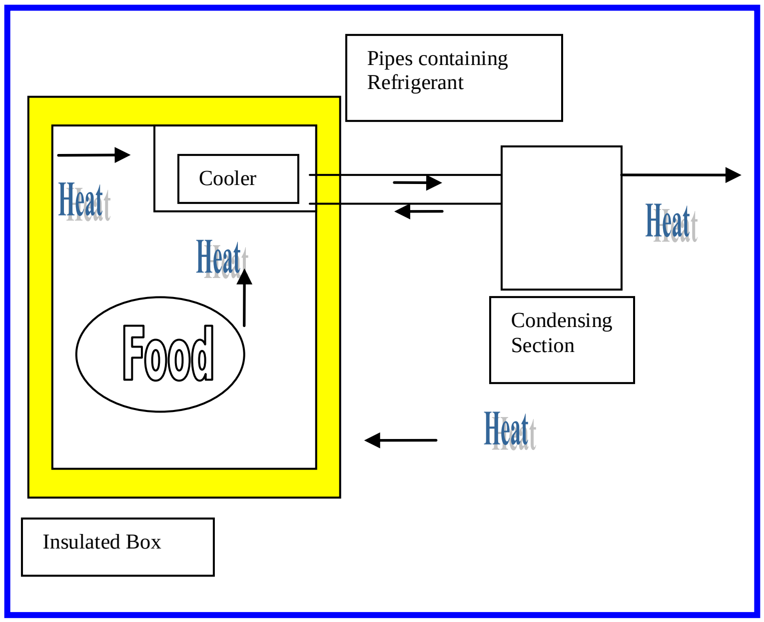
Refrigeration Systems 101

By Ron Prager

How they work, preventive maintenance, and repair strategies.

How it works:



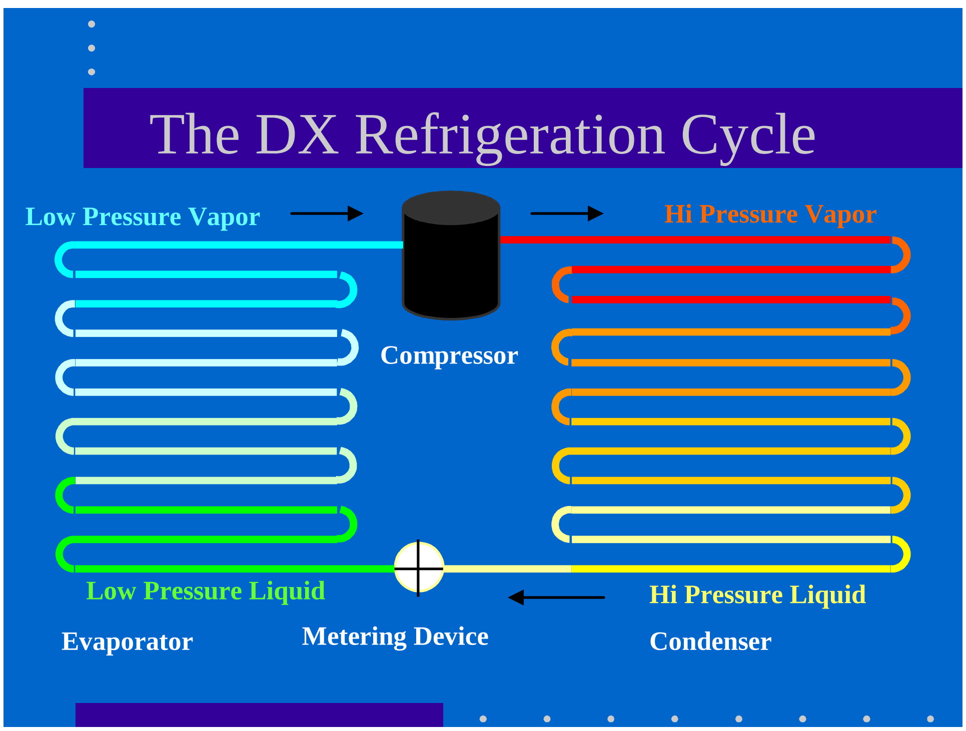
When we discuss the refrigeration process, we are actually describing the transfer of heat. In the case of food storage, as shown in the diagram on the right, we are transferring heat from the food to the air in an insulated container. We then transfer that heat from the air within the container to a cooler or an evaporator coil. The coil transfers the heat to a substance, commonly known as a refrigerant. The refrigerant further transfers this heat to a condenser coil, and this condenser transfers the heat to the air outside the insulated container

In the case of an ice machine, we are describing the transfer of heat from water to a refrigerant and from the refrigerant to the ambient air. In some cases the heat may be transferred to condenser water that is then wasted to a drain. This heat transfer process continues until; the water changes state, from a liquid to a solid. At that point the ice is harvested and dropped into a bin. You see there is really no such thing as making something cold, As we explore the refrigeration cycle, it is important that you remember that the process is actually removal or transfer of heat.
As a facility manager for restaurants, it is important that you understand the maintenance and repairs required by several types of refrigeration equipment. In order to fully grasp refrigeration malfunctions, you must first understand the process the equipment uses to transfer heat. This is known as the refrigeration cycle.

The Refrigeration Cycle:

As shown in the diagram above, in order to maintain food at a particular temperature, we must remove heat from the air surrounding the food at the same rate as the air is gaining heat. The air gains heat every time someone opens the door to our refrigerated container. In addition, heat is constantly passing slowly through the insulation in the walls, floor, and roof of the container, and any lighting or motors within the container add heat as well.. If we want to reduce the temperature of the food, we must remove heat at a rate greater that the rate of heat gain into the container. To remove heat from the air within the container we cause the air to circulate over a series of copper tubes. These tubes are bonded to aluminum fins to increase the surface area of the metal that is in contact with the air. In small containers, the air can be allowed to flow over the tubes and fins due to natural convection. This is a process where warmer air tends to rise and cooler air tends to fall due to temperature difference. If the finned tubes are mounted on the ceiling of our container, warmer air tends to rise to the ceiling and heat is transferred from this air to the finned tubes. As the temperature of the air is reduced, the air tends to fall to the floor of the container. Any product within the container will transfer heat to air that is cooler that the product. It is important to note that heat will always naturally flow from a warmer body to a cooler body. If we wish to increase the speed of the heat transfer from the air to the finned tubes, we can use a fan to increase the volume of air that passes over the fins during any time period. This fan is called the evaporator fan. Most refrigerated boxes today utilize this forced circulation in lieu of the circulation due to convection described above.

In order to cause heat to be transferred to the finned tubes, we must have a method of transferring heat from the tubes at a rate that allows the temperature of the fins to be significantly lower than the temperature of the air in the container. Another name for these finned tubes is an evaporator coil and you're about to find out why. Evaporation, or boiling is the process where a substance changes state from a liquid to a gas. If we think about water as a refrigerant, we find that while it takes one BTU of heat to raise the temperature of a pound of water one degree Fahrenheit, it takes 760 BTU's to convert one pound of liquid water into one pound of water vapor. In both cases, we only had to deal with one pound of water, but the change of state allowed us to transfer 760 times the amount of heat required to raise the temperature one degree. In the evaporator coil of a refrigeration system, we use heat that is transferred from the air in our container or box, to cause liquid refrigerant to evaporate into refrigerant vapor. This process causes a great amount of heat to be transferred from the air. It is also the reason that the coil inside a refrigerator is called an evaporator. If you have any doubt as the effectiveness of cooling with a change of state, consider the fact that your body uses this mechanism all the time. As your body overheats, you produce perspiration. This moisture evaporates on your skin and this process transfers 760 BTU's of heat from your skin for each pound of moisture that is converted from liquid to vapor.



In a refrigeration system, we choose the substance we wish to use as a refrigerant based upon its' boiling point and the quantity of heat that is required for it to change from a liquid to a gas. We can change the boiling point by changing the pressure that the refrigerant within the coil is under. Pressure cooker operation is familiar to all of us. We force water to boil at a temperature in excess of 212°F by sealing the pot of boiling water and allowing the pressure within the sealed vessel to increase. Similarly, if we choose to use Refrigerant 22 (Freon 22) in our system, we are choosing a substance that evaporates or boils at a temperature of -39°F at atmospheric pressure. If we build a system that causes the pressure in the evaporator coil to be 60 pounds per square inch, the refrigerant boils at a temperature of 34°F. We design the components of the refrigeration system and choose the refrigerant used based upon the temperature we need to maintain, and pressures that are reasonable. We might choose R22 for a refrigerator maintained at 34°F and R404A for a freezer operating at 10°F.

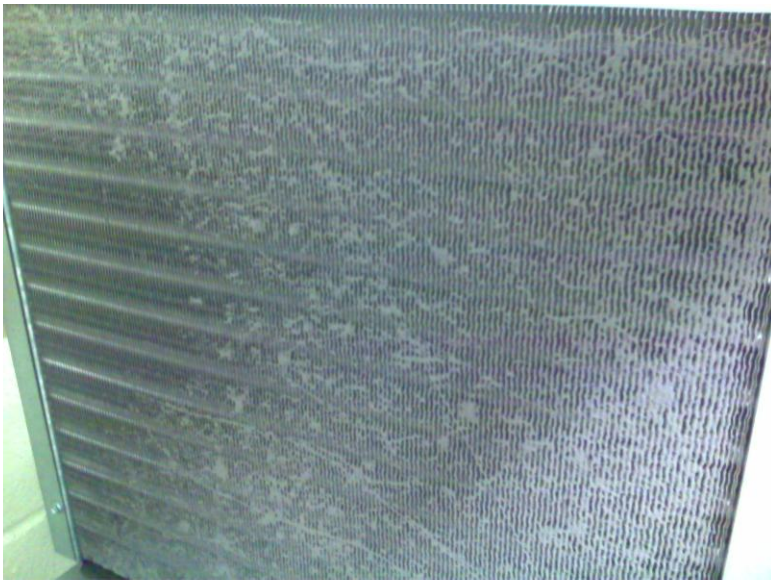
The moisture that evaporates from our bodies condenses in clouds and returns to the earth as rain at some point. Allowing the refrigerant that vaporizes within an evaporator coil to escape to the atmosphere would be extremely expensive, to say nothing of being environmentally unfriendly. We know that the evaporator coil transfers heat from air to the refrigerant. All of the other components involved in the refrigeration cycle exist to allow us to re use the refrigerant after it has been vaporized and to control the temperature at which the evaporator operates. These components allow us to operate a continuous cycle where heat is removed from air within our box and dumped to the ambient air.

Low pressure liquid refrigerant enters the evaporator coil as shown above in green and leaves the evaporator as a low pressure gas. (Blue) The low pressure gas enters the compressor. The compressor is nothing more than a motorized pump that is designed to pump a vapor. So low pressure gas enters the compressor and leaves the compressor as a high pressure gas. In order to be able to use the refrigerant in the evaporator again, we need to convert it back into a liquid. Since we added heat to the liquid refrigerant to convert it to a gas, it makes sense that we should remove heat from the gaseous refrigerant to convert it back to a liquid. Once again by choosing the pressure the refrigerant is under, we can cause the refrigerant to condense back to a liquid at a temperature that is convenient. And, guess where it condenses; in the condenser of course. Since we have lots of air available to transfer excess heat to, and we can usually rely on this air being available at a temperature not exceeding 110°F, we can design a system to condense the refrigerant from a vapor to a liquid at a temperature of around 120°F. This will allow us to transfer heat from the refrigerant via the condenser coil to air that may reach a temperature as high as 110°F. We use a fan to provide a sufficient quantity of air over the condenser for the quantity of refrigerant being condensed. This is called the condenser fan.

If you look at the diagram above, you will see that the only component we have not addressed is the metering device. This component can be a capillary tube, an expansion valve, an orifice, or any other device that controls the quantity of liquid refrigerant that flows into the evaporator. Expansion valves meter the refrigerant flow based upon the temperature of the refrigerant leaving the evaporator. Other devices just restrict the flow so that the quantity of refrigerant delivered to the evaporator changes with the difference in pressure across the metering device. It is important to remember that all of your refrigeration equipment from the largest walk in freezer to the pizza make table to the ice machine works using these same components and the same principals. In the case of an ice machine, the evaporator is designed to transfer heat from water destined to become ice rather than being designed to transfer heat from air.

Preventive Maintenance:

Catastrophic failure of a refrigeration system is usually defined as losing a compressor. Compressors are expensive , can be difficult to locate for immediate delivery, and require many hours and additional materials for replacement. If there is one thing you can do to prevent catastrophic failures of your refrigeration systems it is to keep them clean. We want clean condenser coils, clean evaporator coils, clean fan blades, clean condensate pans, and a sterile condition inside the refrigerant circuit. We spent the entire first half of this article discussing heat transfer. When we want to reduce heat transfer, we cover an object with insulation. Guess what; dirt is a great insulator. And you know what else; nothing causes a build up of dirt like cooking grease. Condenser coils must be kept clean. In addition, they must have an adequate supply of relatively cool air to operate at full capacity. Dirty condensers lead to compressors operating at pressures that are higher than they were designed for. Dirty condensers also prevent the refrigerant from condensing completely, so instead of feeding the evaporator with a steady stream of liquid, we are feeding a mixture of liquid and some hot gas. This reduces the capacity of the evaporator to remove heat. It also causes high superheat. (a second condition that can lead to compressor failure)



<u>Condenser Coil in need of cleaning.</u>

<u>Clean Condenser Coil on a relatively new unit</u>

Compressors pump refrigerant gas as stated earlier, but they also depend on the gas being a particular temperature so that the gas can help cool the windings of the compressor motor. Dirty condensers can lead to a condition known as high superheat. This is where the temperature of the gas entering the compressor is significantly higher than the temperature of the evaporating refrigerant as it enters the evaporator coil. This causes the compressor to operate at temperatures that exceed the normal range and causes damage to components within the compressor.

Dirt build-up in evaporator coils on refrigeration systems is not as large a problem as it is on air conditioning systems. This is due to the fact that the evaporator coils on refrigeration units are normally located within an enclosed box. However, the cleanliness of evaporator coils should be checked during preventive maintenance visits and the coolers should be disassembled and cleaned when the coils are found to be dirty. Dirty finned surfaces on evaporator coils reduce the ability of the coil to transfer heat from the air. This reduces system capacity and prevents complete vaporization of the liquid refrigerant in the evaporator. The compressor is designed to pump a gas. If liquid refrigerant enters the compressor, in significant quantities, a condition known as liquid slugging can occur and the internal components of the compressor can fail.

Air contains moisture and as we reduce the temperature of the air below the dew point, the moisture within the air will condense. The evaporator in a refrigeration system operates at temperatures lower than the dew point of the air surrounding the box. As doors open or as air passes through leaky gaskets, moisture enters with the air. Moisture also enters the air from the food being stored if it is not sealed in a vapor-proof container or wrapper. The moisture in the air condenses on the evaporator coil and forms liquid water if the coil is operating above 32°F or ice if the coil is operating below 32°F. In most refrigerators, this moisture drains into a pan below the evaporator coil during times when the system shuts down due to the box being at its required temperature. Freezers utilize a defrost cycle where ice that forms on the evaporator coil is defrosted by hot refrigerant gas or electric heaters at regular intervals. The moisture that drains from the coils collects in the pan mentioned earlier and is piped into a drain or into an evaporative pan outside the box containing an electric heater. Drainage components vary from system to system, but under any circumstances, it is imperative to keep all drainage components clean. Failure to do so leads to clogged drains and leakage as well as growth of algae and slime.

Speaking of algae and slime, what about ice machine cleaning and sanitizing? Ice machines should be <u>cleaned and sanitized according to the individual manufacturer's recommendations</u> with respect to frequency, method and chemicals. At a minimum, this process should be carried out at least twice a year, but it is a good idea to check local health codes to determine the required frequency and process. Water filters serving ice machines should be replace when the units are cleaned. One of the fastest ways to lose a restaurant's reputation is to have a guest see fuzzy stuff inside the ice cubes in his glass after finishing a soft drink.

In addition to keeping things clean, there are a large number of other tasks that should be included in each periodic preventive maintenance inspection. These inspections should take place between two and six times annually. The frequency will depend on your budget, traffic, geographic location, type of equipment, location of equipment, etc. I recommend that you work with your maintenance provider to determine exactly what frequency is necessary and what tasks should be performed.
Typically, tasks include:

- Check and adjust hinges, and latches and inspect door gaskets for leakage. Seemingly small items like these can lead to increased unit run time. Increased run time leads to increased energy costs and reduced life span.
- Door heaters and defrost timers and controls must be checked for proper operation to prevent a build-up of ice.
- If heated condensate pans are being used, the float switches and the heating elements must be checked.
- Box temperatures should be verified with a good digital thermometer and pressure and temperature control operation should be verified.
- If pressure taps are installed, operating pressures and sub-cooling and superheat should be checked to verify proper refrigeration cycle operation and proper refrigerant charge.
- Bearing play should be checked on both the evaporator and the condenser fan motors.
- Check and replace defective lighting components.

Any components that are found to be failing should be replaced. It is far less expensive in terms of repair costs as well as lost time, business, and food, to find these defects and repair them on a proactive basis than on an emergency basis. Remember, minor issues can lead to catastrophic failure of major components down the road if they are not dealt with quickly. Finally, catastrophic failures occur during periods of high outdoor ambient temperatures and during periods when you have the greatest quantity of product in a box. These just happen to be the times when it is most difficult to make repairs and when repairs must be completed quickly. This is not just Murphy's law. It is due to the fact that high temperatures outside the box cause the compressor to work harder than normal. Loading a box with a large quantity of product that must be reduced in temperature also loads the compressor heavily and components tend to fail when placed under heaviest load.

Strategy:

It is obvious to anyone who works in restaurant facility management, that when it comes to refrigeration, the first major goal is to maintain product at the correct temperature, meeting all health codes and passing all health inspections with flying colors. The second goal is to eliminate catastrophic system failure and resulting food loss or interruption of normal business operation. The third goal is to spend as little money as possible to obtain the first two. Good management requires developing a program and strategies that deliver the maximum value for each dollar spent while staying within budget and meeting your goals.

Things to consider when developing a strategy:

1. How much preventive maintenance is required and how much constitutes overkill on each type of equipment?
2. What equipment should be considered disposable and should be replaced without requesting a service call?
3. What preventive maintenance procedures are your in-house staff capable of performing?
4. What is the lifespan of each type of equipment at your restaurants?
5. Should your program include proactive replacement of equipment?
6. What changes can be made in future facilities to extend the useful life of your refrigeration equipment and lower maintenance costs?
7. What steps can be made to make equipment more accessible so that it receives better maintenance?
8. What extended warranties are available or provided, and are your service providers taking advantage of them?
9. What approval limits should be set; and will increasing approval limits save money or cost money?
10. What reports are required to evaluate the effectiveness of your vendor(s) and are you running them on a regular basis?
11. How much money is being spent on overtime work and how can this be limited?
12. How much time should maintenance take based on your scope of work, and how much are you paying for it?
13. Compare the lifespan of your equipment against the industry standard lifespan.
14. Are there specialized parts that are difficult to obtain for some of your systems and should you or your vendor consider stocking these parts?
15. How much of the work required to manage refrigeration service and maintenance is your staff capable of performing, and does your staff have the required expertise?
16. If you cannot secure the funds required to bring your equipment up to desirable levels immediately, develop a three or five year plan to meet your goals.
17. What back up plans do you or your vendor have in place to deal with catastrophic failure of a walk-in freezer or refrigerator assuming that it may take 48 hours to get the equipment operational?
18. What equipment fails most often and what steps can be taken to improve reliability?
19. When emergency service is required, what is the expectation in terms of response time and does your vendor meet this requirement?
20. How will the phase out of R22 be dealt with in your strategy?

There will be many other things to consider that are based on the type of food served, the particular equipment that is 100% essential to business operation, and the estimated cost of downtime for each piece of equipment. We suggest that you work closely with your vendor(s) to develop a strategy, protocols and preventive maintenance work scope based upon your experience, needs and budget. Evaluate the program on an annual basis to determine what changes need to be made. One of the best tools to use to evaluate the program is a spreadsheet that breaks down all repairs by type of failure. Knowing the number of failures of each component, and the cost of these failures will help you to determine what changes should be made in terms of equipment purchase, maintenance procedures, and operating protocol.