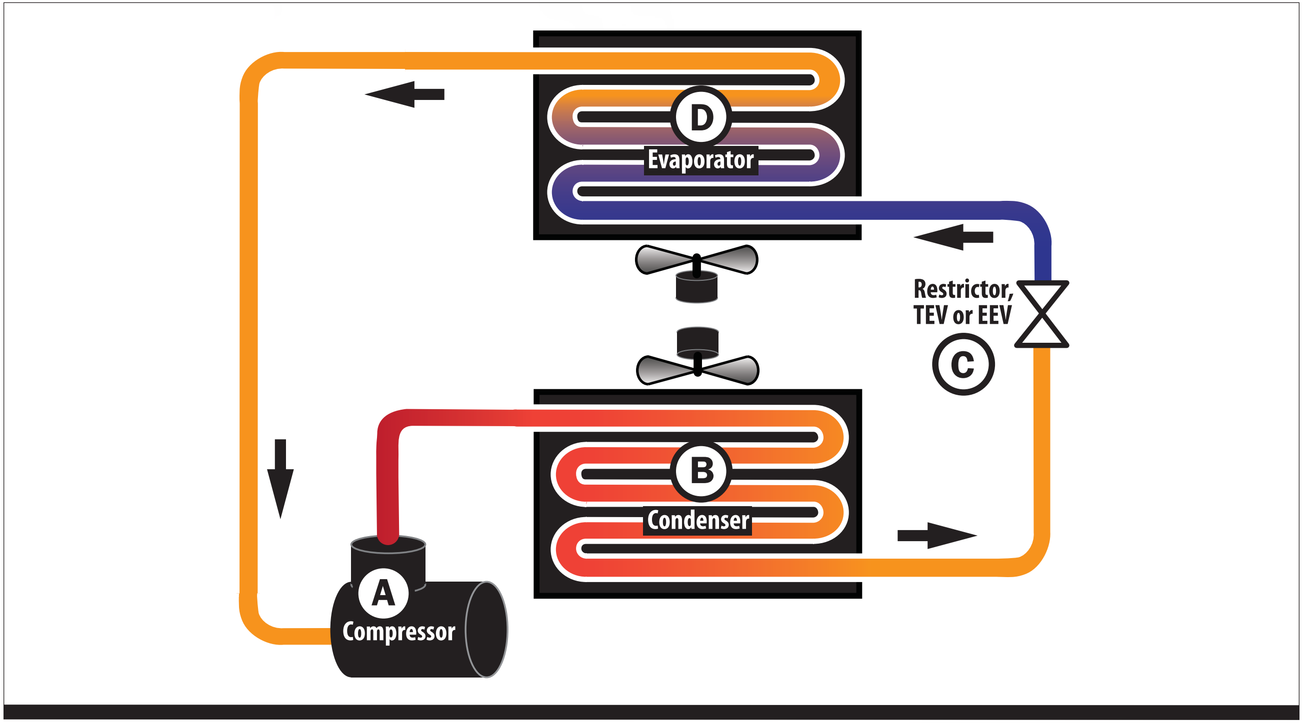
Refrigeration System

Before discussing the controller and its functions, it is necessary to briefly introduce the refrigeration system. A refrigeration system is defined as a group of devices serving the purpose of transferring heat from an enclosed space to an external location. As shown in **Figure 1**, it is comprised of 4 main components: the evaporator, condenser, compressor, and expansion device.

The system's cycle begins at the **compressor** Ⓐ. A compressor is a motor driven device that converts low pressure vapor to high pressure vapor. This is accomplished when the vapor enters the suction valve, is mechanically reduced in volume, increases in pressure, and exits through the discharge valve. The heat created as a result of the increase in vapor pressure must be removed to change the state of the vapor.

The **condenser** Ⓑ removes the heat generated by compression by transferring it to another media, typically air or water. As heat is removed from the vapor, it begins to change from a gas to a liquid. At the exit of the condenser, the refrigerant is in a 100% liquid state. As the liquid exits the condenser, it travels through the piping to the expansion device.

Figure 1 - Basic Refrigeration System



* based on utility rate of $.09/kwh.

The **expansion device** Ⓒ is the divider between the high and low sides of the system, and controls the amount of refrigerant being supplied to the evaporator coil. As the refrigerant passes through the expansion device it enters the low pressure side of the system. At the new lower pressure, the refrigerant begins to boil and is transformed to a two phase liquid. The liquid continues boiling as it transfers heat from the air.

The refrigerant in the **evaporator** Ⓓ, absorbs heat while continuing through the piping to toward the compressor. The evaporator's function is to efficiently transfer heat to the refrigerant. The evaporator transfers heat from the desired media: air, water, glycol, etc. While the evaporator transfers heat to the surroundings, the expansion device controls the refrigerant flow, ensuring all the liquid has fully vaporized prior to exiting the evaporator.

Upon exiting the evaporator, the vapor continues to the compressor where the cycle begins again.

Evaporator

As a major component of the system, an efficient evaporator plays a key role in saving energy. An evaporator consists of the coil, fans, expansion device, defrost heaters, and can include the liquid line solenoid valve. By carefully managing each component, the Surveillant evaporator controller is able to provide the maximum output, with the minimum amount of energy input.

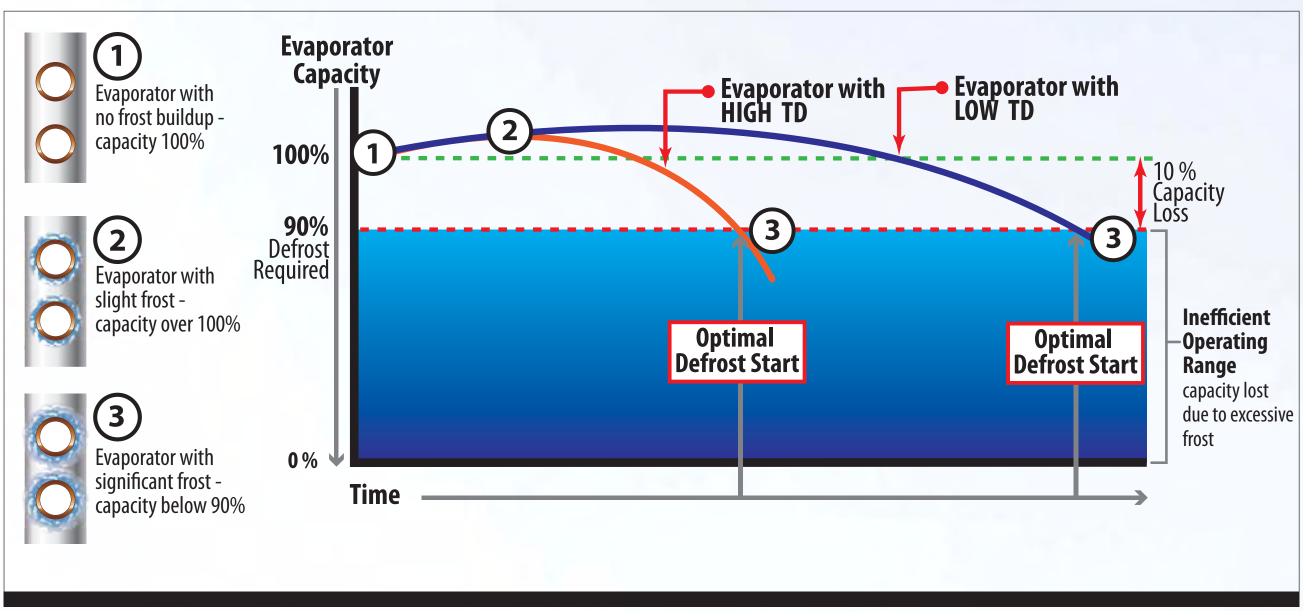
Although frost is unavoidable, it is also the most common cause of inefficiency in evaporator coils. When the evaporator temperature drops below the dew point, moisture begins collecting on the cool surfaces. If the temperature continues to drop below freezing, the moisture will begin to solidify, forming a thin layer of ice. As moisture builds on the ice, frost begins to form; the layer closest to the surface of the evaporator will tend to be hard, with a consistency similar to ice cubes. Depending on humidity, evaporator temperature and air flow, subsequent layers of frost may be more crystalline or snow-like. This is referred to as radiant frost or hoar frost.

Although building frost on evaporator coils ultimately causes the evaporator to lose efficiency, initially it increases the capacity of the evaporator. **Figure 2** shows typical evaporator performance as the coil builds frost. It is somewhat counter intuitive for something that causes inefficiencies to improve a systems performance. However, the efficiency is boosted due to the increased surface area of the coil. **Figure 2** illustrates how the performance is enhanced initially, but declines over time. As the hoar frost continues to build, more and more air is trapped between the ambient air and the coil, creating an insulating effect. One result of this insulating effect is the temperature of the coil must be reduced to maintain the desired space temperature. When the temperature difference TD increases, it causes the evaporator coil to accelerate the formation of frost.

The Surveillant evaporator controller is designed to harvest the energy stored in the coil, which is not recognized by traditional control. Using advanced algorithms to control the fans based on the systems coil and air temperature. Surveillant uses this information to create a coil profile for each system's evaporator. Once the controller has learned the most efficient method of controlling the evaporator, it uses advanced fan control to extract the energy from the coil. Maintaining a lower TD throughout the evaporator's run time forms frost at a slower rate, extending the time between defrosts.

To explain how the Surveillant controller reduces the temperature difference, it is important to understand how the evaporator

Figure 2 - Typical Evaporator Performance as Coil Builds Frost



temperature changes during the cycle. During normal operation, the refrigeration cycle pulls the coil down to temperature and continues running until the space temperature is satisfied. When the space temperature is achieved, the controller closes the liquid line solenoid valve and turns off the fans. The system continues to run until any liquid refrigerant is fully vaporized. As the refrigerant is pumped out of the coil, **Figure 3** shows how the temperature of the coil continues to drop from the refrigerating effect of the refrigerant remaining in the coil. This residual refrigeration acts as a flywheel, dropping the coil temperature further below the space temperature. Normally this excess energy is wasted, sitting in the coil until the system starts the next cycle. **Figure 3** shows how the Surveillant evaporator controller is able to capture this wasted energy, pumping it back into the system.

Using the fans in place of the compressor reduces the amount of energy used to maintain the space temperature. The energy of the coil is depleted until the compressor must be started again to maintain the space temperature.

In the process of returning additional cooling, frost is reduced naturally through the process of sublimation. Sublimation occurs when frost is transformed directly into vapor, skipping the liquid phase. By cycling the fans, the controller extends the time between compressor runtimes. In addition to adding time between compressor cycles to save energy, the transition of the frost from solid to vapor returns valuable moisture to the space. Maintaining higher humidity levels reduces product shrinkage. Even the most advanced defrost controllers currently on the market melt the frost, running the water and energy down the drain.

Types of Defrosts

It is inevitable that all systems operating near the freezing point of water will eventually need to defrost the coil. This is done to prevent frost from disturbing the space temperature. Systems clear the coil using a variety of methods to raise the coil temperature above the freezing point, until the frost has melted.

To effectively address frost we first need to understand what causes it. There are several factors that influence frost building on an evaporator:

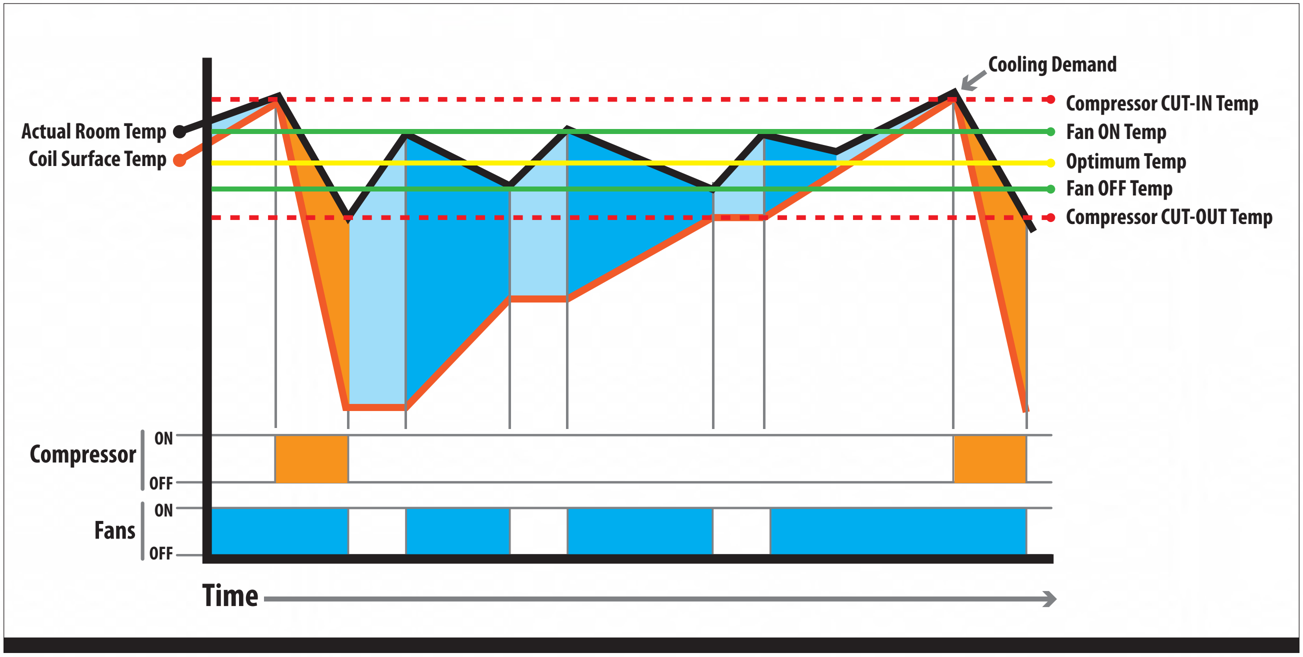
- The thermal conductivity (K value) of the coil
- Atmospheric Conditions
- Product Humidity
- Coil Location
- Plant Design

Some of the most common defrost methods are: off time, electric heaters, and hot gas.

Off-time defrost is the least complicated system. Off-time defrost requires stopping refrigerant flow for a period of time sufficient to eliminate frost on the coil. For this type of defrost to work, the space temperature must be above freezing. Defrosting with off-time, forces the fans to run at all times. Continuously running the fans will impact the energy usage of the system.

Electric heaters are the most common type of defrost on low temperature applications. The evaporators must be designed and built for this type of defrost, and incorporate passages either on the face of the coil, or through the evaporator fins, parallel to the refrigeration tubing. Electric resistance heaters are placed into the provided passages and are energized to raise the temperature of the evaporator surface above freezing.

Figure 3- Latent Energy Recovery

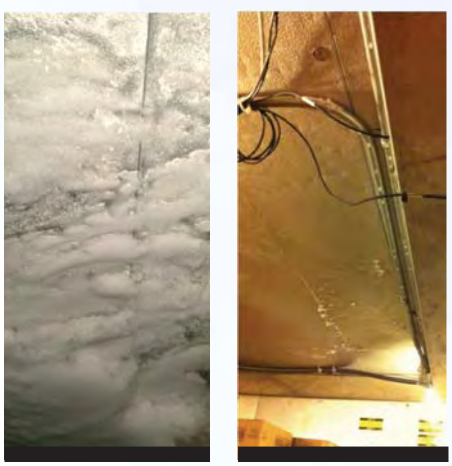


Although simple to install and control, electric defrost can be expensive. The heaters are energized at the beginning of the cycle and remain on for the entire duration of the defrost cycle. On average they use 1 kW per foot of evaporator length.

Since standard timed defrosts are usually set for 3 or more per day and may last 45 to 60 minutes, the power consumption will affect the energy efficiency. When energized, the heaters' surface temperature can exceed 300˚F. When the melting frost comes into contact with the element, it can flash into steam, creating a fogging effect. The fog will re-condense on cold surfaces in the refrigerated room, often creating unwanted ice. It is not uncommon to see ice on the ceiling of a room with this problem.

This new ice formation will not be removed during a routine defrost, so occasionally an electric defrost will be extended to try to remove this buildup. Running the heaters beyond the time needed for defrosting the evaporator creates excessive heat. By trying to fix the symptom and not the cause, damage may occur to the surroundings. **Figure 4** shows a walk-in before and after the Surveillant evaporator controller was installed. Despite the system going through over four defrosts per day for months, without Surveillant the before picture still shows ice remaining in the walk-in. Electric defrost, though simple and common, is not always controlled as effectively and efficiently as possible.

Figure 4 - Before and After Surveillant Evaporator Controller Installed (results from actual field installation)



Before **After**

Hot gas defrost is the third type of common defrost method. It is the most complex, and requires the most up front capital to install. The quality and effectiveness of this defrost method is more efficient than the other styles. In hot gas defrost, the liquid refrigerant flowing through the evaporator is interrupted and replaced by gas directly from the discharge of the compressor. This "gas" is really a superheated compressed refrigerant vapor and can easily exceed 200˚F. Since the heat source is being supplied from inside the tubes of the evaporator, it applies heat to the frost where it forms on the tube. The hot gas travels throughout the entire tubing circuit and will therefore defrost areas of the evaporator that are not reached as effectively by electric resistance heaters.

Unlike off-time defrost, during the electric heater and hot gas cycles, the fans should not only be off during the defrost cycle, but must be held off for some time after the defrost is terminated. During defrost, water is formed on the evaporator as the ice melts. Once the defrost terminates, water must be allowed to drain from the coil. This 'drain time' prevents moisture from being blown off the coil to refreeze on the cold product or other surfaces in the room. Some evaporators are equipped with a thermostat to delay starting the fans until the coil has dried or gotten cold enough to re-freeze the remaining moisture.

Within the different types of defrosts methods, there are also different types of control.

Time-initiated, time-terminated defrosts are most effective when conditions are consistent. Consistent conditions allow the minimum amount of defrosts per day with minimum amount of time. Unfortunately, refrigerated spaces rarely have consistent conditions due to space access, product loading, seasonality, etc. Due to the inconsistent conditions, the defrost schedule must be setup to handle the worst case scenario. This is inefficient most of the time.

Time-initiated, temperature-terminated defrosts are more advanced than the time-time method. Time-temperature defrost controllers can be mechanically or electronically controlled. They are more advanced than the time-time controllers. By terminating defrost on temperature, the defrost heaters reduce the addition of excess heat being transferred to the controlled space. This is better than a strictly time based system. However, this type of defrost control still requires additional, unnecessary, defrost cycles to be performed on the system in anticipation of the worst case scenario. Some, more advanced time-temperature models, measure the amount of compressor runtime to estimate the proper time to defrost the system.

Advanced time defrosts have used a variety of techniques related to measuring run time of the system, but have only had limited effectiveness when applied in the field. This type of control still relies on time. Most of these algorithms estimate the reaction of the system to a series of events. By using estimations, the system will need to plan around worst case scenarios, causing the system to be less efficient. They are also susceptible to being reset by power outages.

The Surveillant Evaporator Controller approaches defrost in a revolutionary way. Surveillant uses an advanced defrost control algorithm, eliminating the dependency on time. Instead, Surveillant monitors the systems efficiency. By monitoring the coil efficiency, Surveillant determines the optimum time for the system to run a defrost cycle.

How the Surveillant Controller Works

The Surveillant Evaporator Controller utilizes a proprietary algorithm to maximize energy efficiency, while minimizing the effects of defrosts on the space temperature.

The Surveillant controller uses a two-tier approach to extend the time between defrosts. First, it reduces the amount of frost built on the coil. This is accomplished when the controller controls the fans as discussed in the Evaporator section. Although it is intuitive that reducing frost buildup on the coil will allow the system to go longer between defrosts, the system must be able to determine the amount of frost on the coil. Instead of using a time based formula, the controller monitors the coil performance to extend the time between defrosts from hours to days, yet is smart enough to reduce the time back to hours, to adjust to changing system conditions. The second tier monitors the coil's efficiency and only calls for defrost when necessary, rather than based on the time since the last defrost.

Surveillant creates the evaporator profile from a series of measurements the controller makes and records when powering the controller initially. The controller completes a sequence of operational tests of the system, identifying a temperature relationship between the coil temperature and the space temperature. (The air sensor is located in the return air of the coil, while the coil sensor is located in the coldest point in the coil fins. See

Figure 5 - Coil and Air Sensor Locations

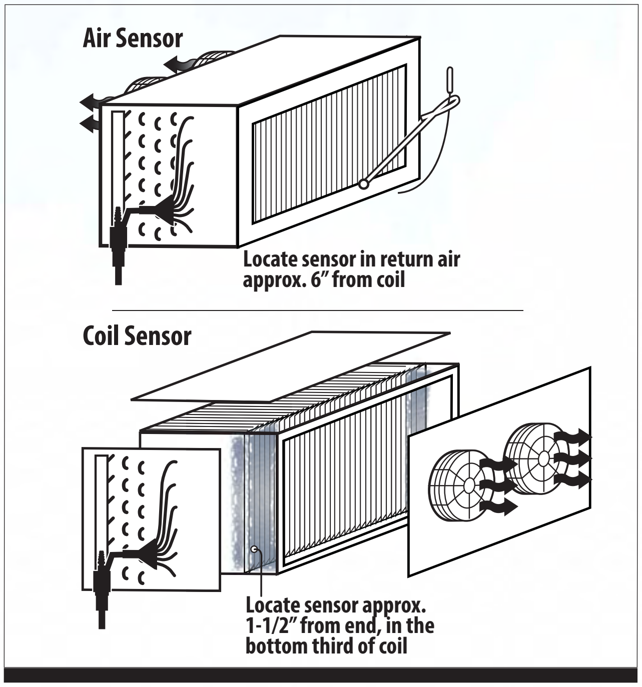


Figure 5 for an example of sensor location.) It initially brings the space down to temperature, and then defrosts the coil. This is repeated as necessary, to ensure the coil profile is accurate.

When the system is in normal operation, the controller monitors the efficiency of the coil, comparing the temperature of the coil to the space temperature. The incoming data is compared to the evaporator profile data stored in the controller's memory. Once the efficiency is determined to be outside of the acceptable limit, 90% efficiency, the Surveillant controller initializes the defrost cycle.

Figure 6 illustrates how the algorithm determines when the evaporator is losing efficiency. The sensors function together to maintain a constant measurement of the coil temperature vs. air temperature, shown as (TD_1), providing a reference point for the controller. The sensors provide the input to the algorithm to determine when the coil temperature is falling more rapidly than expected. This indicates the coil is becoming less efficient transferring heat. If the coil begins to lose efficiency, shown as (TD_2), the controller knows to initialize defrost.

Once the controller initializes defrost, it shows a distinct difference in the defrost cycle control. A traditional defrost controller will power the heaters and keep them on until it receives a signal to terminate based on time or a temperature cut out. **Figure 7** illustrates how a traditional defrost cycle operates the heaters. This type of control will remove the frost from the coil; however, it has the potential to create other issues.

One of the issues is a fogging effect. This is caused when the resistance heater surfaces become hot, often reaching 300° F. When the water dripping from the coil touches these hot surfaces, it vaporizes, creating a fog in the room. As the fog exits the coil, it will move to the coldest point in the room. This may be another evaporator coil, the product, the ceiling, etc. When the vapor refreezes it can create a buildup of frost and ice in an area of the space without defrost heaters, making it difficult to remove. Surveillant controls the defrost cycle differently.

Figure 8 illustrates how Surveillant's defrost cycle saves energy. Instead of applying power to the heaters for the duration of the cycle, the Surveillant controller carefully monitors the coil temperature throughout the cycle. As the temperature of the coil increases to a predetermined point, the controller turns off the heaters, allowing the heat in the elements to be transferred to the coil. When the heat has dissipated, the heaters are powered again to continue defrosting the coil.

The Surveillant controller manages the frost level of the coil to maintain a concise defrost cycle, returning the system to cooling the space in a time comparable to a traditional defrost cycle, while using 40% less energy than traditional control. In addition to creating a fogging effect, traditional defrost methods, using resistance heaters, waste approximately 80% heat due to high heater temperatures. Surveillant's heat recovery control reduces the heat loss to just 20%. This is a savings of 60%.

Valve Control

As a key component of refrigeration systems, expansion devices have been a focused area for improvement. The Surveillant Defrost controller offers the latest in electronic expansion valve (EEV) control technology to maximize the evaporator surface area, by maintaining precise superheat control.

Thermal Expansion Valves (TEVs) are installed on many existing units. TEVs provide consistent control on most systems and are

Theory of Operation

Figure 6 - Recognition of Necessity to Defrost

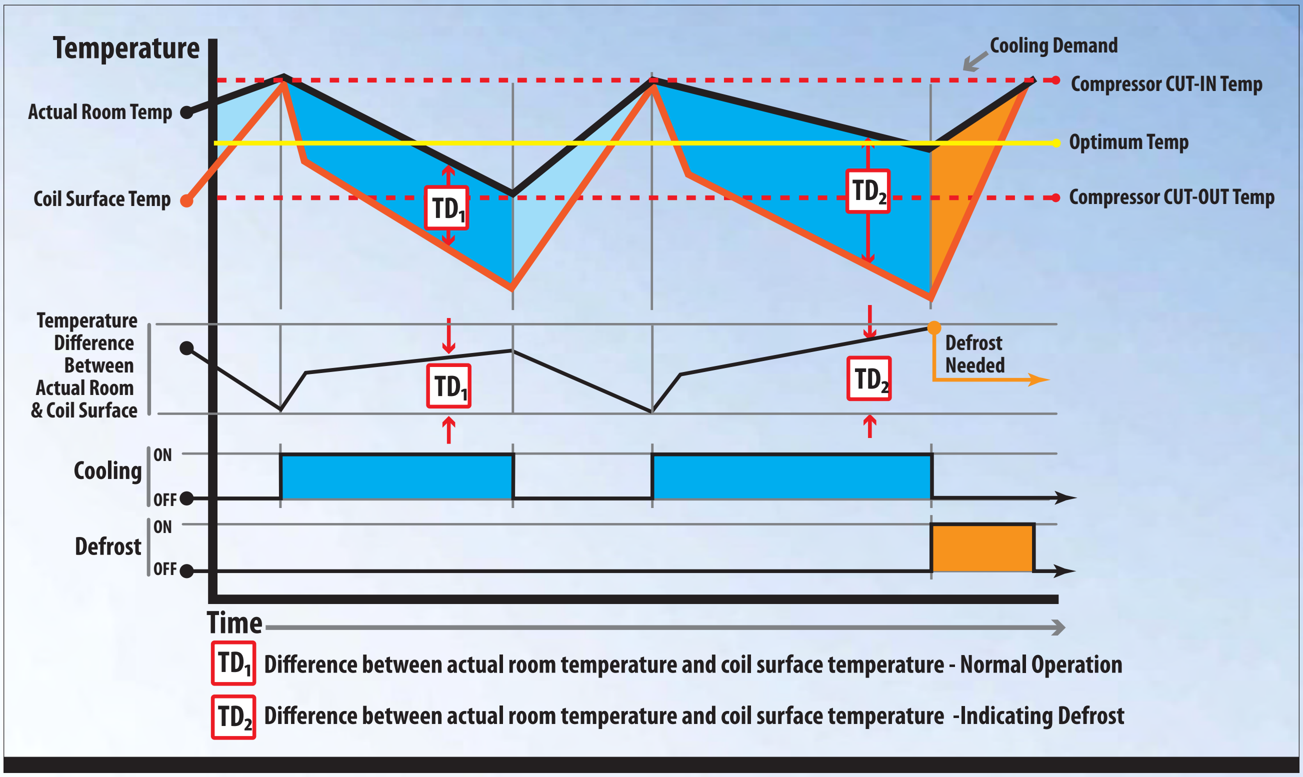


Figure 7 - Traditional Defrost Cycle

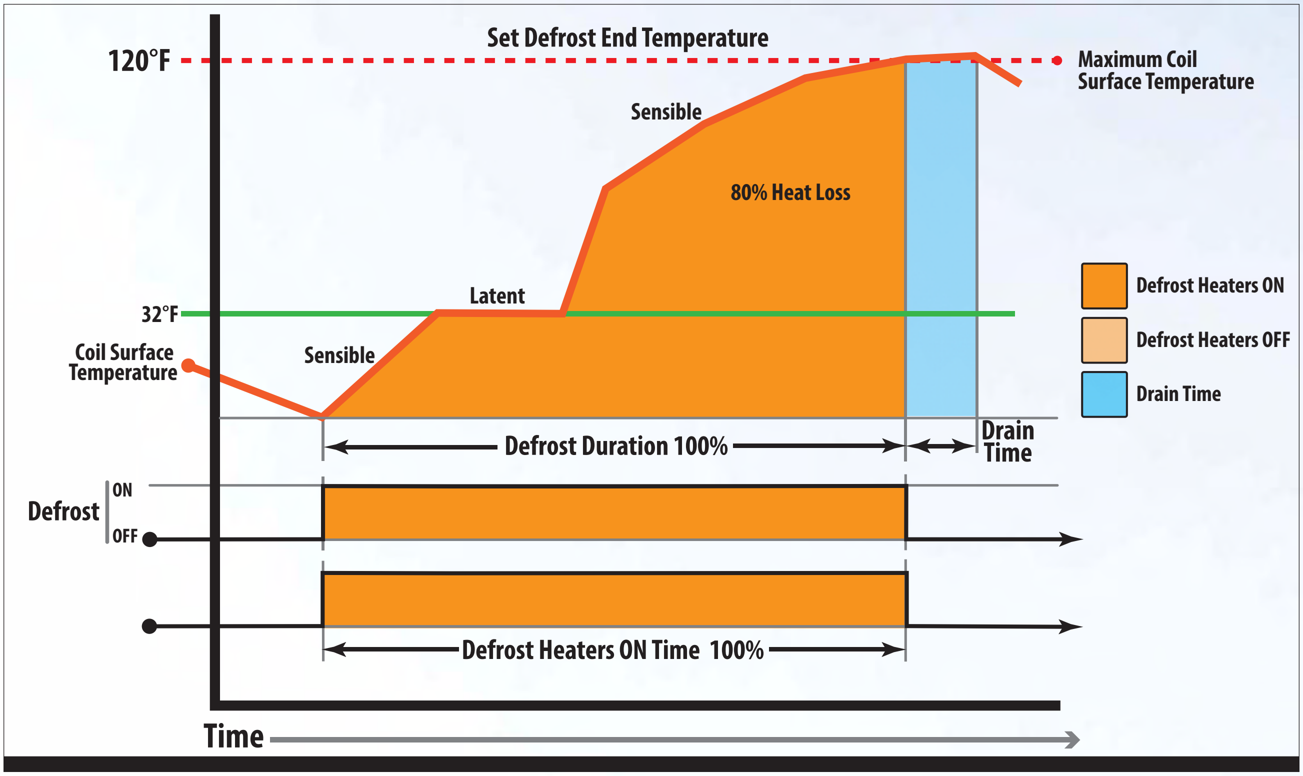
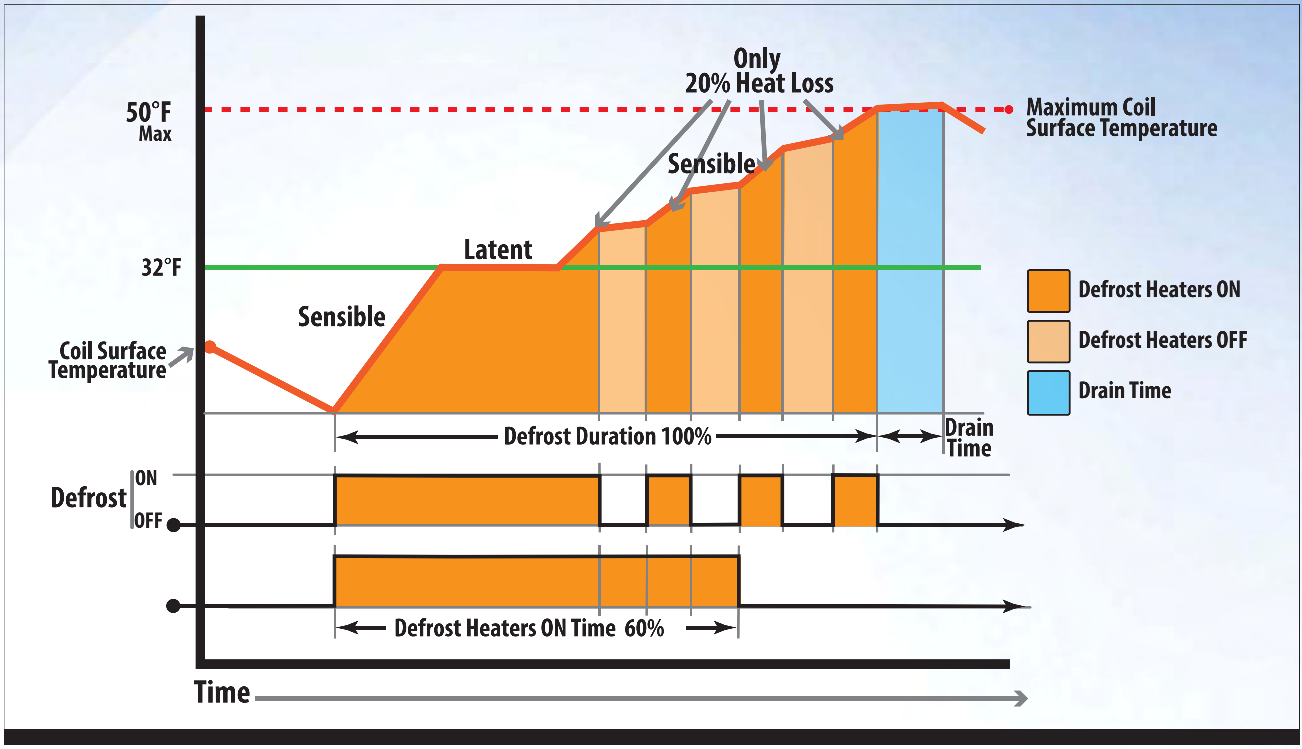


Figure 8 - Defrost Cycle Chart



not required to be replaced. TEVs are widely used due to their inexpensive nature. The Surveillant Evaporator Controller can be used effectively on these types of systems, especially when it is not feasible to break into the system.

Installing an EEV does offer advantages. Since an EEV does not require a pressure differential to operate, the EEV controls down to a fraction of the total capacity of the valve. A traditional TEV can only control down to 50% capacity, while an EEV can control down to 10%. This provides an opportunity for the system to operate at lower head pressures.

Lowering head pressure is possible during times of lower ambient temperatures. Since condenser capacities are designed for the hottest temperatures of the year, they are oversized during cooler ambient temperatures. Mechanical valves require controls to raise the head pressure to maintain the pressure drop required by the TEV. Being able to reduce the head pressure increases the energy savings of the system.

Communication

Ethernet communication continues to gain popularity in industrial and commercial refrigeration installations. One of the many benefits is that it allows owners and contractors to remotely view refrigeration system's performance. This information can be invaluable – potentially saving time and money in service calls.

Communication has been complicated in refrigeration by the many different protocols (languages) being used. Adding to the complexity, there are several options for wiring controllers in a refrigeration system. Serial bus is the topology used for most implementations. Although many are familiar with this antiquated approach, it is not the best choice in terms of costs, performance and availability. Ethernet is the standard of choice for communications in most markets.

The Surveillant Evaporator Controller approaches communications in a different way. In the Surveillant Refrigeration Network, the controller provides the ability to monitor and communicate. Surveillant controllers are Ethernet Network Devices, supporting industry standard protocols (ie:TCP/IP), can easily be plugged into an existing network, natively support remote access and can be managed by a web page.

The Surveillant Evaporator Controller is the first product to perform true demand defrosts utilizing real-time measurements of the system's performance to determine when to initiate defrost. Defrosting the system only when required reduces the number of defrosts by 84% compared to traditional control. Fewer defrost cycles also eliminates the associated temperature spikes; providing more uniform product temperature, helping reduce product shrinkage. While it is advantageous to maintain constant product temperature, the energy saved through the advanced control techniques provides further benefit by reducing overall energy usage. The combined benefit of reduced product shrinkage and reduced energy use effectively pays back the owner over and over again.