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REFRIGERATION SYSTEM BASICS AND ENERGY EFFICIENT MEASURES

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Cody Meschke, PE

Center for Energy and Environment

Welcome all to this webinar on the fundamentals of refrigeration systems and energy efficient measures that can be implemented at various applications.
This will be an approximately 4 hour training session with a break halfway in between.

Before we get started I wanted to do a quick poll for those who are attending this webinar on what your backgrounds are. Are you an engineer, sales representative, technician or a different background.
It helps give me an idea of the audience I'm speaking to.
There will be a poll in the google meet. Please pick the best option that applies to you.

What is your work/technical background?

1. *Engineer*
2. *Sales Rep*
3. *Technician*
4. *Other*

Learning Objectives

- Refrigeration Fundamentals
  - Refrigeration Cycle and How It Works
  - Components
- Refrigeration System Applications
  - Ice Arenas
  - Grocery Stores
  - Industrial Cold Storage
- Energy Efficient Measures
  - Description
  - Identifying and Implementation
  - Energy Savings and Benefits

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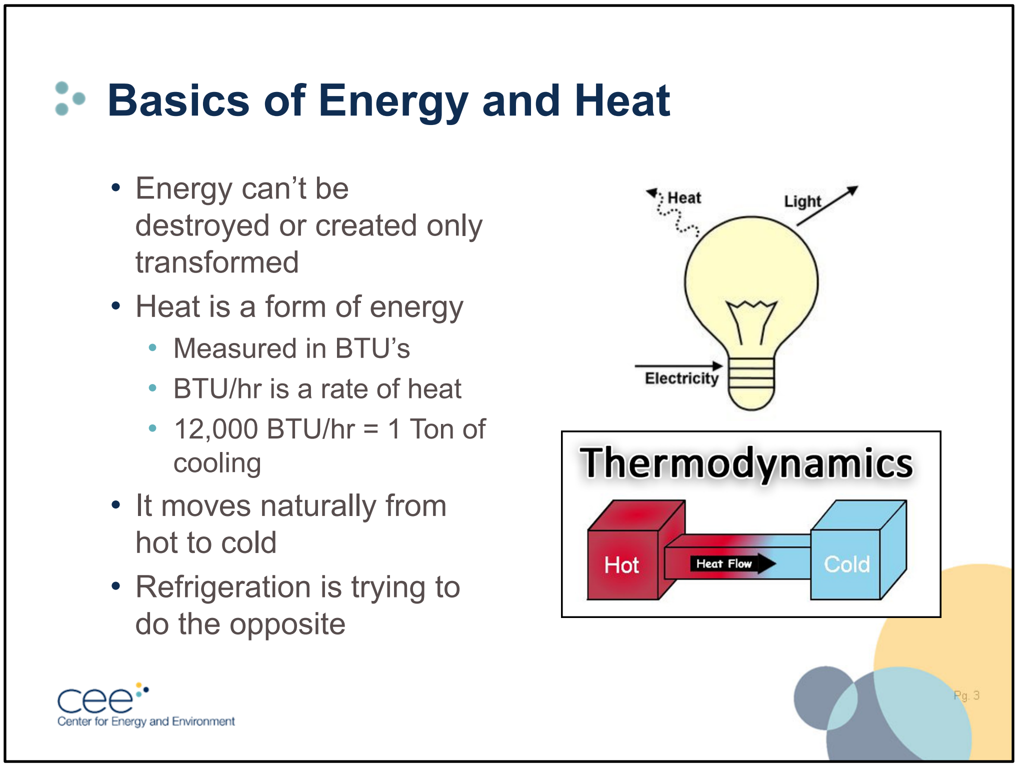
Over the course of this webinar, I will be going over three main objectives.

First, we will look at how refrigeration works and the science behind it.
We will also look at common types of refrigerants.
We will then explore, at a high level, the main components of a refrigeration system and how they function separately and together.

Next, we will go over the three main types of refrigeration system applications, ice arenas, grocery stores and industrial cold storage.
The goal is to be able to provide you enough information so that you can identify the components that are commonly found in each application and how the systems operate when you're onsite at one of these facilities.

Finally, we will review energy efficient measures that can be implemented in these different applications.
These measures focus on improving the efficiency and operation of the components individually and as a whole.
A few measures pertain specially to one of the three applications mentioned earlier but most can be implemented in all three.

Please feel free to ask questions in the chat as we go along.
Myself or Russ will try to answer these questions either at an appropriate time during the presentation or follow up with you afterwards



Before we discuss what the refrigeration cycle is, we need to review a few concepts on heat and energy.

First, any form of energy can't be created or destroyed. It must be transformed from something else.
For example, the current figure on the slide shows light and heat from a light bulb that comes from the electricity provided to it.
Energy in the form of electricity is converted into light and heat is emitted from the bulb.

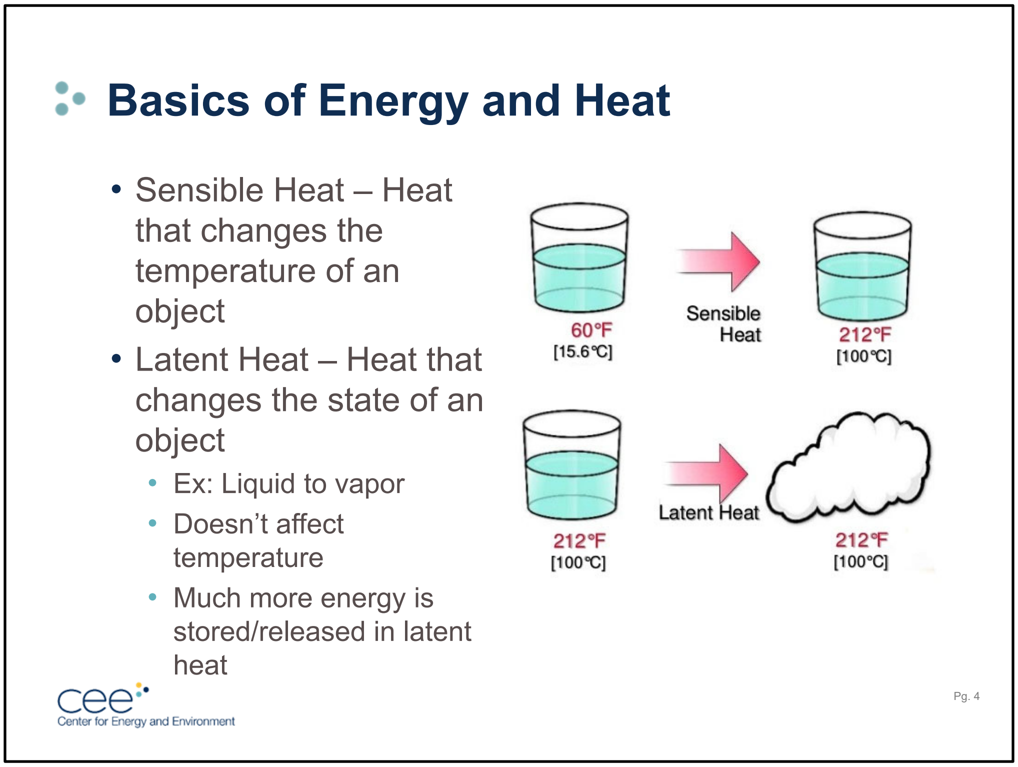
Heat is a form of energy. It is normally measured in btus, which stands for British Thermal Units.
1 BTU is the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.
It can also be a rate of heat, expressed as btu/hr.
The equipment we will discuss later typically expresses energy in either btu/hr or Tons of cooling.
Both express how much heat can be removed or added in an certain amount of time.

A ton of cooling is equal to 12,000 btu/hr and has nothing to do with the weight of an object.
For example, you may have heard someone mention a piece of equipment has a capacity of 5 Tons.
This means it can provide 60,000 btu/hr of cooling to a space or object.

In other words, it can remove this much heat from the space.

Heat always flows naturally from hot to cold.
The goal of a refrigeration system is to take heat from a space or object you're trying to keep cold and transfer it to something else that is generally warmer than the cold object.
This is the opposite of how heat naturally moves.

A useful analogy is to think of a refrigeration system as moving water uphill from a low temperature, bottom of the hill, to a high temperature, top of the hill.
To do this requires work and the amount of work increases as the size of the hill increases.
I'll describe where this work comes from but first I want to explain the two types of heat.

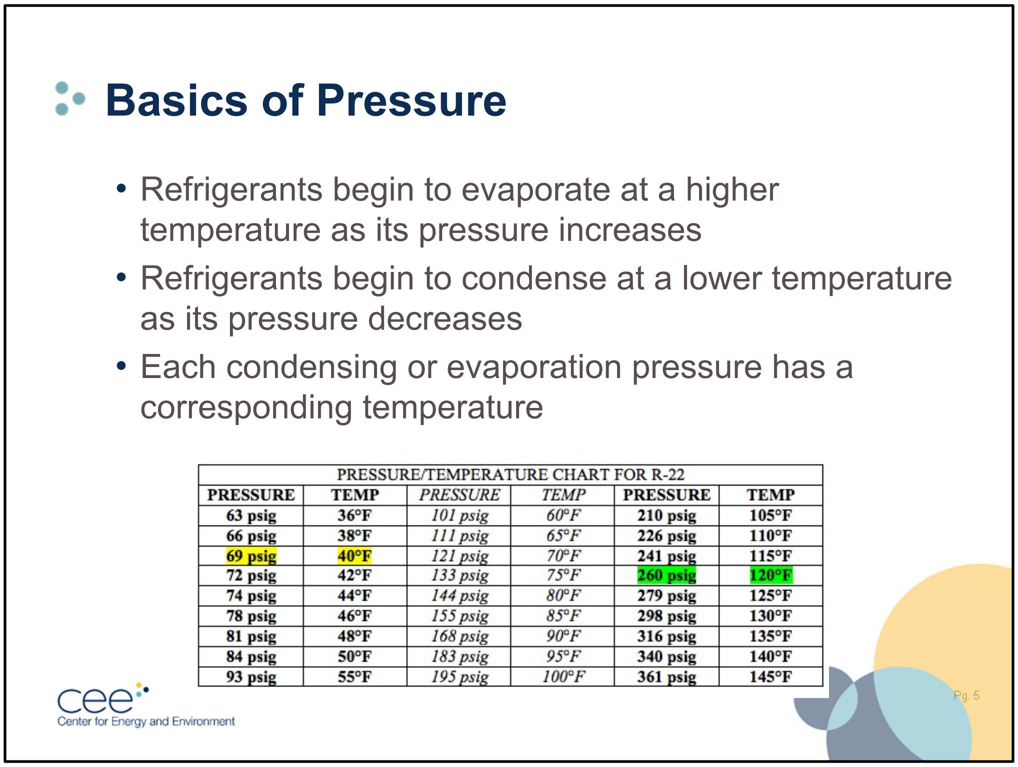


The first is sensible heat which is heat that changes the temperature of an object.
The top portion of the figure on the slide shows an example of heating a glass of water from 60°F to 212°F.
Sensible heat caused only the temperature to change.

The second is latent heat which is heat that changes the state of an object.
When I say "state" I'm referring to the current form of the object, whether it's a solid, liquid or vapor.
Latent heat does not change the temperature of the object.

The bottom portion of the figure on the slide shows an example of latent heat.
The water has been heated to 212°F by sensible heat.
All additional heat added to it will be used to begin changing its state from a liquid to vapor.
Once enough heat has been added, all the liquid water will change to water vapor but will still be at 212°F.

A lot more energy is required to change the state of an object than to raise its temperature.
This is a key fact to remember in refrigeration that we will discuss again shortly but for now remember that using latent heat is much more efficient than using only sensible heat in refrigeration.



PRESSURE/TEMPERATURE CHART FOR R-22					
PRESSURE	**TEMP**	*PRESSURE*	*TEMP*	**PRESSURE**	**TEMP**
63 psig	**36°F**	*101 psig*	*60°F*	**210 psig**	**105°F**
66 psig	**38°F**	*111 psig*	*65°F*	**226 psig**	**110°F**
69 psig	**40°F**	*121 psig*	*70°F*	**241 psig**	**115°F**
72 psig	**42°F**	*133 psig*	*75°F*	**260 psig**	**120°F**
74 psig	**44°F**	*144 psig*	*80°F*	**279 psig**	**125°F**
78 psig	**46°F**	*155 psig*	*85°F*	**298 psig**	**130°F**
81 psig	**48°F**	*168 psig*	*90°F*	**316 psig**	**135°F**
84 psig	**50°F**	*183 psig*	*95°F*	**340 psig**	**140°F**
93 psig	**55°F**	*195 psig*	*100°F*	**361 psig**	**145°F**

Next, we're going to discuss pressure, how it relates to temperature and when things condense, change to a liquid, and evaporate, change to a vapor.

A refrigerants evaporation point, or the temperature it will begin to boil, will be higher as the pressure of the refrigerant increases.
A refrigerants condensing point, or the temperature it will begin to become a liquid, will be lower as the pressure of the refrigerant decreases.
This will become important when we analyze the main components of a refrigeration system and their energy use.

At each of these condensing and evaporation pressure points there is a corresponding temperature.
For example, the table on the slide shows the corresponding temperature of the refrigerant, R22, at its condensing and evaporation pressures.
Taking the example highlighted in yellow on the table, the refrigerant, R-22, will begin to evaporate at 40˚F when its pressure is 69 psig.
Likewise, if we look at the values highlighted in green on the table, it will begin to condense at 120˚F when its pressure is 260 psig.

Basics of Pressure

- Condenser (Head/Compressor Discharge) Pressure
  - Condenser Saturation Temperature (CST)
- Evaporator (Suction) Pressure
  - Saturated Suction Temperature (SST)

PRESSURE/TEMPERATURE CHART FOR R-22

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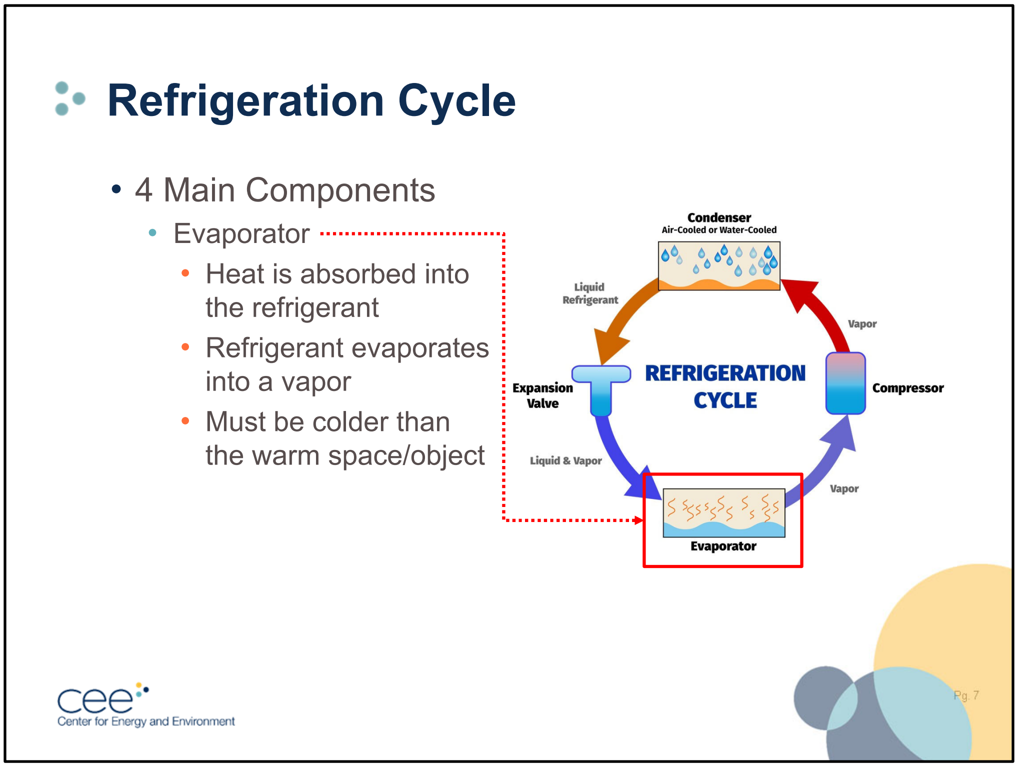
When discussing refrigeration systems there are a couple of common names given to these corresponding pressures and temperatures that are good to know as they can be used interchangeably.

Condenser pressure is the pressure at which the refrigerant will begin to condense and change into a liquid in the condenser.
It can also be called head or compressor discharge pressure as this is the pressure at the discharge of the compressor.
The temperature at this pressure is known as the condenser saturation temperature.

Evaporator pressure is the pressure at which the refrigerant will begin to evaporate and change into a vapor in the evaporator.
It can also be called suction pressure as it is the pressure at the inlet of the compressor which we will discuss later in the presentation.
The temperature at this pressure is known as its saturated suction temperature.

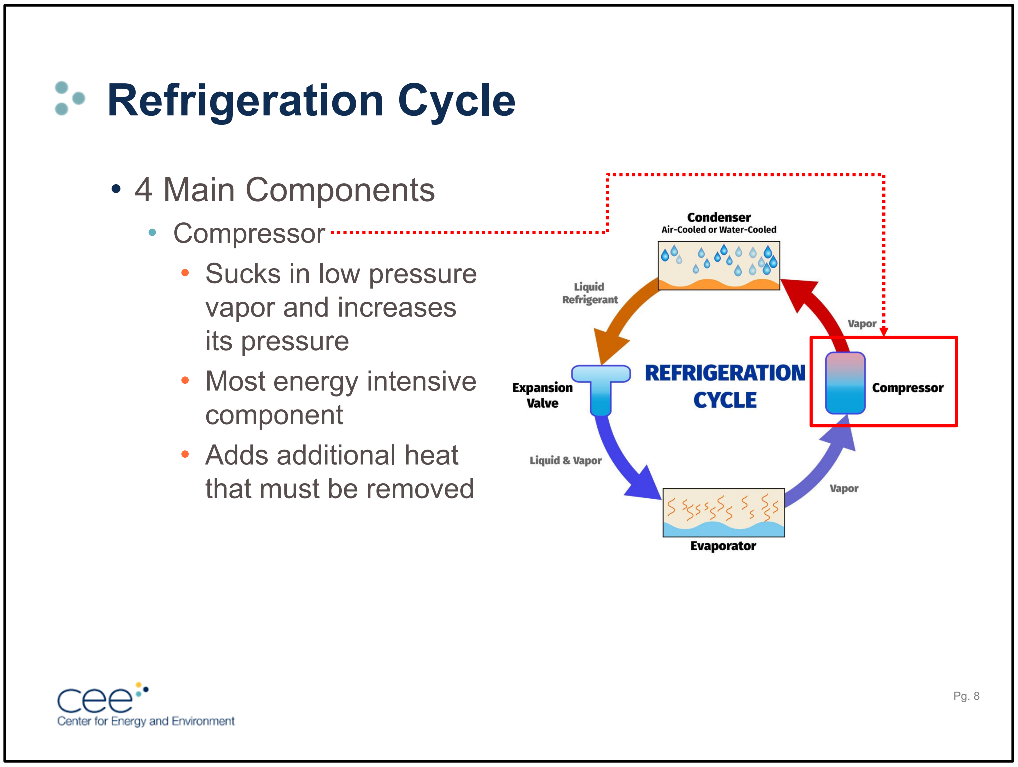
These terms can be used interchangeably depending on who you are speaking to, but they all refer to the same point at which the temperature or pressure of the refrigerant is at.



Now that we have a basic understanding of heat and pressure, we will look at the refrigeration cycle and what occurs at each point.

There are four main components in every refrigeration system; an evaporator, compressor, condenser and expansion valve.

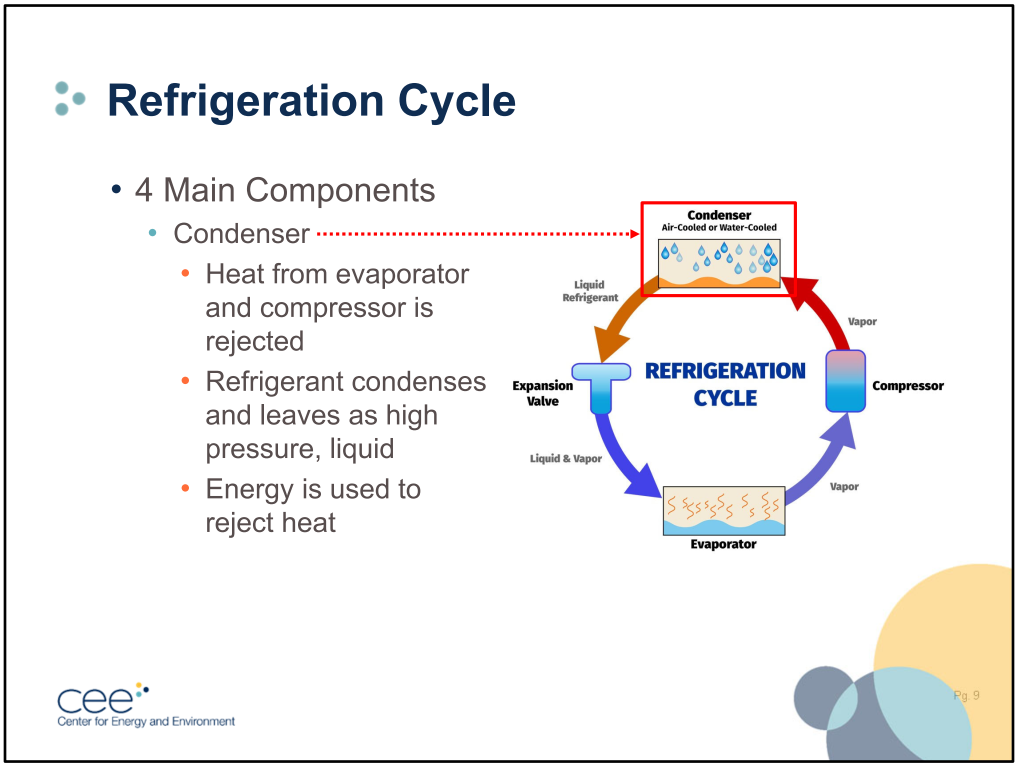
We will start at the evaporator.
The evaporator absorbs the unwanted heat from the space or object we are trying to keep cold.
The figure on the slide shows the change of the refrigerant as it passes through the evaporator.
The refrigerant changes from a mixture of liquid and vapor to all vapor as it absorbs the heat.
For the heat to be transferred to the refrigerant, the refrigerant must be colder than the object or space temperature.



Once the refrigerant has absorbed the heat in the evaporator, it then moves to the compressor.
The figure on the slide, shows that at this point the refrigerant is all vapor and is at a low pressure.
It is sucked in by the compressor and the compressor raises its pressure to the condenser pressure at the condenser.
At the discharge of the compressor, the refrigerant is still a vapor but is very hot.
It can be in the range of 190°F to 210°F for R22.

A substantial amount of work is required for the refrigeration system to work as we are trying to essentially move heat uphill.
The compressor consumes the most energy as it is trying to force the heat uphill. The larger the hill, the more energy the compressor will consume.

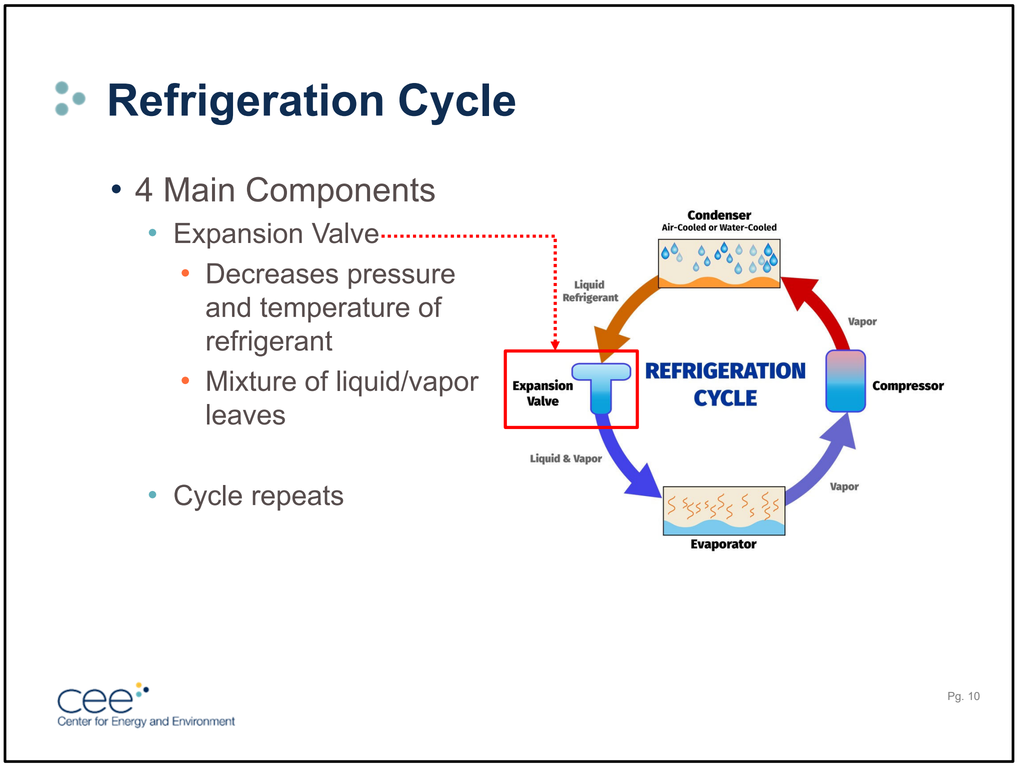
Because of this work, some of the energy from the compressor is transferred to the refrigerant as additional unwanted heat.
This must be removed in addition to the heat absorbed in the evaporator. This leads us to the third component the condenser.



The condenser is the component that rejects or removes the heat that was absorbed from the evaporator and added by the compressor.
Typically this heat is rejected to the outside air.

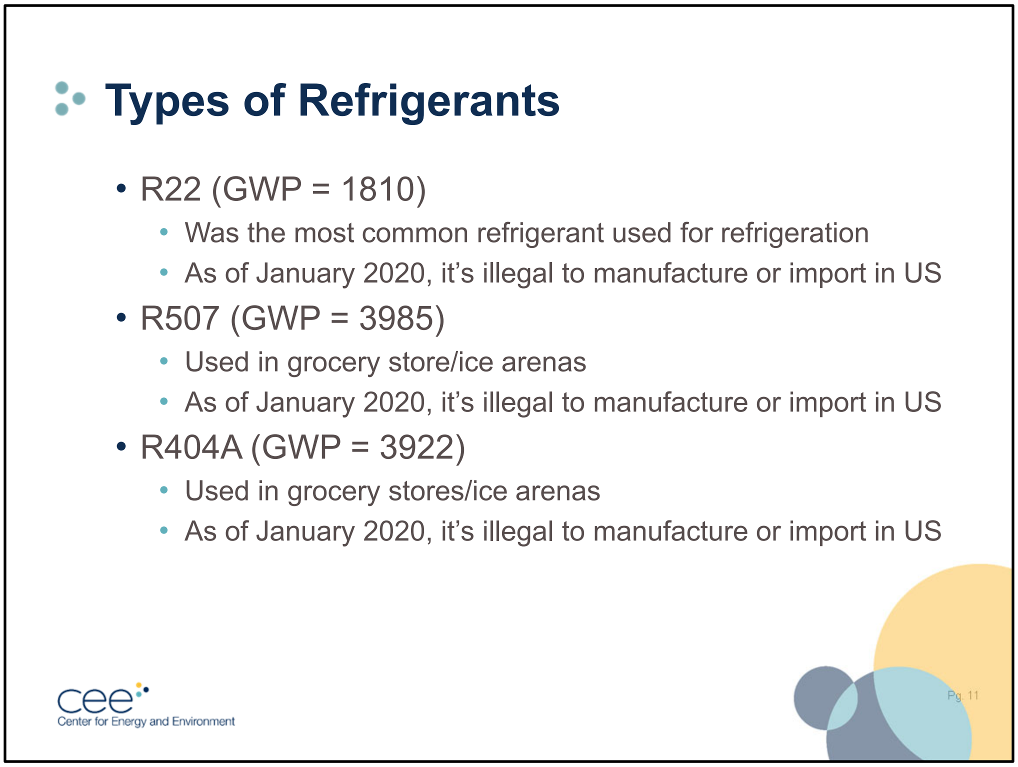
Referencing the figure on the slide again, the refrigerant will enter the condenser as a high pressure and high temperature vapor.
Again, the refrigerant must be a higher temperature than the outside air temperature in order for the heat to move.

As the refrigerant flows through the condenser and releases its heat, it will condense and change from a vapor to a liquid.
It will leave as a high pressure, medium temperature liquid.
Energy is required at the condenser in order to release this heat.
This is normally in the form of fans that move outdoor air over the refrigerant to help with removing the heat.



The final component is the expansion valve.
This is a small device that will decrease the pressure, and correspondingly its temperature, as the refrigerant is metered through it.
The figure on the slide shows that the refrigerant will expand or drop in pressure, hence the name of the device, and leave the expansion valve as a low pressure and low temperature mixture of liquid and vapor.
It will then enter the evaporator and the cycle is repeated.

The cycle is simple when reviewing it on paper, but the difficult part is ensuring the system operates efficiently as a whole.
Before we go into more detail on the four components of the refrigeration cycle, we will review common refrigerants used for refrigeration.



First, I'm going to define what Global Warming Potential or GWP is as it is becoming more important in the refrigeration field.

GWP is a measure of how destructive a climate pollutant is compared to carbon dioxide, which has a value of 1, over a period of 100 years.
The higher the value, the more warming the gas can cause to the climate.
For example R22's GWP is 1810 which means that it will cause 1810 times as much warming as CO_2 over a period of 100 years.

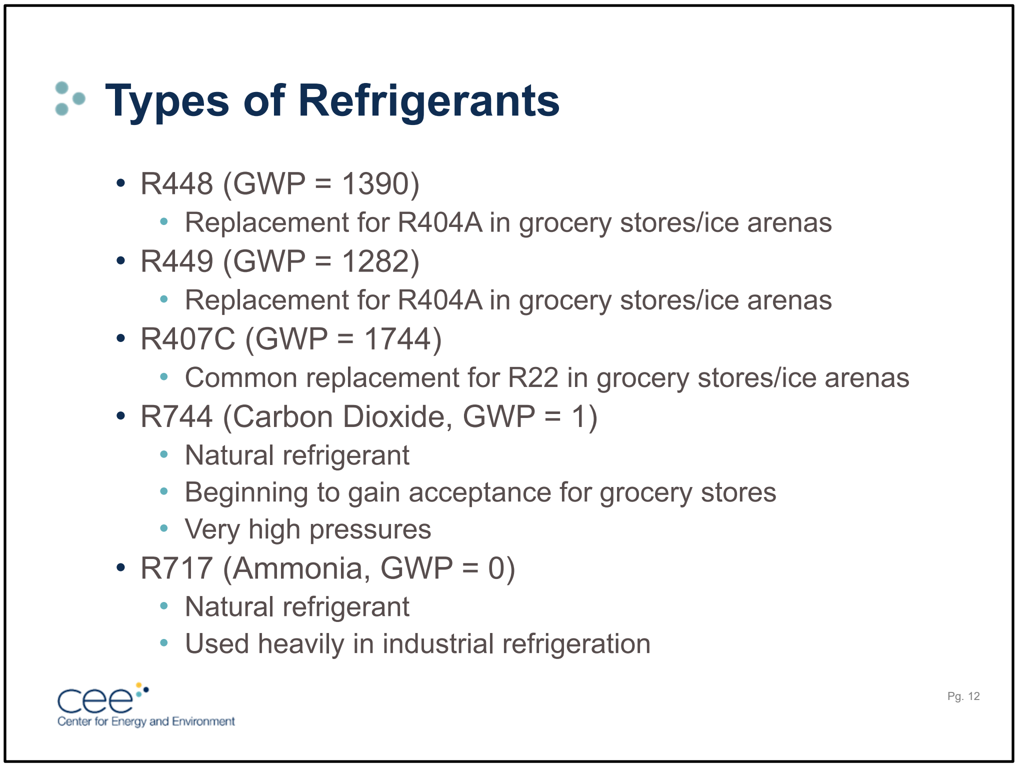
This is important to know as the industry moves to using refrigerants with low GWP's and phasing out refrigerants with high GWP.

Now let's discuss the three main refrigerants that were commonly used but are now prohibited from being manufactured or imported.

The first is R22.
This has been the most common refrigerant used since the refrigeration cycle was first developed.
As of January 2020, it is now illegal to manufacture or import in the US.
The refrigerant can still be used and reclaimed refrigerant can be sold but no new R22 can be created.

Two additional refrigerants that are prohibited to be manufactured or imported are R507

and R404A which were common refrigerants for grocery stores and ice arenas refrigeration systems.
Both of these have very high GWP’s which is the reason they are being phased out.



These next refrigerants, at the moment, are still able to be manufactured in the US for refrigeration.

R448 and R449 are both common replacements for R404A used in grocery stores or ice arenas.
They have a GWP of 1390 and 1280, respectively.

R407C is currently a common replacement for R22 systems used in grocery stores or ice arenas.
It has a GWP of 1744.

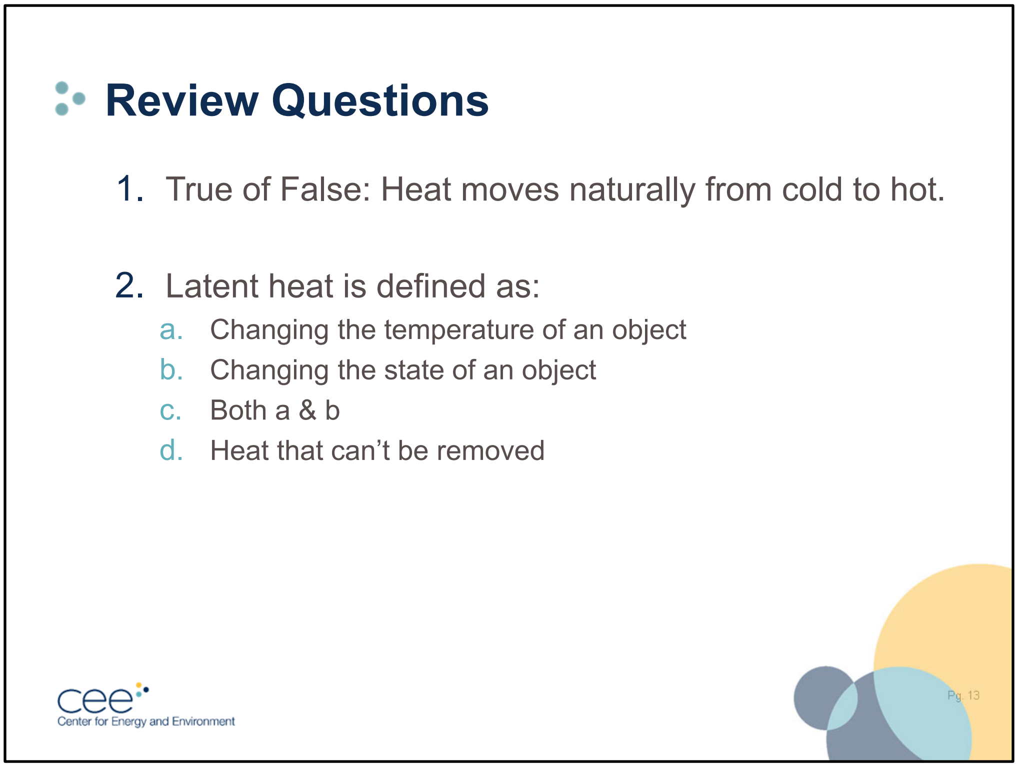
The next two refrigerants are known as natural refrigerants as they can be found in nature and do not have to be created.

The first is R744 which is Carbon dioxide or CO2.
CO2 systems are beginning to gain acceptance and be used for grocery store applications as they do not affect the climate like other refrigerants and offer great heat removal capabilities.
CO2 systems operate at very high pressures compared to other refrigerants which makes some people hesitant to implement.
They can reach pressures of 1000 psig and above at certain operating points while other refrigerants max out in the 200 psig range.

The final refrigerant R717 or Ammonia is heavily used in industrial refrigeration.
It has a GWP of 0 meaning it is environmentally benign.
It also has great heat removal capabilities.
Ammonia is hazardous in large quantities and leak detection systems are required for any system.

Now that we've covered the basics of refrigeration I'm now going to move into discussing the individual components in more detail.
Before that are there any questions on the topics we've covered?

If not, I have a few review questions on the topics we've covered to help you remember a few of the main points.



1. False

2. B

These questions will be asked in the google poll and participants will put there answer in the poll prompt.

Review Questions

1. Which component of the refrigeration cycle removes the heat from the warm space to the outside air?
    a. Compressor
    b. Condenser
    c. Expansion Valve
    d. Evaporator

2. What refrigerant has a GWP of 1?
    a. R22
    b. R410A
    c. CO_2
    d. R404A

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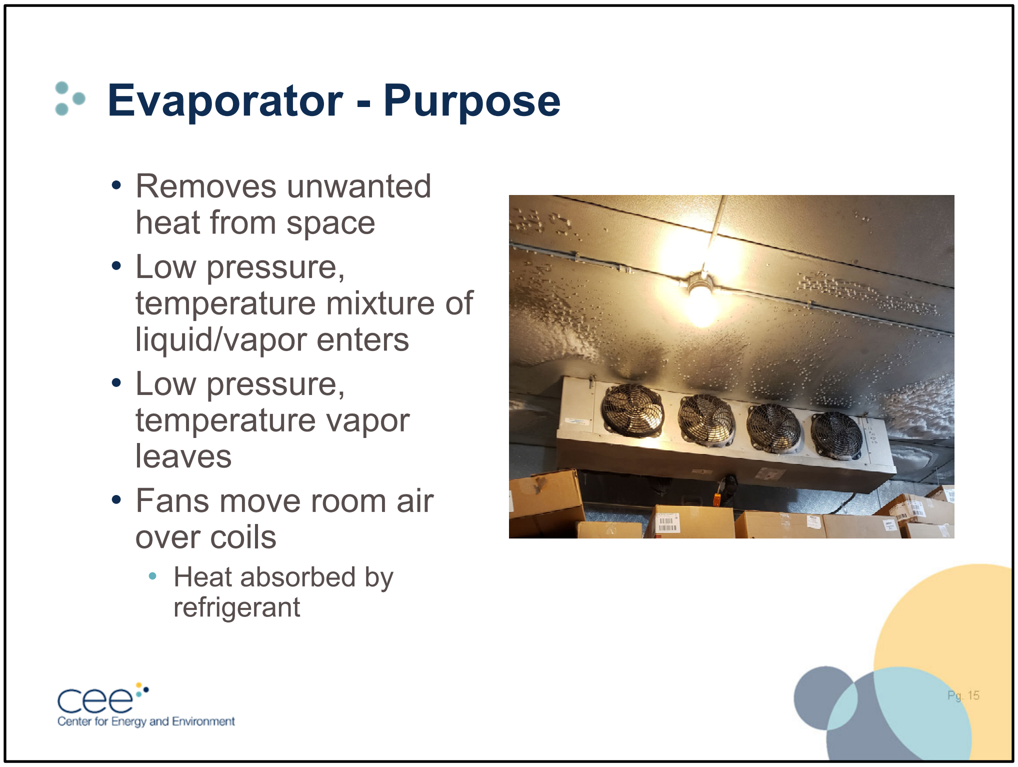
1. B

2. C

These questions will be asked in the google poll and participants will put there answer in the poll prompt.



We will now turn our focus on discussing in more detail the four basic components in a refrigeration cycle.
We will start with the evaporator.

Our focus will be on evaporators seen in grocery stores and industrial applications as ice arenas use a different type of evaporator. It performs the same function but operates a little differently.
We will discuss this type of evaporator when reviewing the three different refrigeration applications.

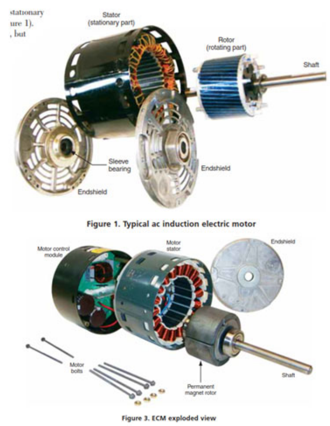
The picture on slide shows what a typical evaporator looks like for a grocery store.

The purpose of the evaporator is to remove the unwanted heat from a space.
Here the refrigerant will enter at a low pressure and temperature mixture of liquid and vapor from the expansion valve.
As it moves through the evaporator, it absorbs heat from the space, and evaporates into a vapor as it leaves.
Remembering our discussion on latent heat, the refrigerant can absorb a lot of energy as it changes from a liquid to a vapor.
Another key takeaway is the saturated suction temperature of the refrigerant, must be lower than the room temperature in order to absorb the heat.

To assist with the movement of heat from the space to the refrigerant, fans are used to blow the room air over the refrigerant, providing additional help in absorbing the heat.

Evaporator - Components

- Fan Motor Efficiency
  - Shaded Pole – 30%
  - Permanent Split Capacitor (PSC) – 60%
  - Electronically Commutated Motor (ECM) – 80%
- Coil
  - Refrigerant flows through tubing
  - Fins placed on tubing to increase transfer of heat



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Evaporators are relatively simple pieces of equipment that have a few key components worth discussing.

The first being the fan and its motor.
There are three types of motors that can be used with evaporator fans.

One is shaded pole motors which are the least expensive and most inefficient.
Their efficiency is typically around 30% which means 30% of the electricity that is input into the motor is used to operate it.
The other 70% is lost to things such as heat or sound.

Second, is a Permanent Split Capacitor or PSC motor, which is shown in the figure on the slide.
It is like a shaded pole motor in how it works but is a little more efficient, approximately 60%.

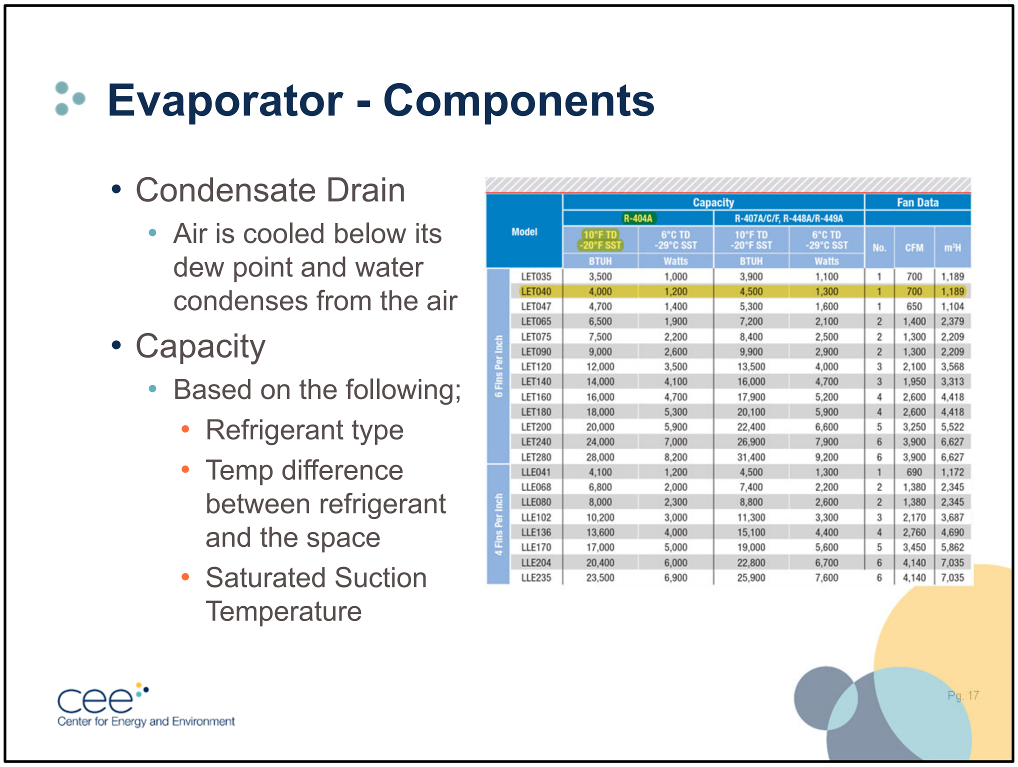
Without delving to far into the electrical aspect of the motors, I will briefly describe how these motors work and reference the figure on the slide, which shows the components of an AC motor, for explaining the different parts.
Both motor types use alternating current (AC) to energize the motor.
An AC motor creates a magnetic force in the stator, the large black cylindrical device with orange wiring, which remains stationary.
This magnetic force causes the rotor, the blue cylindrical device, and thus the shaft to

rotate.
The motor operates at a single, constant speed.
These are the most common motors found in evaporators especially older models.

The third type are Electronically Commutated Motors or (ECM) which operate differently then the prior two.
The figure on the slide shows an exploded view of an ECM and its components.
An ECM uses a control module, the brains, to operate the motor. In the figure it is the back half of the motor.
Power is supplied to the control module which is converted from AC voltage to direct current (DC) in order to be used by the electronic controls.
This gives the motor a much higher efficiency, approximately 80%.
ECM's operate at a single, constant speed like the previous two motors but have the capability, with the control module, to operate at varying speeds.
Some controllers will take advantage of this and the evaporator fans will be able to operate at different speeds when full speed isn't required.
This makes ECM's a worthwhile investment in evaporators for both new and existing.

The next component in an evaporator is the coil. The coil consists of tubing, commonly made of copper, that the refrigerant flows through.
The fans blow air over the tubing to assist in the refrigerant absorbing the heat.

Closely spaced fins are placed on the tubing to improve the transfer of heat.
The closer the fins are together the better the transfer of heat from the air to the refrigerant.
Standard fin spacings are 4 to 6 fins per inch or FPI.
The downside of having closer spaced fins is there is a higher chance of the fins becoming clogged in some areas, reducing the absorption of heat.



	Model	Capacity				Fan Data		
		R-404A		R-407A/C/F, R-448A/R-449A				
		10°F TD -20°F SST	6°C TD -29°C SST	10°F TD -20°F SST	6°C TD -29°C SST	No.	CFM	m³H
		BTUH	Watts	BTUH	Watts			
6 Fins Per Inch	LET035	3,500	1,000	3,900	1,100	1	700	1,189
	LET040	4,000	1,200	4,500	1,300	1	700	1,189
	LET047	4,700	1,400	5,300	1,600	1	650	1,104
	LET065	6,500	1,900	7,200	2,100	2	1,400	2,379
	LET075	7,500	2,200	8,400	2,500	2	1,300	2,209
	LET090	9,000	2,600	9,900	2,900	2	1,300	2,209
	LET120	12,000	3,500	13,500	4,000	3	2,100	3,568
	LET140	14,000	4,100	16,000	4,700	3	1,950	3,313
	LET160	16,000	4,700	17,900	5,200	4	2,600	4,418
	LET180	18,000	5,300	20,100	5,900	4	2,600	4,418
	LET200	20,000	5,900	22,400	6,600	5	3,250	5,522
	LET240	24,000	7,000	26,900	7,900	6	3,900	6,627
	LET280	28,000	8,200	31,400	9,200	6	3,900	6,627
4 Fins Per Inch	LLE041	4,100	1,200	4,500	1,300	1	690	1,172
	LLE068	6,800	2,000	7,400	2,200	2	1,380	2,345
	LLE080	8,000	2,300	8,800	2,600	2	1,380	2,345
	LLE102	10,200	3,000	11,300	3,300	3	2,170	3,687
	LLE136	13,600	4,000	15,100	4,400	4	2,760	4,690
	LLE170	17,000	5,000	19,000	5,600	5	3,450	5,862
	LLE204	20,400	6,000	22,800	6,700	6	4,140	7,035
	LLE235	23,500	6,900	25,900	7,600	6	4,140	7,035

As the warm air passes over the evaporator coil, it reduces in temperature and eventually is cooled below its dew point.
The dew point is the temperature at which water will begin to condense out of the air.
We don't want water being blown out of the evaporator into the space.
To remove this water, there will be a drain from the bottom of the evaporator called a condensate drain.
The condensate drain will be routed outside of the space to an open drain.
The drain line must slope down as gravity is used to drain the water.

The next item isn't a physical component of the evaporator but affects how well it will operate in a certain space.
All evaporators have a certain cooling capacity, or how much heat they can remove from the space, based on certain factors such as the type of refrigerant, the temperature difference between the refrigerant and space, and the saturated suction temperature of the refrigerant.

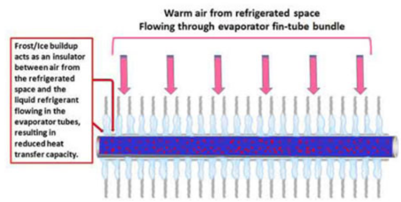
For example, on the table shown on the slide, the Model "LET040" has a capacity of 4,000 btu/h at the following conditions;
The refrigerant R-404A is used
There is a 10°F temperature difference between the room and refrigerant
The refrigerant has a Saturated Suction Temperature of -20°F.

If the space required 12,000 btu/h of heat to be removed, either a larger evaporator must be selected, such as the model “LET120” or 3 of these evaporators must be installed. Typically the single, larger evaporator will be selected as it’s cheaper to install 1 evaporator instead of 3 and requires less space.

It’s important to make sure the evaporator has the capacity for the room otherwise temperatures won’t be maintained.

Evaporator - Operation

- Typical refrigerant saturated suction temperature
  - Coolers: 15 to 20°F
  - Freezers: -20 to -10°F
  - 10 to 15°F temperature difference
- Fans operate continuously except during defrost



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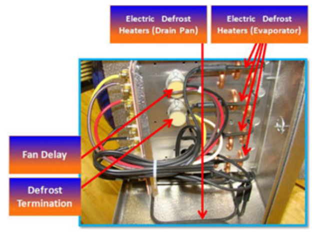
Evaporators are used in both coolers and freezers.
Typically coolers will have a refrigerant temperature between 15°F-20°F and freezers will have the refrigerant temperature between -20°F to -10°F.
The refrigerant temperature is normally 10°F - 15°F below the temperature of the space being cooled.

Evaporators typically operate continuously even if there is no demand to remove heat from the space.
The exception to this is a during a period known as a defrost cycle.
As mentioned earlier, moisture from the warm air will begin to condense as it is blown over the evaporator coil and cooled.
The refrigerant and the coil temperature are below the freezing point of water and the condensed water will begin to freeze on the evaporator coil creating frost.
As shown in the figure on the slide, if enough frost is built up, it can reduce the amount of heat absorbed by the refrigerant.
To combat this, defrost cycles are implemented to remove this frost.

Evaporator - Operation

- Defrost Cycles
  - Off Time – Uses air from space
    - Coolers only
  - Electric – Resistance heating rods inserted along coil
  - Hot Gas – Refrigerant discharge vapor from compressor
- Defrost cycles are typically scheduled and time based



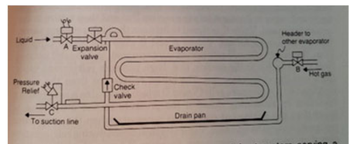


Figure 6-37. Piping and controls of hot-gas defrost system serving a direct-expansion evaporator coil.

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There are three kinds of defrost.

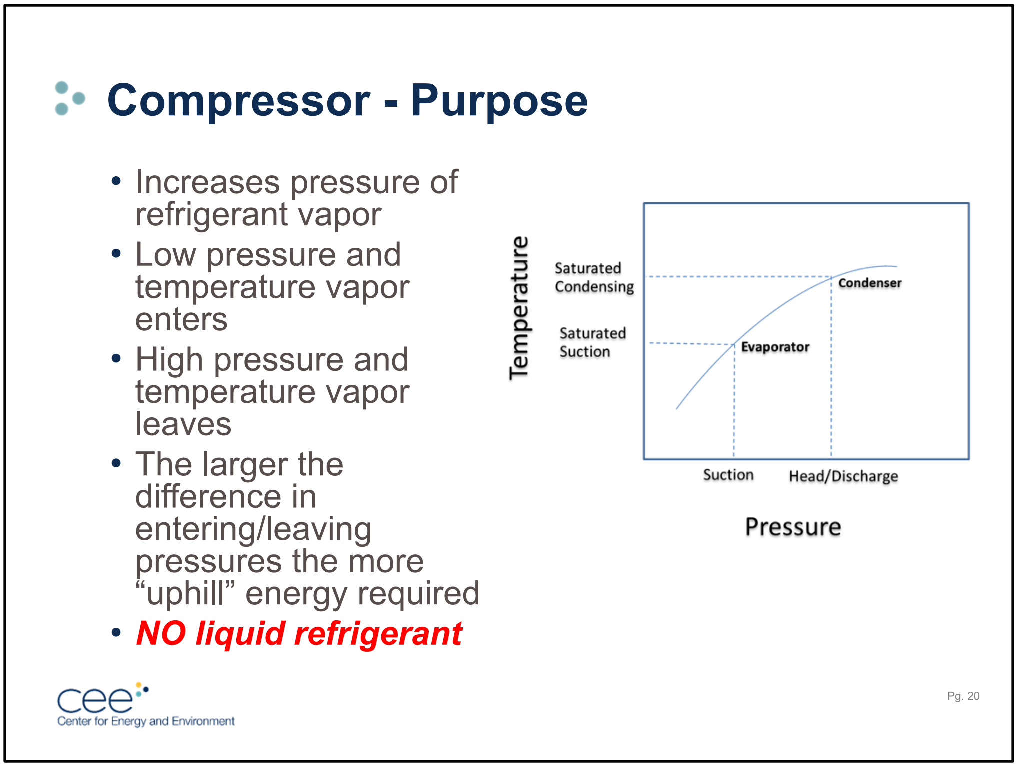
Off time is only used in coolers as it will stop the flow of refrigerant through the coil and the fans will blow the warm room air over the coil to melt the frost.
The room temperature must be above freezing for this to work.
With off time, the fans remain on 24/7.
This is the simplest form of defrost.

The second type is electric defrost.
In the figure on the slide, you can see electric resistance heating rods that are installed along the coil.
When the cycle is activated, the refrigerant flow is stopped, the fans are turned off, and the heaters are turned on to melt the frost.
The fans are turned off to prevent any water, created from the melting frost, from being blown into the room.
Electric defrost is commonly found for freezer applications.

The third type is called hot gas defrost.
Some of the refrigerant discharge vapor from the compressor is routed through the coil and used to melt the frost.
During the cycle, the liquid refrigerant from the expansion valve is stopped and the fans are turned off.
In the figure currently shown, the valve labeled "A" closes to stop the liquid refrigerant

from the expansion valve from entering the evaporator.
Valve “B” on the right side of the figure, opens to allow hot refrigerant vapor from the compressor discharge to enter the evaporator and warm the coil to melt the frost.
This is the most complex and expensive form of defrost and commonly used in freezers.

A common method of controlling when a defrost cycle is initiated is by a set schedule and time length.
An example of a typical schedule is 4 defrosts per day for 45 minutes.
With this control method, a defrost cycle will be performed even if it’s not needed.
This will be revisited later in the presentation as it involves an energy efficient measure.



We will now look at the next component after the evaporator in the refrigeration cycle, the compressor.

The purpose of the compressor is to increase the pressure of the low temperature refrigerant vapor to a higher pressure.
The pressure it compresses it to is the head pressure the condenser is maintaining.

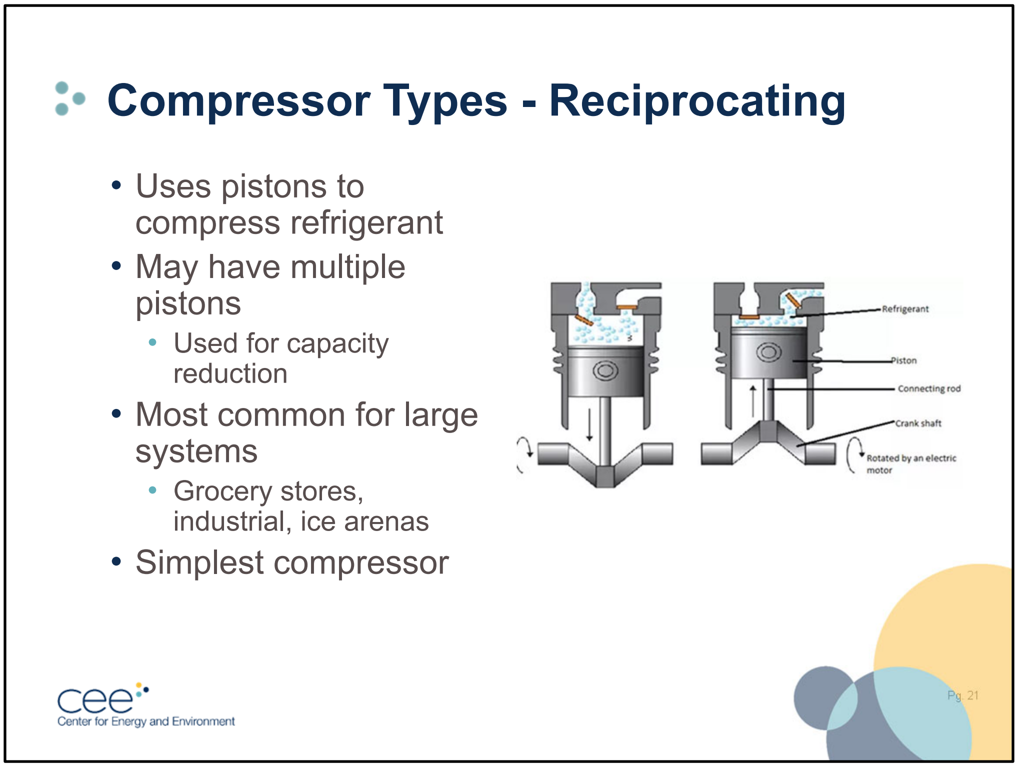
The compressor performs the uphill work I mentioned earlier. The higher the "hill" the more energy it consumes.
This hill can be visualized in the figure on the slide.
It must climb the hill to increase the refrigerant from the suction pressure to the head pressure.

Anything that can be done to decrease the amount of uphill work, the less energy it will consume and the more efficient it will operate.
The compressor consumes most of the energy in the refrigeration cycle compared to the other components.
As stated earlier, the compressor adds heat to the refrigerant that must be removed by the condenser.
By reducing this uphill climb, we also reduce the amount of extra heat added to the refrigerant.

A key point to remember is that most compressors do not like liquid refrigerant entering it.

Liquid can’t be compressed and therefore causes problems in the compressor.
The refrigerant must be all vapor upon leaving the evaporator.
The expansion valve, which we will discuss shortly, meters the amount of refrigerant to the evaporator to ensure this.

In refrigeration, there are three main types of compressors that can be used, and we will discuss those briefly.
The first are reciprocating compressors.



Reciprocating compressors use pistons to raise the pressure of the refrigerant, similar to the pistons in a car.
On the left side of the picture on the slide, the piston is performing what's known as the suction stroke.
As the piston moves down the pressure drops and the orange valve on the top left side of the piston opens, drawing in the refrigerant.
The piston will then perform its discharge stroke, as shown on the right side of the figure, and begin to rise. As it rises the refrigerant is compressed and its pressure increases.
The orange valve on the top right side of the piston opens, discharging the refrigerant to the condenser. The piston then repeats this cycle continuously.

Most reciprocating compressors have multiple pistons, except for very small compressors, and they commonly have sets of 2.
With multiple pistons, the compressor can essentially turn off a few pistons when the refrigeration demand is low, preventing it from cycling on/off.

Reciprocating are commonly found in all three refrigeration applications.
They are the simplest compressor type in regards to how it functions.

Compressor Types - Scroll

- Uses a fixed scroll and an orbiting scroll
- Becoming common in commercial refrigeration and HVAC for smaller systems
- Lower sound levels
- Can use Variable Frequency Drive (VFD)

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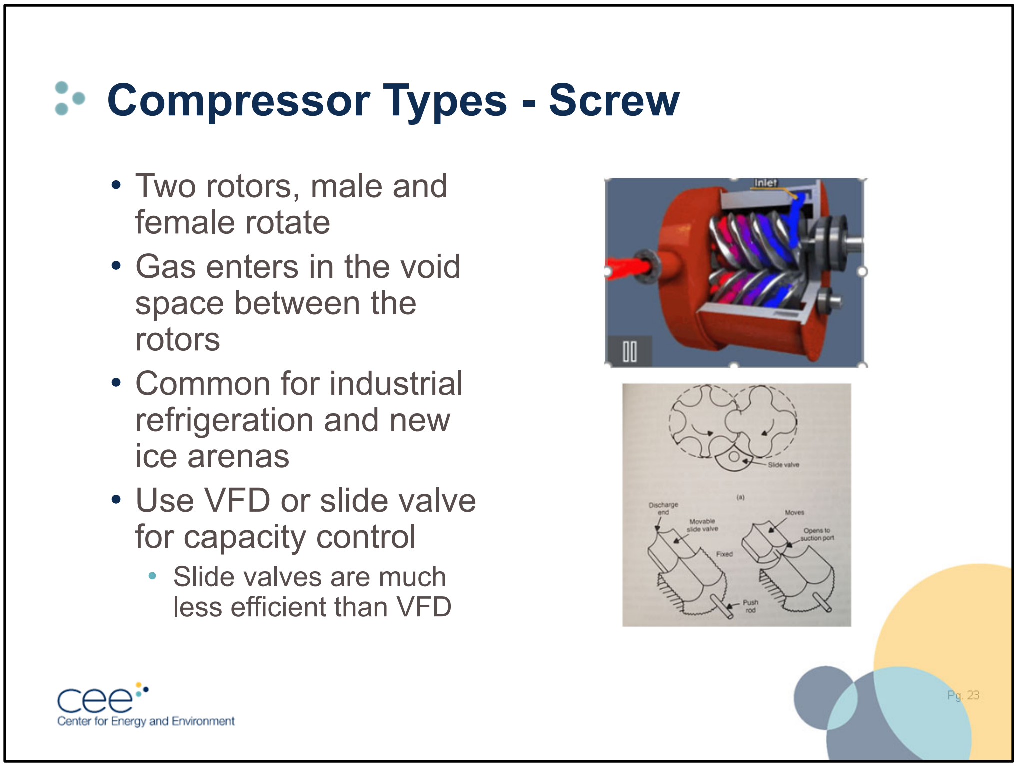
The next type of compressor is the scroll compressor.

A scroll compressor has two main components; a fixed scroll and an orbiting scroll. There is an orbiting motion that creates a series of gas pockets traveling between the two scrolls.
On the outer portion of the scroll the pocket draws in vapor, then moves it to the center of the scroll where it's discharged.
As the vapor travels through the increasing smaller inner pocket, the pressure of the refrigerant increases and is then discharged to the condenser.
These are becoming more common in commercial refrigeration such as grocery stores and for small HVAC system.

One benefit of the scroll compressor is it has lower sound levels compared to the other two types.
This makes it ideal for applications where sound is critical.

They can also use Variable Frequency Drives or VFD's to slow down the speed of the motor and the scroll when the refrigeration demand is low, preventing it from cycling on/off.



The third type of compressor is known as the screw compressor.

There are two rotors, a male and female, that continuously rotate.
These rotors look like rotating screws which can be seen in the animation on the slide.
The animation shows the refrigerant vapor entering the void space between the spaces on the rotors, compressing the vapor.
It's then discharged to the condenser.

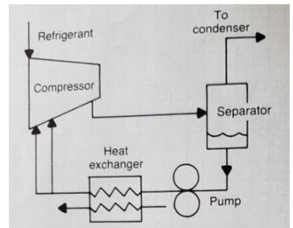
Screw compressors are commonly found in industrial refrigeration and new ice arenas.

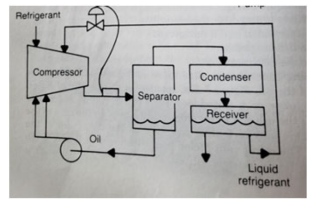
To assist in regulating how much refrigerant is compressed, VFD's can be used to slow down the speed of the motor and the rotors.

Another option is to use slide valves.
Slide valves essentially decrease the amount of void space between the rotors, which decreases the amount of refrigerant that can be compressed.
They are much less efficient than using VFD's to control the amount of refrigerant compressed by the compressor.

Compressor – Oil Management

- Reciprocating and screw require oil to lubricate moving parts
- Oil and refrigerant mix and oil temperature increases, requiring cooling
- Oil Cooling Methods:
  - Air
  - Water or Cooling Liquid
  - Liquid Injection





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Like any type of moving machinery, oil is needed to ensure all the moving parts work efficiently.
Reciprocating and screw compressors both require oil in order to keep the moving parts of the compressor lubricated.
Scroll compressors are unique and don't require oil.
Screw compressors require much more than reciprocating due to more moving parts.

The oil lubrication process involves circulating oil through the compressor and it's moving parts.
Oil and refrigerant will mix during the process which requires the oil to be separated from the refrigerant before it goes to the condenser.
If the oil isn't separated, the evaporator can become oil-logged, meaning the tubing in the coil will become coated with oil.
This reduces the ability for the refrigerant to absorb heat from the space.

The separated oil from the discharge of the compressor will be at an elevated temperature and needs to be cooled before being recirculated back to the compressor.
There are a couple methods used to cool the oil.

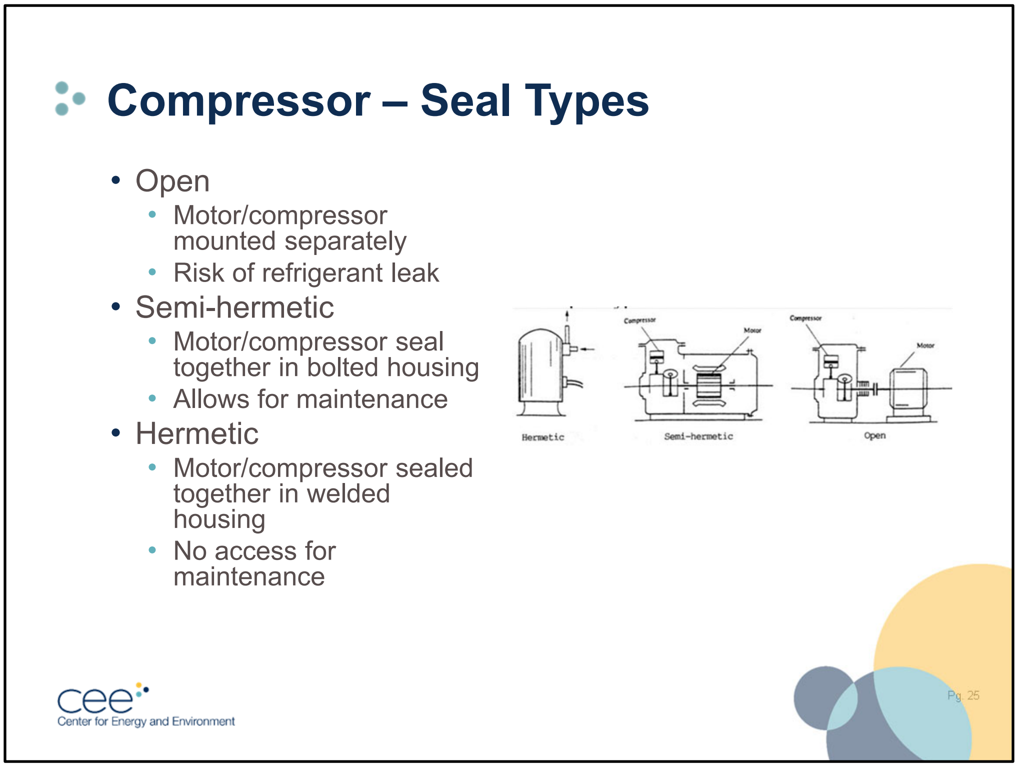
First, there is air cooled which requires moving cool air across the oil tubing to remove the heat.
Typically this requires access to outside air because if the room air from where the compressor is located is used, the room will eventually overheat especially during summer

months.

A second method is using water or a cooling liquid to absorb the heat.
The figure on the slide shows the cooling liquid is passed through a heat exchanger with the oil to cool it.
The oil is first removed from the refrigerant in a separator where the refrigerant vapor rises to the top of the vessel and the oil is collected at the bottom.
It is then circulated through the heat exchanger before moving through the compressor again.
This is a common method if the building already uses water or a different cooling liquid for there HVAC system.

A third method is liquid refrigeration injection.
The current figure on the slide shows that in this process, some liquid refrigerant from the discharge of the condenser is fed into the compressor from a receiver or tank that holds it.
When the liquid refrigerant enters the compressor, it absorbs heat from the oil, evaporates, and is then compressed again.

A thermal expansion valve, as shown on the top portion of the figure, is used to meter the amount of liquid refrigerant used to cool the oil to ensure safe operation.
This method is commonly used due to its simplicity but comes with consequences such as an increase in compressor power.
We will discuss more of these consequences later in the presentation as there is a fourth type of oil cooling method that can be implemented to increase the efficiency of the oil cooling system.



Another component of compressors is the type of seal used to prevent refrigerant leakage.

There are three types of seals used with compressors. These can be referenced in the figure shown on the slide.

If a compressor has an open seal, the motor and compressor are mounted separately. The compressor does not have a seal around it, creating the risk of refrigerant leaking. Open compressors are inherently a little more efficient than the next two types as the motor heat is rejected to the space the compressor is in, while the motor heat for the other two is absorbed by the refrigerant. This increases the amount of work the compressor must do and the amount of heat the condenser must remove.

A semi-hermetic compressor, has the motor and compressor sealed together, preventing any leakage of refrigerant, in a housing that is bolted.
Because it is bolted, this allows the compressor/motor to be accessed for maintenance.

The third seal type is a hermetic compressor.
Similar to semi-hermetic where the compressor/motor are sealed together but the seal is welded.
There is no way to access the motor/compressor for maintenance.

Hermetic compressors are generally used for small compressors in light residential and commercial HVAC applications.

Semi-hermetic and open are used most in commercial and industrial refrigeration with semi-hermetic being the most common for grocery stores and ice arenas and open for industrial.

Before we move on to the two final components in a refrigeration system, I have a couple review questions that I will create a poll for to review some of the main points we've discussed.

Review Questions

1. What is the state of the refrigerant when it enters the evaporator?
   a. Mixture of low temperature liquid/vapor
   b. High temperature vapor
   c. High temperature liquid

2. What type of defrost is used only for walk-in coolers?
   a. Electric
   b. Air
   c. Hot Gas
   d. Hot Liquid

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1. a

2. b

These questions will be asked in the google poll and participants will put there answer in the poll prompt.

Review Questions

1. True or False: Liquid refrigerant can enter the compressor.

2. A semi-hermetic sealed compressor is defined as which of the following?
   a. Motor/compressor seal together in bolted housing
   b. Motor/compressor sealed together in welded housing
   c. Motor/compressor mounted separately

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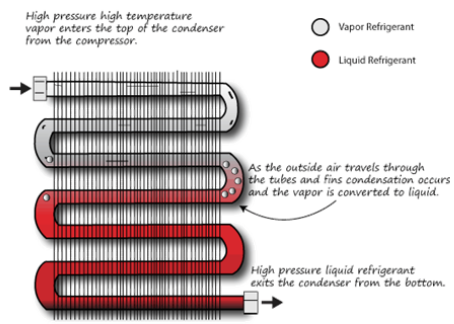
1. False

2. a

These questions will be asked in the google poll and participants will put there answer in the poll prompt.

Condenser - Purpose

- Rejects heat from;
  - Compressor
  - Heat removed from evaporator
- High pressure, temperature vapor enters
- High pressure and medium temperature liquid leaves
- Refrigerant temperature must be higher than cooling medium
- Fans assist with removing heat



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We will now move into discussing the third component of the refrigeration cycle, the condenser.

The heat that is absorbed in the evaporator and produced by the compressor is rejected by the condenser to a heat sink.
This heat sink is typically outdoor air.

Refrigerant enters the condenser as a high pressure and high temperature vapor.
The figure on the slides shows that as it moves through the condenser, heat moves from the refrigerant to a different source, causing the refrigerant to condense and become a liquid.
In some instances, the refrigerant will continue to release heat after it's changed from a vapor to liquid and its temperature will be reduced slightly.
Remember that when a refrigerant changes state, it absorbs or releases a lot of latent heat.
In this case, it is releasing heat from the refrigerant to the outdoor air.
This latent heat is what allows a refrigeration system to remove large quantities of heat.

The refrigerant then leaves the condenser as a high pressure and medium temperature liquid.
As mentioned earlier, the refrigerants temperature or condenser saturation temperature must be higher than the source it is trying to reject the heat to.
Most condensers are designed to have the condenser saturation temperature 10-15F above the heat sink temperature.

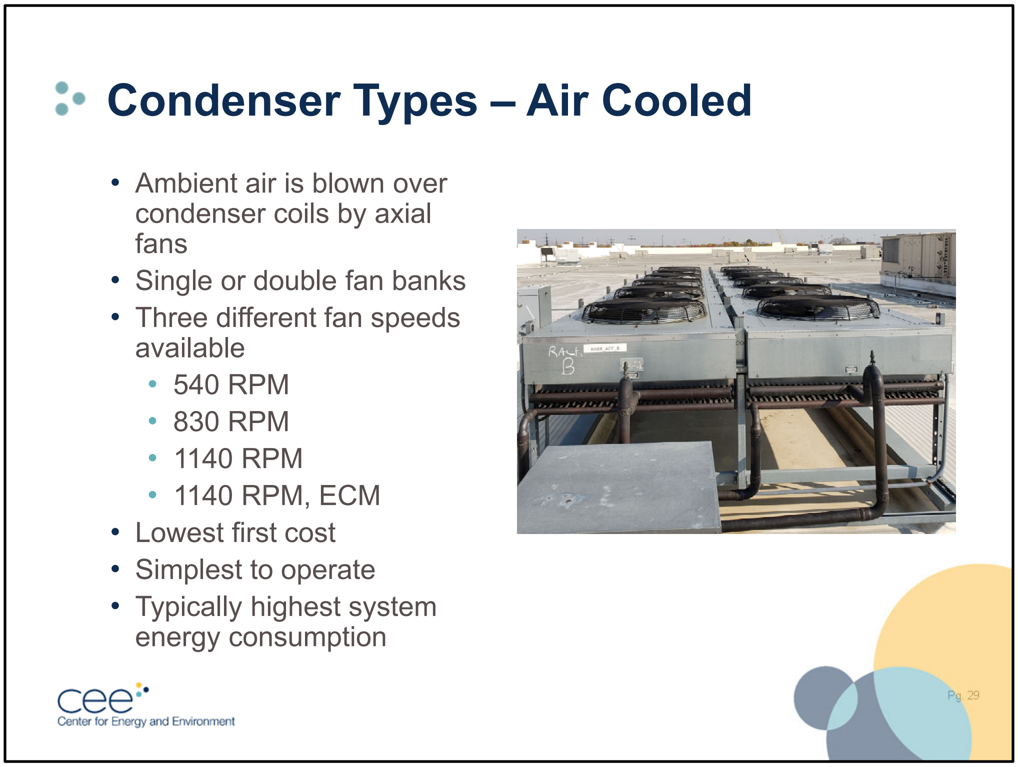
Energy in the form of condenser fans are used to assist with the removal of heat from the refrigerant.
The amount of energy used by the fans depends on the minimum condenser saturation temperature set for the system.
Condensers are controlled to maintain the condenser saturation temperature from dropping below a set minimum.

With a higher minimum condenser saturation temperature, for example 90F, the fans will work less at lower outdoor air temperature, due to the higher temperature difference between the refrigerant and outdoor air temperature, but the compressor consumes more energy as it must constantly climb a large hill to maintain the minimum condenser pressure.

If the minimum condenser saturation temperature is low, around 70-75F, the fans will consume more energy at lower outdoor air temperatures because of the smaller temperature difference but the compressor will consume less energy.
Therefore it’s important to analyze the system and not just one component when looking at implementing certain energy saving measures.

On average the condenser consumes 5-25% of the total energy used in the refrigeration cycle, with the remaining primarily coming from the compressor.

Now we will look at the three main types of condensers that can be used.



The first and most common type of condenser is the air cooled condenser.
With this condenser, the refrigerant is circulated through the coils as seen in the picture on the slide.
Air is then blown over the coils by the fans you see on top.

Fins are installed on the coils to help with the removal of heat.
These are similar to what are used in evaporators but the fin spacing can vary between 8 fins per inch to 14 fins per inch.
A smaller fin spacing will allow the removal of more heat but it has a higher chance of becoming clogged from debris.
A common fin spacing is 10 fins per inch.

The condenser can have a single or double bank of fans depending on how much heat must be removed and the amount of space available for the condenser.

There are three fan speed options for most air cooled condensers; 540 rpm, 830 rpm and 1140 rpm.
A condenser with a lower operating fan speed will be larger and require more fans than a condenser with a higher fan operating speed at the same heat removal capacity.
We will discuss the pros and cons of the different fan speeds later in the presentation during the energy efficient measures.

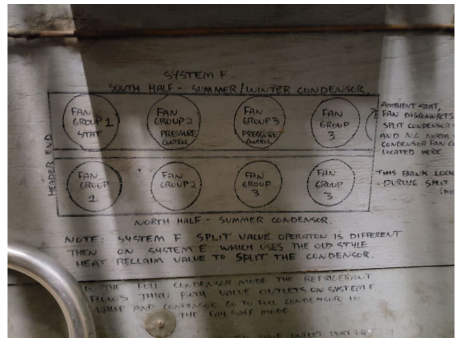
There is also the option to have an ECM on the condenser fans for the higher fan speed

models.
This provides the condenser the ability to modulate the speed of its fans, reducing the amount of energy consumed.
A VFD can also be installed to give the ability to modulate the fan speed for multiple fans but ECM’s are more common.
This is another energy efficient measure we will discuss later.

Air cooled condensers generally have the lowest first compared to the other types and are the simplest to operate, but typically have the highest system energy consumption.

Condenser Types – Air Cooled Operation

- Fans are controlled to maintain a minimum condenser/head pressure
  - Fans stage on/off or modulate as pressure rises/falls
  - ECM's and VFD's provide more consistent condenser pressures
  - Minimum condenser pressure typically fixed



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Air cooled condensers operate rather simply.
The fans are controlled to maintain a minimum head pressure required for the system.
Typically, fans are staged on/off in banks to maintain this pressure.

For example, if a condenser has 6 fans, two fans may stage on as the head pressure begins to rise above an initial setpoint.
If the pressure continues to rise and increases above a second pressure setpoint, two additional fans will come on.
Finally, the last two fans will come on when a third pressure setpoint has been exceeded.
The fans will then turn off in a similar reverse manner as the pressure begins to decrease.

If a condenser has an ECM or VFD, the fans may all modulate together or the fans may be controlled by a combination of on/off and modulating.
Using the same example, 4 fans may be staged on/off and two fans will modulate.

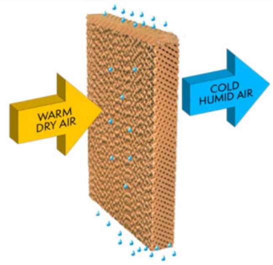
The ability to modulate the fan speed, provides more consistent condenser pressures compared to on/off.
We will explore the benefits of ECMs and VFDs later in the presentation during the energy efficient measures.

The minimum condenser pressure is commonly a fixed setpoint and doesn't change.
There is a control method that modulates the condenser pressure as the outside air temperature changes.

This allows the condenser and compressor to operate at lower condenser pressures as the outside air temperature decreases, saving energy.
We will expand on this when we discuss the energy efficient measures.

Condenser Types – Adiabatic

- Similar to air cooled condensers
- Cooling pads, saturated with water, cools entering outside air
  - Water evaporates into air, cooling it
  - Dryer air absorbs more water and is cooled more
- Lower outside air temperature = Lower condenser saturation temperature



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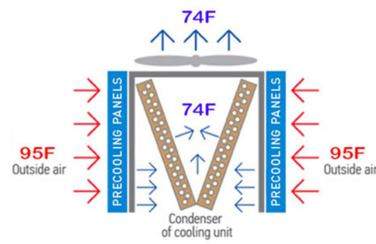
The second type of condenser is the Adiabatic Condenser.
It’s like an air cooled condenser where fans blow outside air over the condenser coils.
The difference is that before the air passes over the coils it’s blown through cooling pads that are saturated with water.
The bottom figure on the slide shows that as the warm outside air is drawn through the cooling pads it absorbs some of the water, cooling the air.
The dryer the air, the more water it can absorb and the lower the temperature it can be cooled to.

The reduction in temperature of the outside air allows the condenser to operate at a lower condenser saturation temperature.
This becomes very important on hot 95°F summer days when the refrigeration system is working the hardest.
Instead of operating at a condenser saturation temperature of 110F it can be around 95F.
This decreases the amount of uphill climb for the compressor to raise the refrigerants pressure and thus reduce the amount of energy it consumes.

Adiabatic condensers provide the opportunity for energy demand savings during peak operating conditions. We will circle back to this topic during the energy efficient measures.

Condenser Types – Adiabatic Operation

- Similar fan operation to air cooled
- Small pump used to keep pads saturated
  - Can be circulated or once through
- Highest condenser saturation temperature is commonly 95°F
- Can operate dry when outside air temp becomes low enough



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Adiabatic condensers operate in a similar manner to air cooled condensers.
The fans blow outside air over the condenser coils, cooling the refrigerant, causing it to condense into a high pressure liquid.
The fans can be controlled to be staged on/off or have an ECM or VFD and modulate their fan speed to maintain the minimum head pressure.

The key difference are the cooling pads. A small pump is used to continuously keep the pads saturated.
This water could be circulated or be once through.
If circulated from a tank, the water is typically dumped every 3 to 4 hours to ensure no bacteria growth.

With these cooling pads, the outside air temperature is reduced as it absorbs the moisture from the pads.
The current figure shows an example of how much the outside air temperature can decrease.
It can be reduced from 95°F down to 74°F.
The required condenser saturation temperature for the refrigerant can then be reduced.
The highest condenser saturation temperature typically seen for adiabatic condensers is 95°F.

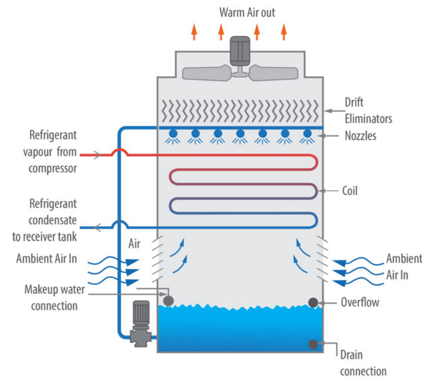
An adiabatic condenser can also operate dry which means the cooling pads are no longer kept wetted. The pump will shut off when this occurs.

Typically, there is a certain outside air temperature where the condenser will switch from using the cooling pads to operating dry.
When operating dry, the adiabatic condenser is essentially an air cooled condenser.

One key piece of information to keep in mind when operating an adiabatic condenser dry is that the amount of heat it can remove from the refrigerant may be reduced.
Operating with the cooling pads even down into lower outside air temperatures will help reduce the refrigeration systems energy consumption and demand.

Condenser Types – Evaporative

- Uses evaporation to cool, condense the refrigerant
- Water is sprayed over condenser coil
- Water evaporates into air blown over coils, removing heat from refrigerant
- Multiple Types:
  - Induced draft axial fan
  - Forced draft axial fan
  - Centrifugal fan



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The third type of condenser is the evaporative condenser.

This type of condenser uses evaporation to cool and condense the refrigerant.
The current figure on the slide shows that as the refrigerant moves through the condenser coils, water is sprayed from nozzles above onto the coil.
Fans are used to blow outside air over the condenser coils.
As the air moves over the wetted coils, the water evaporates into the air, removing heat from the refrigerant.
The water that is sprayed over the coils is collected in a sump at the bottom of the condenser.
It is then recirculated by a pump up to the top of the condenser and the process repeats.
This water must be treated in order to prevent any build up or growth of bacteria.

There are three different types of evaporative fans, distinguished by the type of fan used or the location of the fan. They all operate in the same way though.
The first two are the induced draft axial fan and forced draft axial fan condensers.
The induced draft axial fan condenser has its fans located at the top of the condenser and draws air in from the bottom.
The forced draft axial fan condenser has its fans located at the bottom of the condenser, drawing air in from the bottom.

The third type is a centrifugal fan evaporative condenser.
The centrifugal fan is located at the bottom of the condenser.

Centrifugal fans are typically quieter than axial, making them ideal in noise sensitive areas but usually have a larger horsepower motor.

Evaporative condensers typically require less fan horsepower and consume less energy than air cooled condensers to remove the same amount of heat.

Condenser Types – Evaporative Operation

- Dryer air = more heat removed
- Highest condenser saturation temp. is 95°F
- Water continuously sprayed for most of the year
  - Dry operation reduces capacity
- Fans stage on/off or modulate (VFD) to maintain min. head pressure
- In cold climates, spray water sump located indoors

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Evaporative condensers are able to reject more heat from the refrigerant when the outside air is dry.
The dryer the air the greater the heat removal capacity of the condenser.
This is what makes evaporative condensers ideal in hot, dry climates.
Hot-humid climates like in Florida may not benefit as much from an evaporative condenser like New Mexico would which has more of a hot-dry climate.

They are implemented in MN but must be sized correctly for our more humid climate.
Even with this caveat, evaporative condensers are almost always used in industrial cold storage and sometimes ice arena applications in MN.

Similar to an adiabatic condenser, evaporative condensers typically see their max condenser saturation temperature around 95F.
Again decreasing the amount of uphill climb for the compressor to raise the refrigerants pressure and thus reduce the amount of energy it consumes.

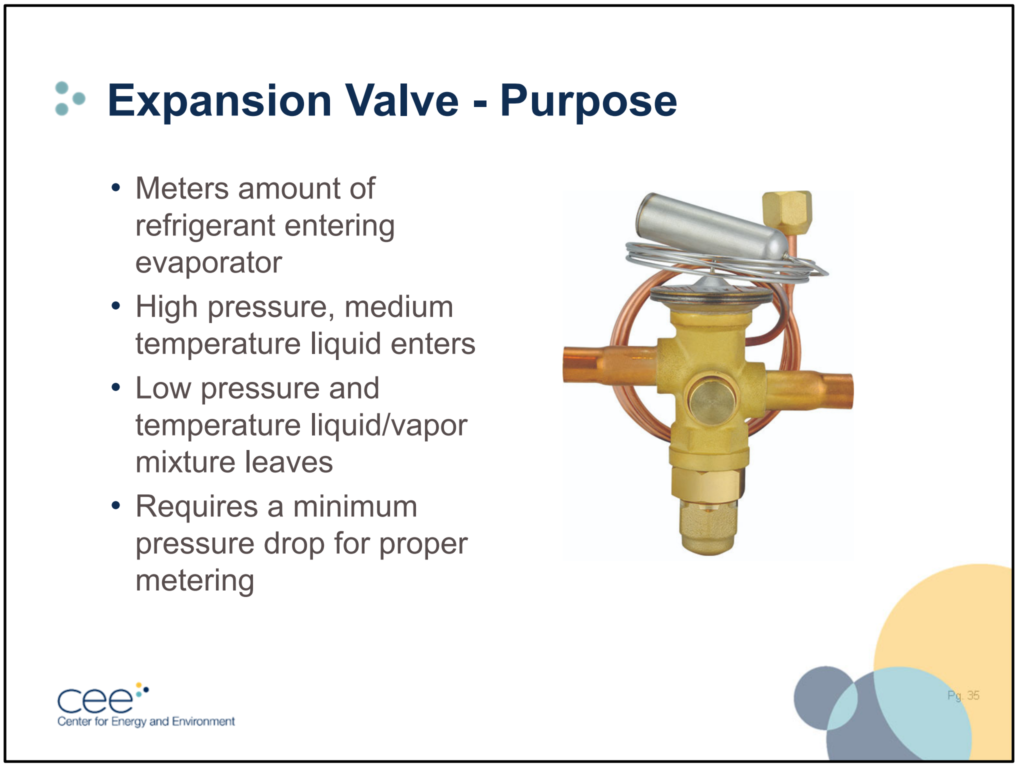
During operation, water is continuously sprayed over the coils for most of the year except when outside air temperatures become very cold.
Typically below freezing is when the water will shut off but sometimes water will continue to be used down to 15-20F.

When water is no longer used, the condenser is operating in the dry condition.
Like adiabatic condensers, its heat removal capacity can be reduced when operating dry so

it must be verified the condenser can remove the required amount of heat from the refrigerant at these conditions.
Typically this isn’t a problem due to the large temperature difference between the refrigerant and the outside air temperature.

Regardless if water is being used, the fans for the condenser will either stage on/off or modulate, if there is a VFD, to maintain the minimum head pressure.

Because some of the water that is sprayed over the coils evaporates, new water must be introduced periodically.
As mentioned earlier, all water must be treated to prevent any growth of bacteria.
The current figure on the slide shows that in cold climates, such as in MN, the sump that collects the water after it has been sprayed over the coils, is installed inside to prevent the water from freezing.



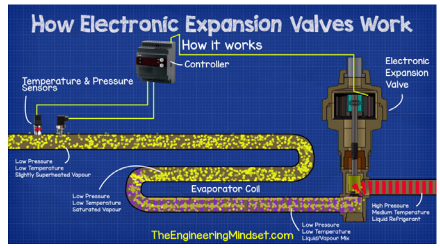
The final component of the refrigeration cycle is the expansion valve.

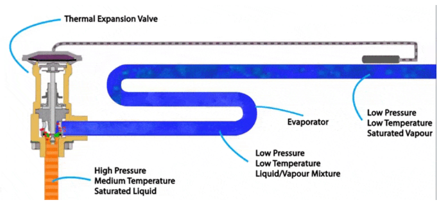
Its purpose is to meter the amount of refrigerant entering the evaporator to ensure enough heat is absorbed by the refrigerant and removed from the space.
High pressure, medium temperature liquid refrigerant enters the valve.
The refrigerant expands and leaves as a low pressure and temperature liquid and vapor mixture.

Expansion valves require a minimum pressure drop in order to meter the refrigerant correctly.
This is what commonly dictates the minimum condenser pressure for a system.
The expansion valve seems small and insignificant when compared to the other components, but it plays an important role on how efficient the system operates.

Expansion Valve - Operation

- Too much refrigerant;
  - Potential of liquid entering compressor
- Too little refrigerant;
  - Space temperature may become too warm
  - Warmer refrigerant enters compressor
- Can be thermostatic or electronic





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If too much refrigerant enters the evaporator, there is a chance not all the refrigerant will evaporate into a vapor before it enters the compressor, causing issues with its operation. If too little enters the evaporator, not enough heat will be removed from the space and it will enter the compressor at a much warmer temperature, increasing the amount of energy required by the compressor and reducing its capacity.

There are two types of expansion valves that can be used.
The current figure on the slide shows a thermostatic expansion valves which uses pressure differentials to move a mechanical diaphragm that meters the refrigerant entering the evaporator.

An electronic expansion valve performs the same operation but the valve is powered.
The current figure on the slide shows that a controller decides how much to open/close the valve based on the leaving temperature and pressure of the refrigerant from the evaporator.
Electronic expansion valves can react quicker than thermostatic valves and provide more consistent refrigerant temperatures entering and leaving the evaporator.
Thermostatic valves are simpler and have a lower first cost but aren't as efficient as electronic.

We've now covered all four components of a refrigeration system.
Before we move to the different refrigeration applications, I have a few review questions on the last two components we just discussed.

Review Questions

1. Which type of condenser utilizes pre-cooling pads?
   a. Evaporative
   b. Adiabatic
   c. Air Cooled

2. What is the typical highest condenser saturation temperature seen for evaporative condensers?
   a. 95°F
   b. 110°F
   c. 100°F

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1. b

2. a

These questions will be asked in the google poll and participants will put there answer in the poll prompt.

Review Questions

1. What is the state of the refrigerant when it enters the expansion valve?
   a. High pressure and temperature vapor
   b. High pressure and medium temperature liquid
   c. Low pressure and low temperature vapor

2. Which of the following can be a problem if too little refrigerant enters the evaporator?
   a. Space temperature may become too warm
   b. Potential of liquid entering compressor
   c. Condenser becomes back logged with refrigerant

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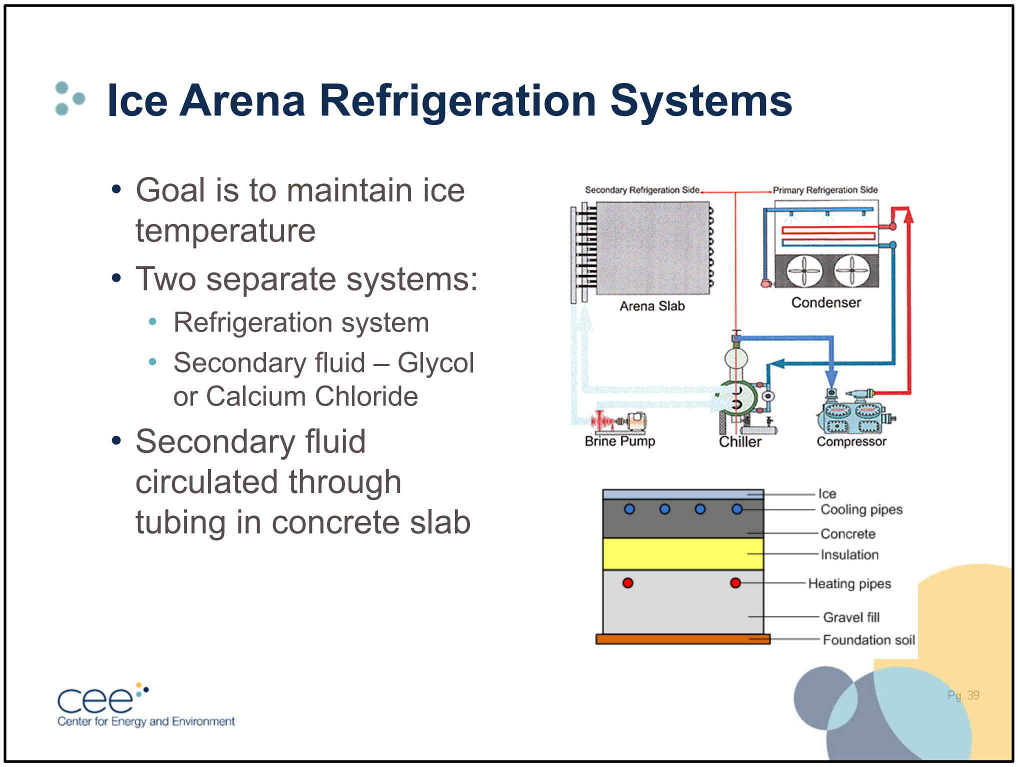
Pg. 38

1. b

2. a

These questions will be asked in the google poll and participants will put there answer in the poll prompt.



Now that we've covered the basic components involved with the refrigeration cycle, we will now review the typical refrigeration systems seen in ice arenas, grocery stores and industrial cold storages.

We will start with ice arenas.

The purpose of a refrigeration system for an ice arena is to maintain the ice temperature of an ice rink at the desired level.
Commonly, there are two separate systems that are used to maintain the ice temperature. The current figure on the slide shows these two systems which are the refrigeration system and the secondary fluid system.

The secondary fluid system, on the left side of the figure, is the cooling fluid that is circulated under the ice rink to maintain the ice temperature.
This fluid is normally ethylene/propylene glycol or Calcium Chloride. Calcium chloride can also be known as a brine solution.

The secondary fluid is circulated via pumps through tubing that is installed in the concrete slab for the ice rink.

The current figure on the slide shows a typical floor construction for ice arenas.
On the top is the ice sheet.
Underneath the ice is a concrete slab that is poured with tubing in it.

Some older ice rinks will have sand floors instead of concrete but this is not as common for newer rinks.
This tubing contains the secondary fluid that is continuously circulated under the ice sheet.

Sometimes under the concrete slab there will be insulation installed if there is subfloor heating.
Subfloor heating is used in some ice arenas to keep the ground temperature above freezing, typically 38F.
This insulation and subfloor heating is typically used in ice rinks that operate year round.

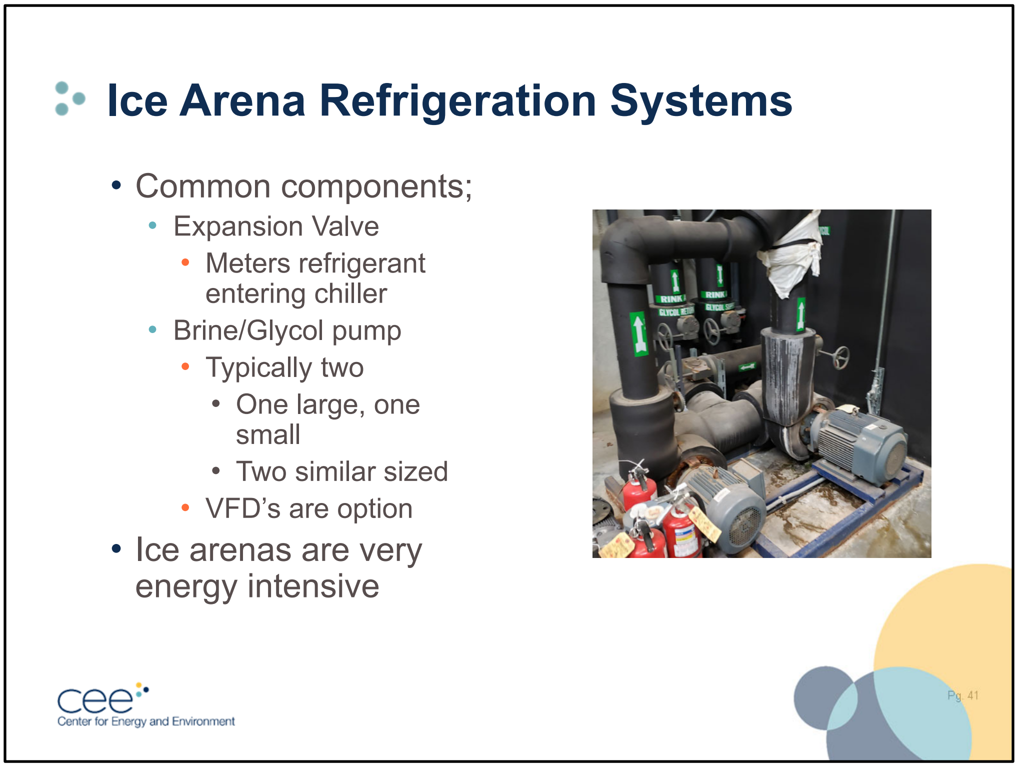
We will now look at the main components of an ice arenas refrigeration and secondary fluid systems.

The compressors are normally semi-hermetic, reciprocating compressors as shown in the picture on the slide. These are very common in existing ice arenas.
Screw compressors though are beginning to become more popular for new ice arenas.

Typically, there are 2-3 compressors for each ice rink.
The compressors are commonly controlled by one of two methods.
Either they cycle on/off to maintain an ice temperature or to maintain a secondary fluid return temperature.

Condensers for ice arenas are generally air cooled or evaporative.
They are controlled and operate as we discussed earlier, and are trying to maintain head pressure above a minimum value.

An ice arenas evaporator is known as a chiller as it is used to cool the secondary fluid.
It normally looks like a long-insulated tube.
It performs the same function as an evaporator except instead of removing heat from air, it removes heat from the secondary fluid.
The chiller is a heat exchanger where the refrigerant and secondary fluid do not mix but pass near each other in order for the refrigerant to absorb the heat from the secondary fluid.



There is a single expansion valve used to meter the amount of refrigerant entering the chiller.
These can be thermostatic or electronic.

The last component are the glycol pumps.
Commonly, there are two glycol pumps and one pump is usually larger than the second one.
Occasionally, systems will have the two similar sized pumps.
One pump will operate all the time and the second is for redundancy in case one fails.

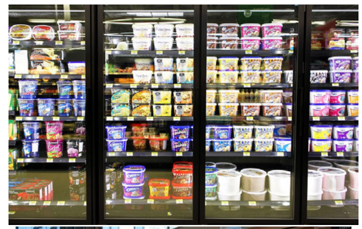
The pumps circulate the secondary fluid which is typically in the temperature range of 13°F to 17°F.
There are multiple ways to control when and which pump operates but one method is to run the small pump when the refrigeration load is low, during colder months, and to operate the larger pump when the refrigeration load reaches its peak, during the summer.
The pumps can be installed with VFD's to reduce their speed during certain periods.
We will talk more on optimizing glycol pumps in an energy efficient measure.

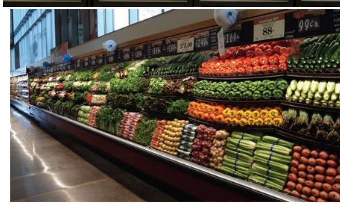
Ice arenas are a very energy intensive system and small changes in setpoints or operation can greatly reduce the amount of energy consumed.
We will learn some energy saving measures that can be applied at ice arenas later in the presentation.

Next we will discuss the refrigeration systems for grocery stores.

Grocery Store Refrigeration Systems

- Goal is to maintain space temperatures for coolers, freezers and cases
- Two product temperatures
  - Medium temp. – Coolers, produce/dairy/lunchmeat cases
  - Low temp. – Freezers, frozen food cases





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The next refrigeration application are grocery stores.
The goal for these refrigeration systems is to maintain space temperatures in walk-in coolers, freezers and display cases to ensure the food remains at a safe temperature.

In grocery stores there are two different product temperatures, medium temperature and low temperature.
The current figure on the slide shows an example of medium temperature spaces which refers to walk-in coolers, and produce, dairy, and lunchmeat display cases.
These temperatures are all above freezing.

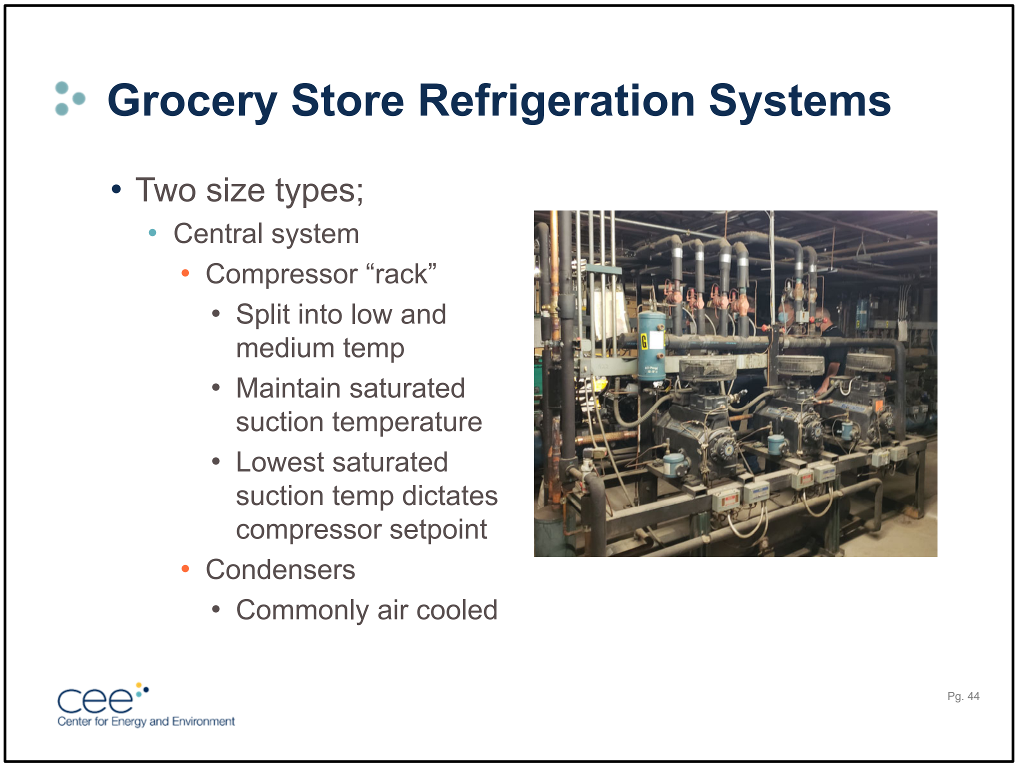
Low temperature, as shown on the current figure on the slide, refers to walk-in freezers, and frozen food display cases where the temperatures are all below freezing.

There are two distinct refrigeration system types for grocery stores.

The first are central refrigeration systems.
These are found in large grocery stores like Walmart and Coborns.

It consists of multiple evaporators throughout the store.
Each have their own expansion valve located near it.

Because each evaporator is serving a different type of space or display case, the design saturated suction temperature to absorb the required heat is often different.
Evaporators serving medium temperature cases have a saturated suction temperature between 10°F to 20°F.
Low temperature saturated suction temperatures are between -20°F to -10°F.



Because there are two different temperature categories this often requires splitting the compressors into different groups or "racks".
As shown in the current figure on the slide, racks can consist of 2 to 4 compressors, split into low or medium temperature racks.
All evaporators with saturated suction temperatures in the medium temperature range will be part of a medium temperature compressor rack and the other low temperature evaporators will be on a low temperature compressor rack.

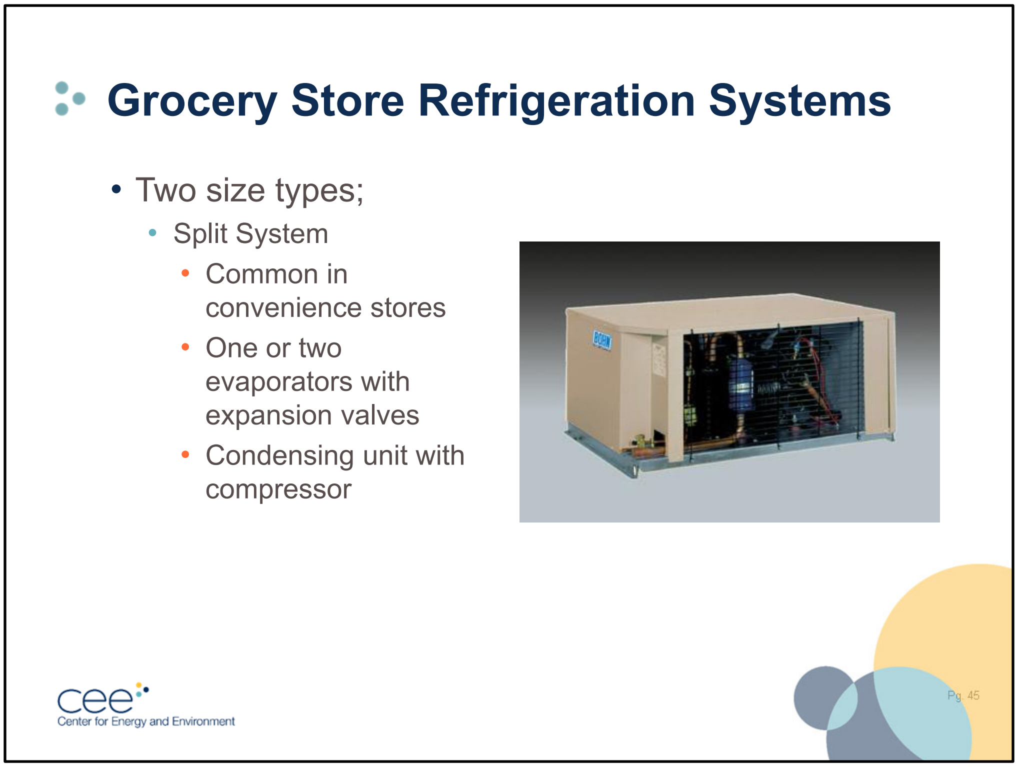
Proper grouping of evaporators is important in the energy consumption of the compressors and the system.
The compressors on each rack are trying to maintain the lowest required saturated suction temperature for that group of evaporators.

If a medium temperature rack has two evaporators, one with a saturated suction temperature of 20°F and the other with 10°F, the setpoint for the compressors must be the lowest.
In this example, the compressors will try to maintain 10°F for the saturated suction temperature.
The compressor will use more energy for the 10°F setpoint than for 20°F.
If we use the analogy of pushing heat up a hill again, the starting point of the hill is much lower at 10°F than 20°F.

If there is a large temperature range between the evaporators in each product temperature

category, it may be beneficial to have multiple medium or low temperature compressor racks.
This can help with reducing the overall energy consumption of the system.
Compressors for central refrigeration systems are typically semi-hermetic reciprocating.

There can also be multiple condensers for central refrigeration systems where one removes the heat from each temperature category.
The condenser's purpose remains the same and is to remove the heat from the evaporators and the additional unwanted heat from compressors.
These are commonly air cooled but adiabatic are beginning to become more prevalent in the grocery store industry.



The second system type are known as split systems.
These are found in small convenience stores that have only one or two walk-ins or display cases for each temperature category.

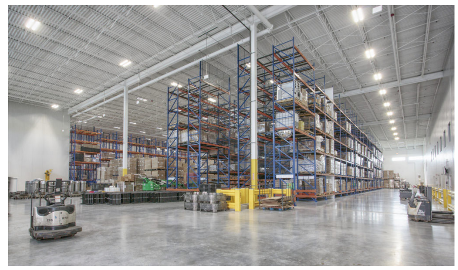
There will typically be only one or two evaporators for each split system, each with their own expansion valve.
They will be operating in the medium or low temperature saturated suction temperature range.

The heat absorbed by the evaporators will then be removed by a condensing unit.
The current figure on the slide shows a condensing unit that is a single piece of equipment that contains the condenser coil and compressor.
They are small units typically located on the roof or a sidewall of the store.

The compressor will cycle on and off to maintain the saturated suction temperature setpoint, while the condenser portion will remove the heat to the outdoor air while maintaining the head pressure above the minimum setpoint.
They have a lower first cost compared to central systems but have a lower system efficiency.

Industrial Refrigeration Systems

- Goal is to maintain space temperature in large cooler and freezer warehouses
- Medium and low temperature product categories
- Central refrigeration system
- Refrigeration load is highly temperature dependent



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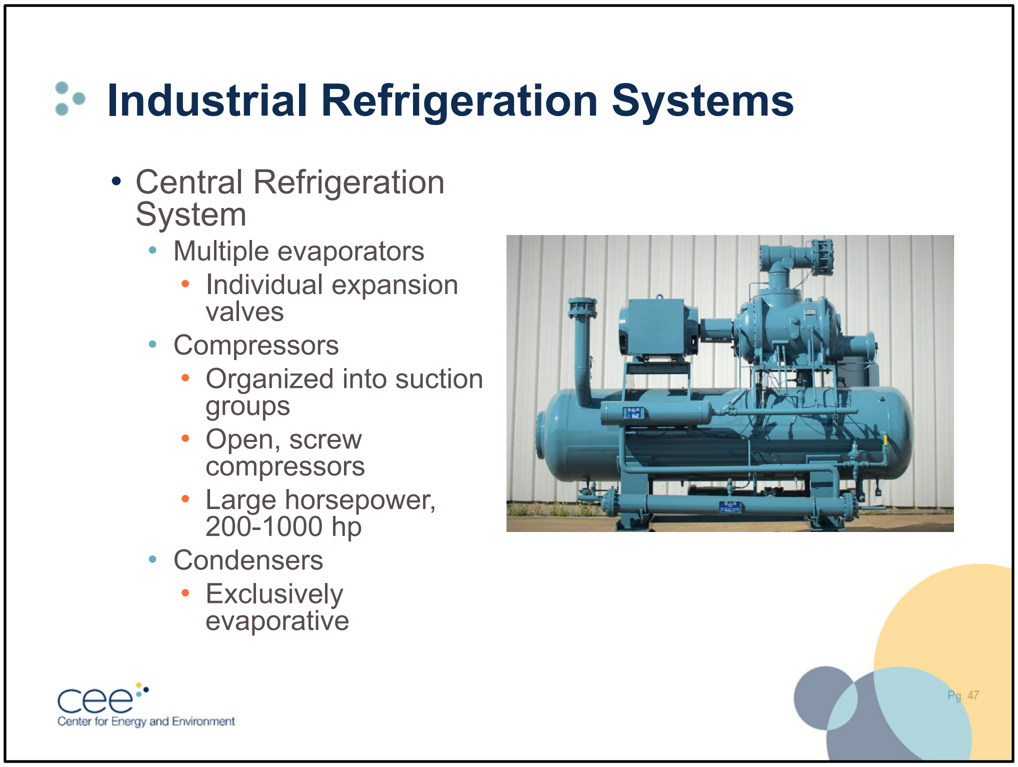
The third major refrigeration application is industrial cold storage.

This application is similar to grocery stores but on a much larger scale.
The system is trying to maintain space temperatures in large cooler and freezer warehouses to ensure the product stays at a safe temperature.

Like grocery stores there are typically two temperature product categories with similar saturated suction temperature ranges for the refrigerant.
Blast freezing can have saturated suction temperatures down to -40°F in order to rapidly cool and freeze the product.
Industrial cold storage typically use central refrigeration systems due to the large refrigeration loads which are highly outside air temperature dependent.



Industrial cold storage will have multiple evaporators throughout the facility serving different temperature warehouses.
Each evaporator will have its own expansion valve to meter the refrigerant, and are typically much larger in size compared to grocery store evaporators.

Compressors are organized into low and medium temperature suction groups based on the evaporators they are serving.
The compressors are generally open, screw type, like the example figure shown on the slide, where the motor is separate from the compressor.
They are controlled to maintain the saturated suction pressure setpoint for each rack.

Compressors are much larger for cold storage compared to the other applications and can range from 200 to 1000 hp.
As mentioned earlier, screw compressors can use slide valves or a VFD to reduce their capacity which is critical for large systems such as these.
They also require much more oil compared to reciprocating compressors, making oil cooling very important.
Cooling of the oil is typically done by liquid refrigerant injection where liquid refrigerant is introduced into the compressor, cools the oil by evaporating and is then compressed again by the compressor.

Condensers are almost exclusively evaporative, as shown in the current figure on the slide, due to the large amount of heat that must be removed by the refrigeration system.

The spray water is generally run continuously even through much of the winter so precautions such as an indoor sump are used to ensure the water doesn't freeze. VFD's are often installed on the condenser fans to modulate their fan speed and provide more consistent condenser pressures.

Industrial cold storage refrigeration systems are very energy intensive so any measures that can be implemented to improve the operation and efficiency of the system should be discussed and reviewed.

We've now reviewed the 3 different refrigeration applications you will commonly see. Before we take a 5 minute break I have a few additional questions I will ask as a poll on the material we just covered.

Review Questions

1. Which type of condenser is almost always seen for industrial refrigeration?
   a. Evaporative
   b. Adiabatic
   c. Air Cooled

2. What is the saturated suction temperature range for low temperature systems in grocery stores?
   a. 10°F to 20°F
   b. -20°F to -10°F
   c. 5°F to 10°F

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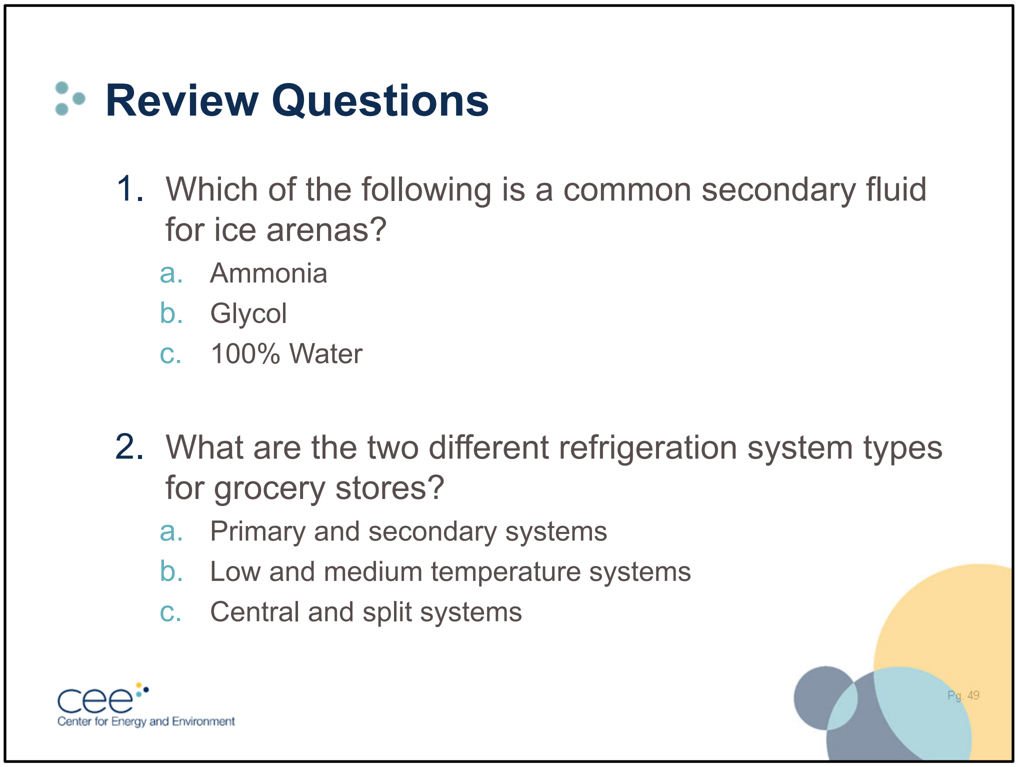
1. a

2. b

These questions will be asked in the google poll and participants will put there answer in the poll prompt.



1. b

2. c

These questions will be asked in the google poll and participants will put there answer in the poll prompt.

Break/Questions?

5 Minute Break

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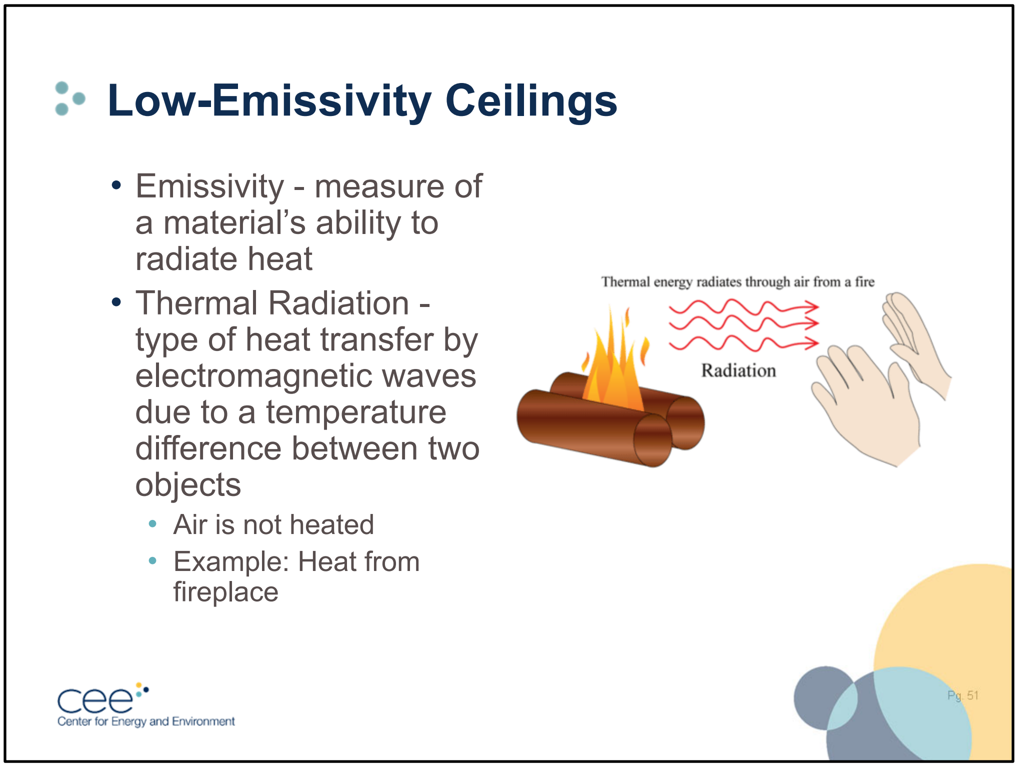

We will now shift gears and begin reviewing energy efficient measures that were developed from the Refrigeration Market CARD Study Russ conducted that can be implemented at the three refrigeration applications we just discussed.

The first two measures apply just to ice arenas with first being low-emissivity or low-e ceilings.

First, lets define what emissivity and thermal radiation are.

Emissivity is a measure of a material's ability to radiate heat. Emissivity can range between 0 and 1. The closer a materials emissivity is to 1 the more heat it will radiate.
Common construction materials such as wood have a high emissivity, 0.85, meaning it radiates 85% of its maximum heat radiation.

Thermal radiation is a type of heat transfer by electromagnetic waves due to a temperature difference between two objects.
The air between the two objects is not heated, only the objects. The higher the temperature difference between the two objects, the more energy that will be radiated.
The current figure on the slide shows an example of thermal radiation which is the heat felt from a fireplace.
Energy is radiated from the hot flames to your body, the colder object.

Low-Emissivity Ceilings

- Thermal radiation makes up 25-40% of total refrigeration load
  - Majority of radiated heat comes from warm air near ceiling
- Polished aluminum is used as the low-e ceiling material
  - Emissivity = 0.03
- Usually extends 5 to 10 feet wider than the ice surface

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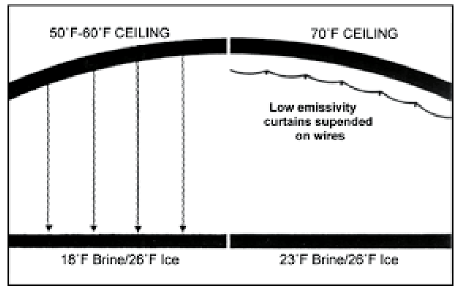
Ice arenas are commonly built with wood or painted metal ceilings which have a high emissivity.
Heat from lights, people, heaters, and equipment warm the air in the arena which rises naturally and warms the ceiling surface.
The ceiling directly faces the ice, a much colder surface, and heat transfer by thermal radiation constantly occurs between the two materials.
This can make up 25-40% of the total amount of heat that must be removed by the refrigeration system.

Because of this high impact on the refrigeration load, low-e ceilings are commonly implemented in existing and new arenas.
Polished aluminum, which has an emissivity of 0.03, is commonly used as the material for a low-e ceiling.
Meaning a low-e ceiling can reduce the amount of heat radiated from the ceiling to 3% of its maximum value.

It is laminated with either a vinyl or fiberglass backing for strength against flying pucks.
A key point to remember as shown in the current figure on the slide is that the low-e surface must point down to the ice and cover a ceiling area 5 to 10’ wider than the ice surface as thermal radiation can occur at all angles.

Low-Emissivity Ceilings

- Benefits:
  - Reduces total refrigeration load and heating load
  - Helps maintain ceiling temperature above the air's dewpoint
  - Improve lighting levels and potentially reduce number of fixtures
  - Increased glycol temperature
  - Low payback, approximately 2 to 4 years



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With a low-e ceiling installed, ice arenas can greatly reduce how much heat they must remove resulting in less energy consumption from the refrigeration system.
Studies have shown it can provide a reduction in total refrigeration load by 23 to 38%.

The heating load for the space can also be reduced by about the same amount.

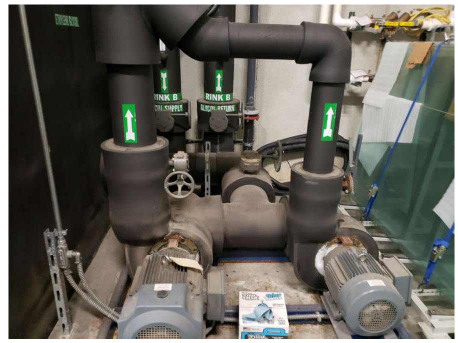
Low-e ceilings also have additional benefits besides a reduction in refrigeration and heating loads.
Ceiling condensation is reduced as the low-e ceiling helps keep the inside ceiling surface warm and above the dewpoint of the air.

They can improve the interior lighting due to the very high light reflectance from the polished aluminum surface.
This can help in reducing the number of lighting fixtures required to light the arena.

The current figure on the slide shows that the glycol temperature under the ice could be increased due to the decreased heat load on the ice.
Low-e ceilings can be installed in new or existing facilities and offer a fairly low payback of 2-4 years.

VFD/Staging of Glycol Pumps

- Ice arenas typically have two glycol pumps
  - Unequal sized
    - One large ≈ 15-40 hp
    - One small ≈ 7.5-20 hp
  - Equal sized
    - 20-60 hp
- Inefficient control
  - Not using VFD appropriately
  - Operating large pump continuously
  - Not alternating pumps



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This next measure again pertains specifically to ice arenas.

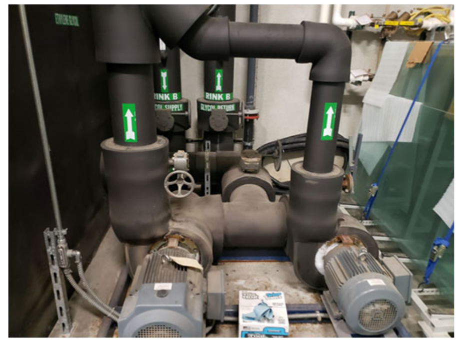
Commonly, there are two glycol or secondary fluid pumps for maintaining the ice temperature in a rink.
Often, the two pumps are two unequal sizes but in some facilities they will use two similar sized pumps for redundancy purposes if one fails.
Two equal sized pumps typically have a size between 20 to 60 hp. Rarely should both similar sized pumps be operating at the same time as it is very inefficient.
Most rink operators realize that only one of the similar sized pumps need to operate to maintain the ice temperature even during peak loads.

If two unequal sized pumps are used the large pump can be between 15 to 40 hp and the smaller pump about 7.5 to 20 hp.
This figure on the slide shows the size difference between two glycol pumps.

These pumps are sometimes controlled inefficiently by either not using a variable frequency drive (VFD) appropriately, if one is installed, operating the large pump continuously even during low refrigeration loads or not alternating the pumps.
This measure focuses on improving the operation and control of glycol pumps.

VFD/Staging of Glycol Pumps

- Optimum control methods:
  - Stage pumps based on refrigeration load
  - Use VFD to step down speed of pump during low refrigeration loads



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There are two control methods that can be implemented to improve the operation of glycol pumps.

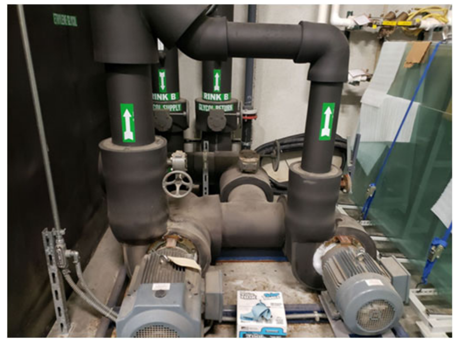
The first, is staging the pumps to come on as the refrigeration load changes.
One method of pump staging is operating the small pump when the refrigeration load may be lower, like during winter or when the ice rink is unoccupied, and then stage the large pump on and the small off once the load has increased above a certain point.

The second control method can be implemented if a VFD is installed on either of the pumps.
Using the VFD, the pump speed can be reduced in stages.
For instance, if the large pump has a VFD its speed can be reduced from 60 Hz down to 40 Hz and then 20 Hz as the refrigeration load decreases.
The small pump could then be staged on at different periods such as when the speed rises from 20 Hz to 40 Hz.

Either of these control methods can yield the following benefits.

VFD/Staging of Glycol Pumps

- Benefits:
  - Can reduce pump peak electric demand
  - Lower energy consumption
  - Extends pump life



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If both pumps had been operating together a majority of the the time or the large pump was operating continuously most of the time, staging the pumps can reduce peak electric demand from the pump.

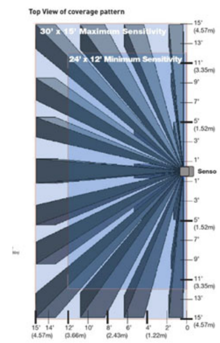
This measure will reduce the electric energy consumption of the pumps.

Finally, the life of the pumps can be extended by not operating one continuously or at 100% speed.

This can be a rather simple measure to implement at ice arenas, especially if a VFD is already installed, that doesn't require many changes.

Grocery Store Case Lighting Controls

- Lights typically on all the time during store hours
- No means of shutting off lights
- Occupancy sensors turn lights on only when customers are near



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The next measure pertains specifically to grocery stores and deals with lighting for the refrigerated cases.

Refrigerated case lighting in grocery stores are commonly on all the time during store hours.
There is no means of shutting these lights off when customers aren't viewing the products.

To improve the controls and efficiency of the case lighting, occupancy sensors, such as the one shown in the current figure on the slide, can be installed to turn lights on only when customers are nearby.
The sensor will detect motion in a large coverage area and will turn lights on upon movement.
The lights will then turn off if no motion is detected after a certain period of time.

Grocery Store Case Lighting Controls

- To identify look for occupancy sensors on top of doors
- Typically installed with LED lights
  - Switching fluorescent lights on/off reduces lamp life
  - Switching LED light on/off increases lamp life

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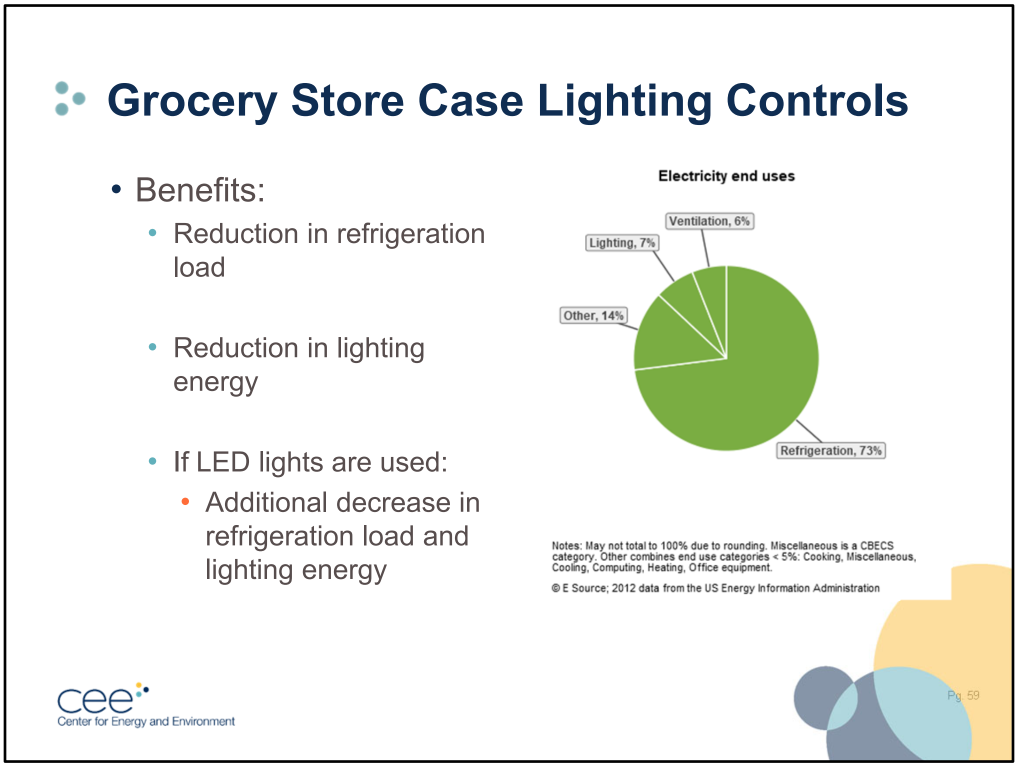
To identify if occupancy sensors are installed at an existing grocery store, look for a sensor as shown in the current figure on the slide on the top of the doors.
It will normally be centered in a bank of doors.

Many times when occupancy sensors are installed for refrigerated cases, LED lights are also installed if they weren't already.
Switching fluorescent lights on and off frequently can reduce their lamp life.

LED lamp life will increase, as the on/off cycling doesn't affect them as the longer they stay off the longer they will last.



The current figure on the slide shows that lighting and refrigeration make up about 80% of the total electricity use for grocery stores.
By implementing occupancy sensors to control refrigerated case lighting, the amount of heat that needs to be removed can be reduced as the lights will be on less and emit less heat into the cases.

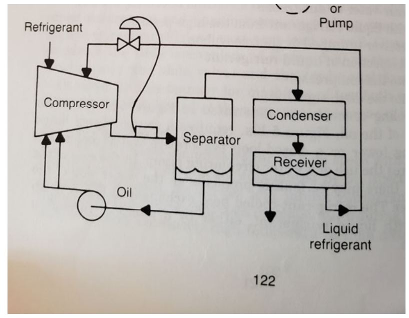
The amount of energy consumed by the lighting will also reduce as they will be on less frequently.

These savings can be increased if LED lights are used or installed with the sensors.
LED lights emit less heat and consume less electricity than fluorescent.
The lamps themselves will also last longer if LED lights are used.

Many stores are moving towards LED lighting so adding occupancy sensors is a simple measure to implement to further improve energy savings and operation.

Thermosiphon Oil Cooling

- Common method is liquid injection oil cooling
  - High pressure liquid refrigerant is injected into compressor side port
  - Expansion valve modulates flow of refrigerant and drops its temperature
  - Liquid absorbs heat from oil
- Cons:
  - Compressor work increases
  - Reduced refrigeration capacity



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The next two measures pertain specifically to industrial refrigeration.

The first is thermosiphon oil cooling.

During our review of compressors, I mentioned the need for oil lubrication for reciprocating and especially screw compressors.
The moving parts must be lubricated continuously to ensure the compressor operates correctly.

With the lubrication process, oil and refrigerant will mix and be discharged from the compressor together.
The oil will then be separated from the refrigerant but will be at a high temperature.
Before the oil can by pumped through the compressor again, it needs to be cooled.

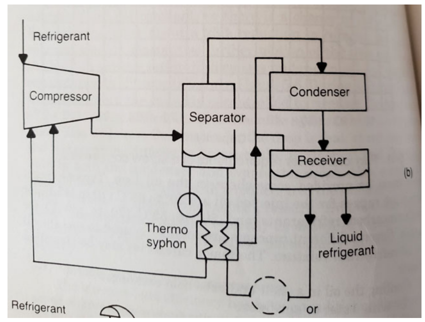
A common oil cooling method for industrial refrigeration applications is liquid injection oil cooling.
The figure on the slide shows how this method injects high pressure liquid refrigerant, from the discharge of the condenser, into the compressor through a side port.
This liquid refrigerant is metered into the compressor by an expansion valve where it drops in pressure and cools. This is similar to what happens before an evaporator.
The refrigerant then absorbs heat from the oil and some of the refrigerant vapor in the compressor.

This is a very inefficient method to cool the oil for two main reasons.
First, the amount of work done by the compressor increases at it must now raise the pressure of the injected liquid refrigerant along with the normal refrigerant vapor entering the compressor.
Second, the compressors refrigeration capability decreases.

An alternative and more efficient cooling method is to use Thermosiphon oil cooling.

Thermosiphon Oil Cooling

- Thermosiphon oil cooling uses a separate heat exchanger
  - ***Elevated*** receiver supplies high pressure liquid refrigerant
  - Oil exchanges heat with refrigerant, making it a vapor
  - Vapor flows to condenser inlet



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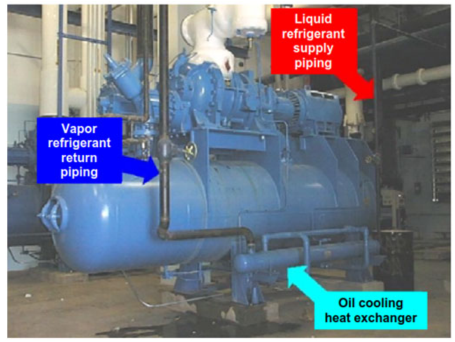
The figure on the slide shows a diagram of thermosiphon oil cooling which uses a separate heat exchanger to cool the oil with liquid refrigerant before its recirculated back into the compressor.
The key to this method is an elevated receiver that supplies high pressure liquid refrigerant by gravity to the heat exchanger.
The refrigerant absorbs heat from the oil and evaporates.
The evaporated refrigerant is then directed towards the condenser inlet to remove the heat it absorbed from the oil.

By using this method, the cooling liquid refrigerant doesn’t need to go through the compressor and increase in pressure again adding to the amount of energy it consumes. The condenser must use a little more energy to remove the heat absorbed from the cooling liquid refrigerant, but the amount of energy used is small compared to what the compressor would use.

Thermosiphon Oil Cooling

- Benefits:
  - Less compressor power used
  - Increases opportunity to lower minimum head pressure
    - Expansion valve requires a minimum pressure difference
  - Prolongs life of compressor



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Implementing this measure in industrial refrigeration screw compressors, provides the following benefits.

Less compressor power is used since the cooling liquid refrigerant doesn’t need to have its pressure increased again.

It allows for a lower minimum head pressure at the condenser.
The expansion valve used in liquid injection cooling requires a minimum pressure drop, just like the expansion valve before the evaporator.
This can necessitate the need to have a higher minimum head pressure than otherwise would be required in order for it to work correctly.

Additionally, thermosiphon oil cooling prolongs the life of the compressor as it is less stressful on the components of the it.

This is a great measure to recommend for screw compressors to help improve the efficiency of the compressor and its oil cooling system.

High Speed Doors

- Implemented in industrial refrigeration
- Standard rolling doors open and close in 11 seconds
- Power operated door system that open/close quickly
  - Can open and close in as short as 2 seconds

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The second measure specifically for industrial refrigeration pertains to the doors for the cooler and freezer warehouses.

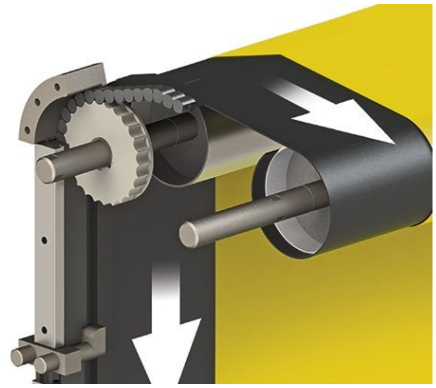
The doors for freezers and coolers in cold storage warehouses are typically power operated to allow forklifts to enter and leave to move product.
When these doors open, warm air will enter the refrigerated space, increasing the amount of heat that must be removed by the refrigeration system.

Standard automatic doors can take up to 11 seconds to open and close.
These doors are frequently used throughout the day and can cause fluctuations in product temperature.

To reduce the amount of time it takes for the door to open and close, high speed doors can be implemented and installed.
High speed doors, like in the figure shown on the slide, are power operated that can open and close very quickly with some being able to open and close in as little as 2 seconds.
It may not seem like much of a difference but when the time to open and close the door is viewed from yearly perspective, the amount of energy that can be saved adds up.

High Speed Doors

- Benefits:
  - Reduce amount of incoming warm air into refrigerated space
    - Reduces refrigeration load
  - Limits risk of losing product quality
  - Better sealing when closed
  - Increases productivity
  - High cycle life



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High speed doors offer the following benefits.

First, they reduce the amount of incoming warm air into the refrigerated space.
This reduces the amount of heat that must be removed by the refrigeration system and thus provides lower energy consumption from the compressors and condenser.

Second, with shorter open/close times, it reduces the risk of losing product quality with fluctuating space temperatures.

Third, these doors typically provide better sealing when closed than standard powered doors.
This means the amount of air that moves through the closed door into the space is reduced.

It also can provide increased productivity from employees.
Forklifts can quickly enter and leave the storage spaces and drivers won't have to wait for extended periods for the door to open or close.

Finally, these doors have high cycle life, and can last much longer than standard powered doors.

High speed doors allow the refrigeration system and operation of industrial cold storage warehouses to work more efficiently.

Before we continue on to the next measure, I have a few review questions on the measures we just discussed.

Review Questions

1. Thermal radiation makes up what percent of the total heat in ice arenas?
   a. 5-10%
   b. 25-40%
   c. 60%

2. Which of the following is an inefficient way to control the glycol pumps for an ice arena?
   a. Using a VFD to modulate the pumps speed
   b. Always operating the large pump
   c. Staging the small pump to operate at reduced refrigeration loads

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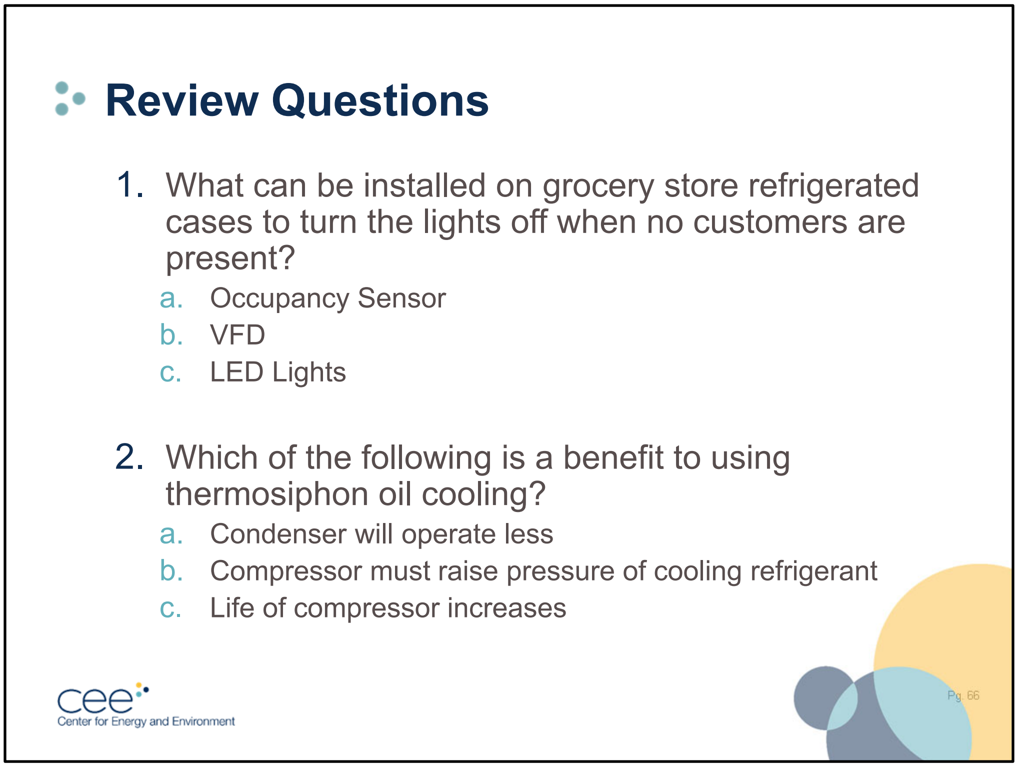
1. b

2. b

These questions will be asked in the google poll and participants will put there answer in the poll prompt.



1. a

2. c

These questions will be asked in the google poll and participants will put there answer in the poll prompt.

Low Speed Condenser Fans

- General speeds available:
  - 540 RPM
  - 830 RPM
  - 1140 RPM (ECM option)
- Condenser input energy increases at higher fan speeds
- Efficiency improves at lower fan speeds

Condenser Info. Summary @ 60 Ton Refrigeration Load, Medium Temp

Condenser Inputs	Baseline, 1140 RPM	1140 RPM, ECM	830 RPM	540 RPM
Mfg. / Model	Russell, RDD-075	Russell, RDD-075	Russell, RDD-080	Russell, RDD-080
Fan Speed (RPM)	1140	1140	830	540
Fan Configuration	2x4	2x4	2x5	2x6
# of Fans	8	8	10	12
Fan Motor HP	1.5	2	1	0.333
Condenser kW Input	14.4	17.6	9	4.2
Condenser Efficiency (BTUH/Total HP)	184967	145438	238460	574600

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This next measure can be implemented at grocery stores or ice arenas that use air cooled condensers.
The measure is only practical though for new systems or if a condenser is being replaced.

As discussed earlier, air cooled condensers typically have three different fan speeds they operate at; 540, 830 and 1140 rpm. The 1140 rpm typically has the option to have EC motors instead of PSC.
At each of these fan speeds, the condenser will have a different peak electrical input expressed in kilowatts or kW for short.

The table on the slide shows the condenser peak electric input in kilowatts for each type of fan speed.
As the speed increases the kW input of the unit also increases.
Condensers will typically operate at peak input at least a few days each month during the summer.

Demand charges from utility companies are based on the single highest electric demand in each month.
So if the condenser operated at its maximum electric input only once during a month, the demand charge will be based on the maximum input.
Anything that can help reduce this peak demand will help decrease the demand charges.

The table also shows that condensers operating with lower fan speeds have better efficiency and can remove more heat per total fan horsepower.

Low Speed Condenser Fans

- Higher speed models generally selected due to smaller footprint and lower first cost
- 540 rpm models provide the largest energy savings

Energy Cost Analysis of Baseline 1140 RPM Air Cool Condenser

Motor Speed	Average Payback	Design Refrigeration Load (Tons)					
		60			40		
		First Cost	Annual Energy Cost Savings	Payback	First Cost	Annual Energy Cost Savings	Payback
1140 RPM	-	$32,663.40	-	-	$23,466	-	-
540 RPM	4.6	$50,390.90	$ 3,792.65	4.7	$36,476	$ 2,821.47	4.6
1140 RPM, ECM	6.1	$50,100.75	$ 2,739.49	6.4	$36,570	$ 2,279.28	5.7
830 RPM, 1 HP	4.2	$41,023.15	$ 1,660.79	4.8	$27,154	$ 1,099.18	3.6

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Higher speed condensers are used more often due to their smaller footprint and lower first costs.
What is not typically looked at though is the operating costs and paybacks of the condensers if they operated at lower fans speeds.

The table on the slide shows the estimated annual energy cost savings for the 540, 830 and 1140 RPM with ECM condensers compared to the 1140 RPM condenser.
Energy savings were calculated at two different refrigeration loads, 40 and 60 Tons, to compare between condenser models.
As mentioned earlier, 1 ton is equal to 12,000 btu/hr.
A 40 ton refrigeration load equates to 480,000 btu/hr of heat that must be removed.

As can be seen, the first cost of the condenser increases as the fan speed increases with the 1140 RPM with an ECM having the highest first cost due to the cost of the motors.
The 540 rpm condenser has the highest energy savings between the three models due to its much lower peak demand input.
It also has a short average payback of a little over 4 years.

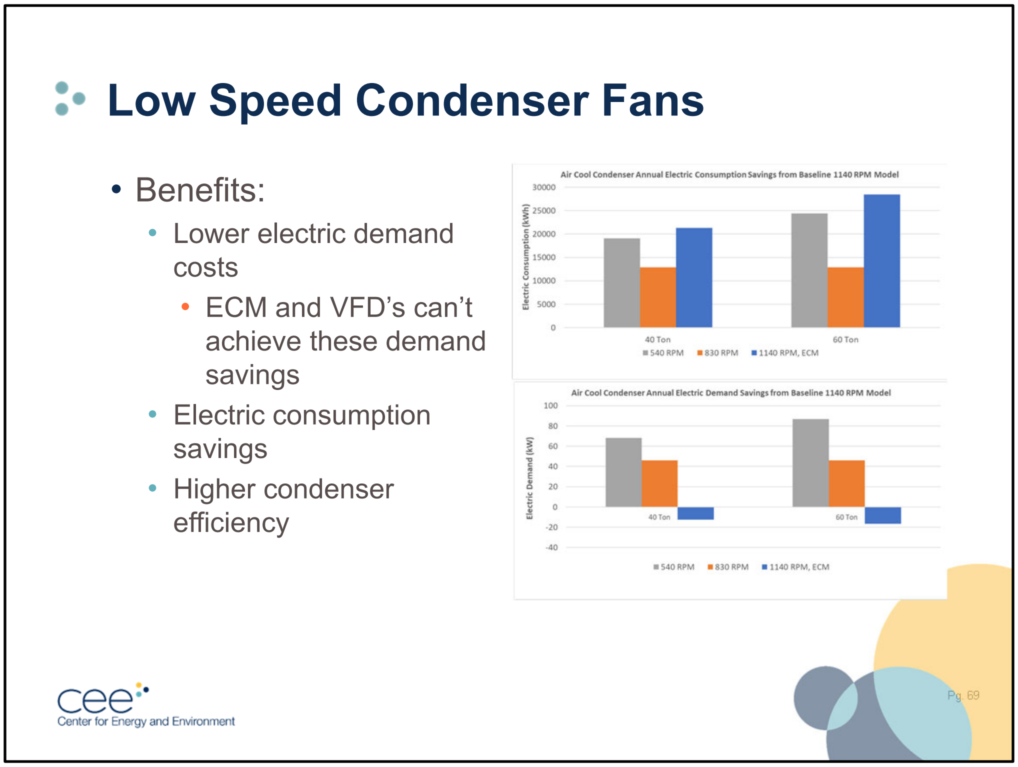
The 1140 rpm with ECM provides good energy savings but with its high peak demand input, it's not able to provide as much savings as the 540 rpm model.
It's high first cost also increases the payback.

The 830 rpm offers the best payback due to its first costs being fairly close to the standard

1140 rpm, but provides the lowest amount of annual energy savings between the three condensers.

Overall, the 540 rpm condenser can provide great energy savings and reduce a client's electric demand costs especially during summer months.

The demand savings provided by the 540 rpm model can’t be achieved with the 1140 rpm model even with an ECM.



Installing a condenser with a low fan speed can provide the following benefits.

First, electric demand costs will be much lower due to the lower peak electrical input. 1140 rpm condensers with ECM's or VFD's can't provide demand savings like the lower speed condensers.

The bottom bar graph on the slide shows the electric demand savings of the 540, 830 and 1140 rpm with an ECM condensers compared to a standard 1140 rpm condenser.
The 540 rpm model provides the highest demand savings.
This becomes beneficial in hot climates, like MN, where the condenser could be operating at its peak electric input at least a few times each summer month.
The 1140 rpm ECM, for this condenser manufacturer, provided negative demand savings as its maximum electric input was higher than the standard 1140 rpm model.

The 1140 rpm ECM can provide higher energy consumption savings as shown in the top bar graph but the 540 rpm can provide comparable energy savings in addition to the demand savings.

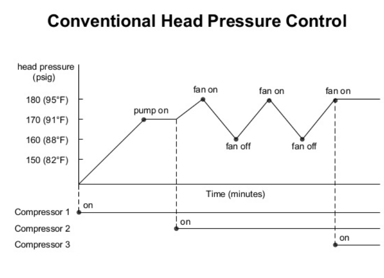
The lower fan speed condensers also have higher condenser efficiencies, allowing them to remove more heat for less motor horsepower.

To reiterate, this measure is only practical for new systems or for condensers that are being replaced.

All these items should be taken into consideration and reviewed before selecting which condenser to install at a new site.
The 1140 rpm condenser may look like the best fit due to its lower first cost and smaller footprint but it can’t deliver on energy savings and demand reduction like the lower speed condenser fan models.

Condenser Fan VFD Control

- Three ways to control condenser fans:
  - On/Off
  - Two Speed
  - Variable Speed
- Fan control can be a mix of operation
  - Stage most fans on/off with 1 or 2 variable speed fans
- Applies to all types of condensers



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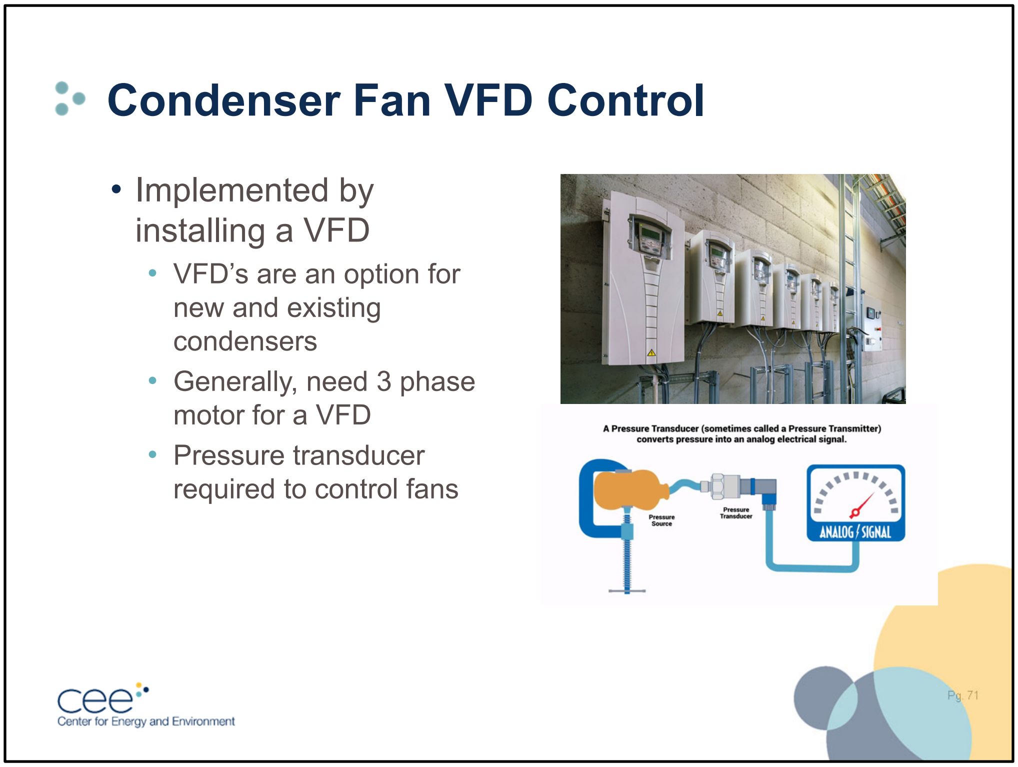
This next measure can be implemented at all three refrigeration applications and for all types of condensers.

We spoke earlier of different ways the condenser fans can be controlled to maintain the minimum head pressure for the system.
The three methods are on/off, two speed or variable speed.

The current figure on the slide shows the most common method which is cycling the fans on/off.
As the pressure begins to rise above a certain value, the fans will cycle on and then turn off once the pressure has fallen below a certain value.
This cycling can create inconsistent head pressures and decrease the life of the fans.

This measure pertains to using VFD’s to modulate the speed of the condenser fans.
VFD’s could be installed on a single fan, all the fans or just a set of fans depending on how large the condenser is and how much heat must be removed.
VFD’s can be used on all types of condensers, air cooled, adiabatic or evaporative.



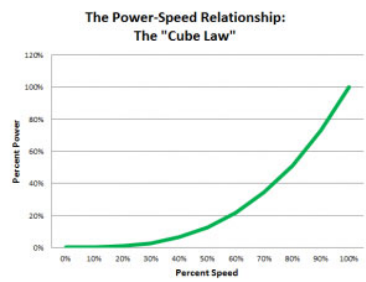
You can identify if this measure has been implemented by verifying if there is a VFD located in a mechanical room for the condenser fans.
A VFD will commonly look like what is shown in the current figure on the slide.

VFD's can be easily installed in new and existing condensers and are generally found on large motors, 2 hp and greater, and require 3 phase electric power.
As mentioned in the previous slide though, a single VFD can also be used to control multiple smaller fans, between ½ to 1 hp, instead of just a single fan.
This is a much more efficient approach and can increase the annual energy savings when a single VFD is used to control multiple small fans on a condenser

One additional component is needed in order to vary the speed of the fan and that is a pressure transducer.
The current figure on the slide shows a pressure transducer which is a sensor that converts a measured pressure into something that can be used by the VFD.

Condenser Fan VFD Control

- Benefits:
  - Reduction in fan energy consumption
  - Less fan cycling
  - Stable head pressure
  - Reduced sound at lower fan speeds
  - Evaporative condensers save energy by optimizing control of fans and pump
    - Reduces water scaling



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Using a VFD to control the speed of the condenser fans can provide the following benefits.

First, the amount of power used is reduced exponentially as the speed of the fan reduces.
The figure on the slide shows how the amount of power used by the condenser relates to a change in speed.
Reducing the speed by 30%, decreases the power input by approximately 70%.
On large motors, this can dramatically reduce the amount of energy consumed.

The fans will cycle on and off less if they modulate, which can increase their life span.

Another benefit is the head pressure will be more consistent if the fan speeds modulated compared to fans that are cycling on/off.
Fans cycling on/off don't react as quickly as a fan that is continuously ramping its speed up and down.

As the fan speed decreases, the amount of noise generated will be reduced.
This can be important in sound sensitive areas.

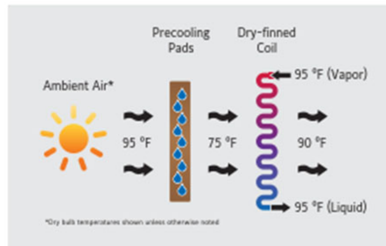
Finally, evaporative condensers can reduce their energy consumption by modulating the fan speed with the control of the water pump.
Typically, the water pump will run continuously and the VFD will ramp the fan speed up and down as needed to maintain the head pressure.
This can also reduce the amount of water scaling on the condenser which is the buildup of

sediment from the water on the condenser coils.

Implementing VFD control on condensers can provide multiple benefits that improve the operation of the condenser and the refrigeration system as a whole.

Adiabatic Condensers

- Similar operation to air cooled but can reduce temperature of outdoor air
  - Reduces required condenser saturation temperature
  - Critical during peak operating conditions
- Can operate dry during mild weather conditions



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We discussed adiabatic condensers briefly earlier in the presentation, but I will now go into a little more detail as they are an energy efficient measure that can be implemented for new ice arenas or grocery stores.

Adiabatic condensers operate in a similar manner as air cooled condensers but are installed with precooling pads.
The current figure on the slide shows how the precooling pads are saturated with water and can lower the temperature of the incoming outside air before it is blown over the condenser coils.
Because the outside air temperature is reduced, the required condensing saturation temperature can be reduced.

This becomes very beneficial during peak operating conditions when the outside air temperature can be up to 95F.
For example, if the outdoor air temperature is 95F and can be cooled down to 75F as shown in the current figure on the slide, the condenser saturation temperature can be 95F instead of 110F as would be typical on an air cooled condenser during peak operation.
This provides energy savings for the compressors as they don't need to climb as high of a hill to raise the refrigerants pressure.

Adiabatic condensers also have the capability to operate dry, or without water in the precooling pads, during mild weather conditions to conserve the amount of water used.
The condensers capacity must be verified that it can remove the required amount of heat

when operating dry otherwise the condenser saturation temperature will increase and you will lose the benefits of an adiabatic condenser.

Adiabatic Condensers

- How to distinguish:
  - Precooling pads on sides
  - Typically more compact, smaller footprint
  - Water pump for pads
    - Water can be circulated or once through
    - If circulated, usually replaced regularly to avoid contamination

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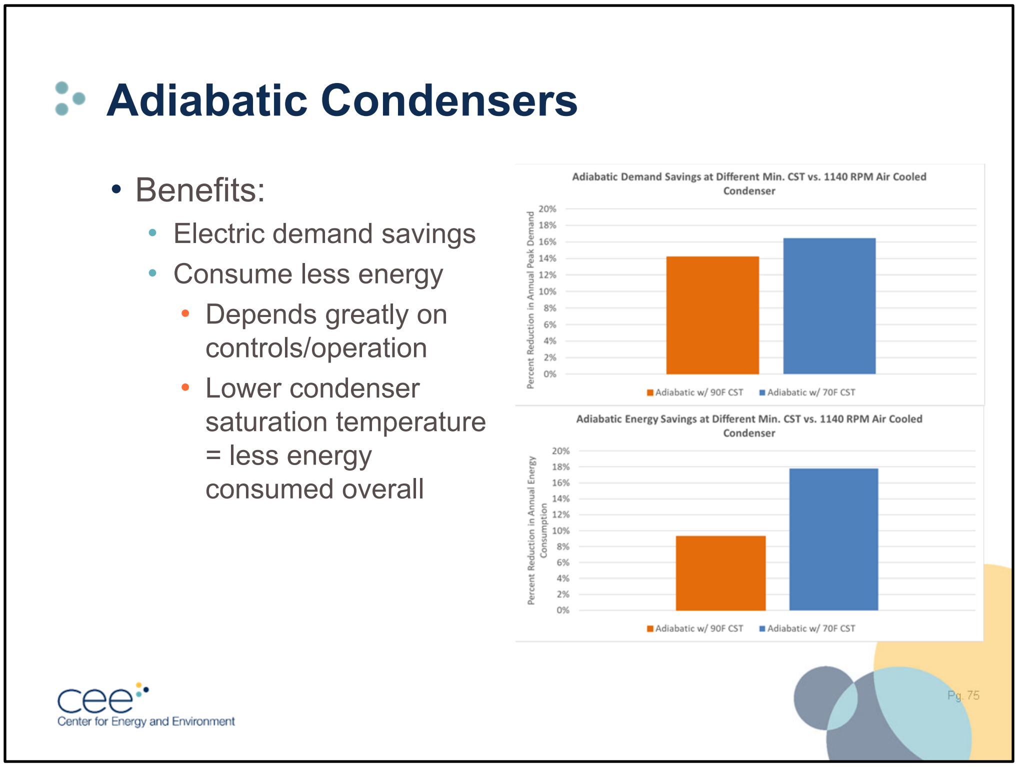
Adiabatic condensers can be distinguished from air cooled condensers in the following ways.

The precooling pads can normally be seen from outside the condenser as they are installed along the sides.
The current figure on the slide shows the precooling pads which is the orange material you see on the side of the condenser.

Adiabatic condensers are typically more compact, have fewer but larger fans and have a smaller footprint than air cooled condensers.

It was also have a water pump for either circulating or providing once through water for the precooling pads.
If the water is circulated, there is normally a small reservoir that holds the water.
This water is usually replaced every few hours to avoid any bacteria growth.



Compared to air cooled condensers, adiabatic condensers provide the following benefits. The one item that needs to be kept in mind though is the minimum condenser pressure for the system.

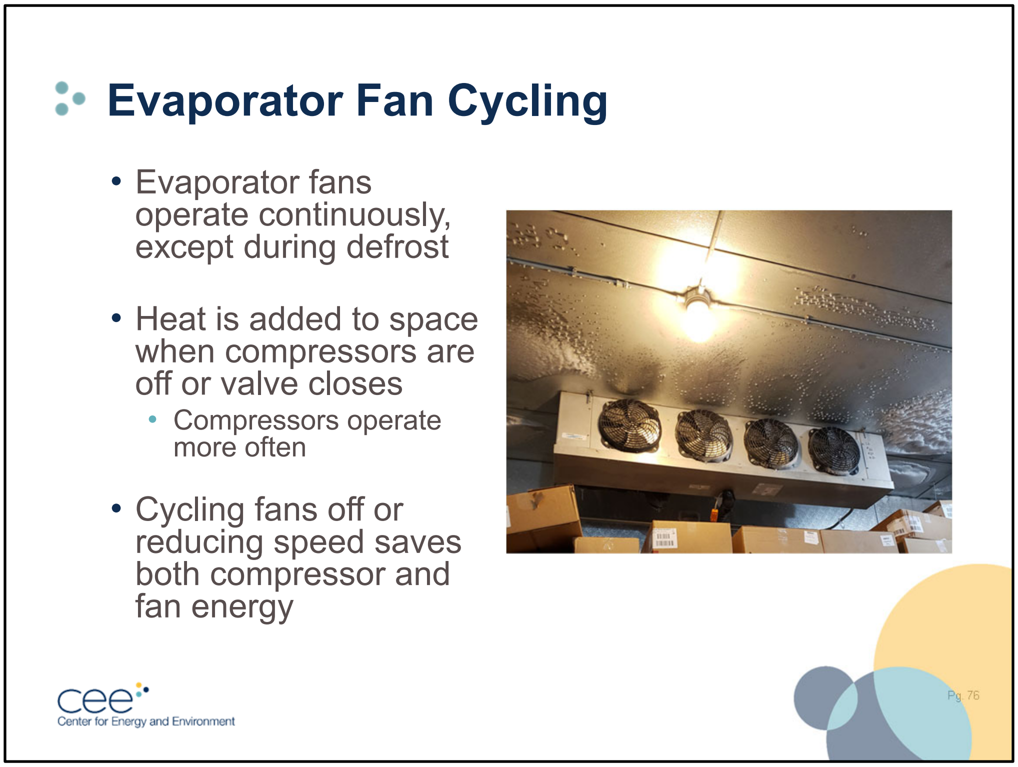
Adiabatic condensers provide electric demand savings during peak operating hours as the compressors don't use as much energy to raise the pressure of the refrigerant.
As seen in the top bar graph, adiabatic condenser demand savings compared to 1140 rpm air cooled condensers are similar whether the adiabatic condenser operates at a high minimum condenser saturation temperature, 90°F, or a low one, 70°F.

Adiabatic condensers consume less energy compared to 1140 rpm air cooled condensers, but unlike demand savings, the amount of energy consumption savings is affected by the minimum condenser saturation temperature setpoint.

As seen in the bottom bar graph, an adiabatic condensers energy savings compared to an 1140 rpm air cooled condenser is much greater when it operates with a low minimum condenser saturation temperature, 70°F.
The energy savings operating at a low minimum condenser saturation temperature are almost doubled when compared to an adiabatic condenser operating with a high minimum condenser saturation temperature, like 90°F.

By allowing the adiabatic condenser to operate with a low minimum condenser saturation temperature especially as the outside air temperature drops, the compressors will

consume less energy.
The key benefit of adiabatic condensers is being able to have a lower peak design condenser saturation temperature.
If we keep the system minimum high, around 90F, you’re limiting the full operating capability of the adiabatic condenser.
It’s important this is known, as just installing an adiabatic condenser without looking at the refrigeration system as a whole can limit the amount of energy savings.



The next measure we will review is Evaporator Fan Cycling and can be implemented in grocery stores and industrial refrigeration applications.

Typically, evaporator fans operate continuously except during their defrost cycle. The exception to this is if off-time defrost is used.
Either way, evaporators essentially operate 24/7 even when the compressors are off.

For small refrigeration split systems, when the saturated suction temperature is satisfied, the compressors will turn off but the evaporator fans remain on.
In central refrigeration systems, there will be a space temperature sensor that opens and closes a solenoid valve that will stop the flow of liquid refrigerant to the evaporator.
When the space temperature is met, the valve will close preventing refrigerant from entering the evaporator. The fans will continue to operate though.

When either occurs, the evaporator coil becomes warm and heat will be added to the space.
This will then cause the compressors to operate more often and potentially cycle for split systems.

If the evaporators fans can be cycled off or reduce their speed when the compressors are off this can save both fan and compressor energy.
This is where implementing the evaporator fan cycling measure can help.

Evaporator Fan Cycling

- Typically identified by a fan controller
- Any evaporator can implement fan cycling
- EC motor required for speed reduction in commercial systems
- VFD required for speed reduction in industrial systems

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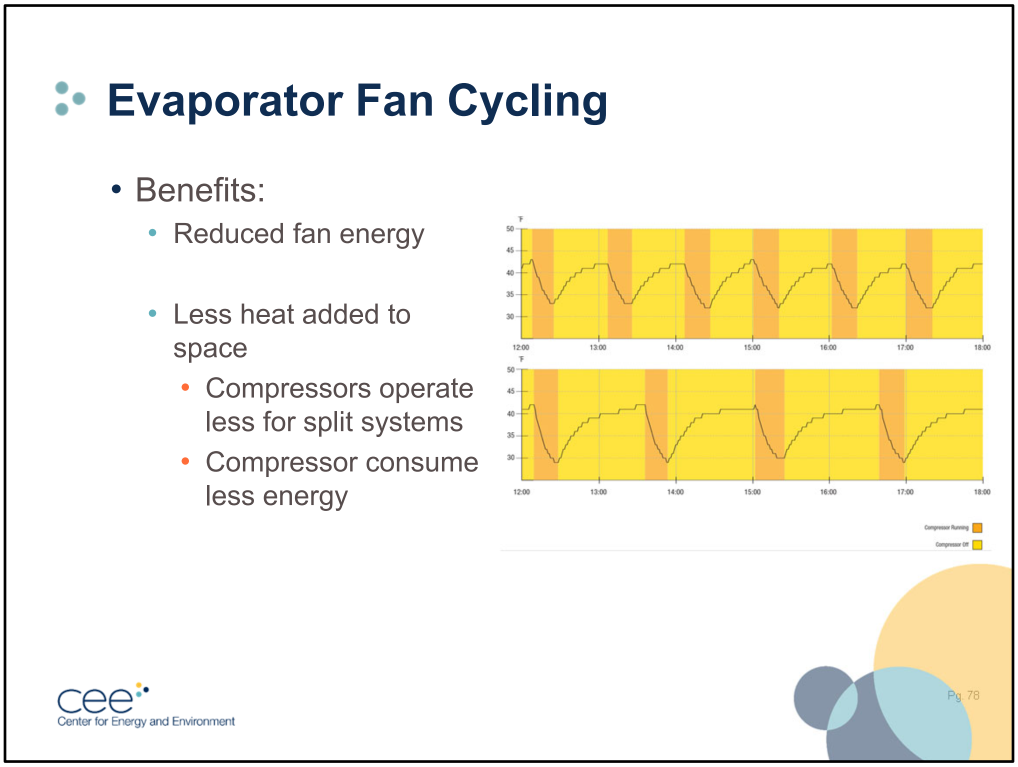
To identify if an existing evaporator has the capability to cycle its fan, there will normally be a controller similar to the ones shown in the figure on the slide.
These controllers control the operation of the fan and will turn them off when the compressor cycles off.
Any evaporator can implement a fan cycling control method.

For an evaporator in a grocery store application to reduce its fan speed instead of cycle on and off, an EC motor must be installed if one is not already present.
This will provide the fan the means of controlling its speed.
EC motors can normally replace most PSC motors for existing evaporators.

For industrial cold storage, a VFD is required in order to reduce its speed.



Implementing fan cycling or speed reduction for evaporator fans has multiple benefits.

First, there will be a reduction in fan energy consumed as they operate less or at lower speeds.

Second, less heat will be added to the space during the compressor off time for split systems and when the solenoid valve closes in central systems.
This reduces the amount of heat that must be removed, the amount of time the compressor will operate for split systems and the amount of energy consumed by the compressors.

The graphs on the right shows a walk-in coolers space temperature and the compressor runtime serving that cooler.

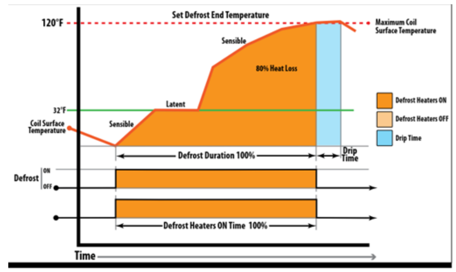
The top graph shows how often the compressor operates and how much the space temperature varies when no fan cycling is implemented.
The bottom graph shows the compressor operation when fan cycling is used.
The orange bands are the times when the compressor is on and the yellow bands are when it's off.
The black line shows how the temperature of the space changes throughout the day.

The space with evaporator fan cycling had a 33% reduction in compressor runtime, and the space temperature didn't increase as quickly between compressor cycles.

This is a measure worth implementing for existing and new evaporators in grocery stores and industrial cold storage.

Improved Freezer Defrost Control

- Defrost cycles typically scheduled
  - Example: 4 cycles per day, 45 min each
- Excess heat created when cycle goes beyond actual time needed
- Improved controls start cycle only when needed and terminate when complete



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The next measure explores improved freezer defrost controls for evaporators in grocery stores and industrial refrigeration.

Earlier, we spoke of the necessity of having evaporator defrost cycles for walk-in freezers for grocery stores and industrial cold storage.
Overtime, frost will develop on the coils of the evaporator due to water condensing out of the air as it's blown over the coil and cooled.
Electric heaters or hot gas is then used to melt the frost on the coils.

Often, these defrost cycles are scheduled to occur several times per day for a preset amount of time.
These occur regardless if the evaporator needs to remove any frost from the coils.

The figure on the slide shows a typical electric defrost cycle and the temperature the evaporator coil can become.
The coil is heated much higher than required, 120°F in this case, and the defrost electric heaters remain on the entire time.

Because of this, excess heat is created from the heaters when the cycle occurs more than needed or goes longer.
This excess heat must then be removed by the refrigeration system, causing the compressor and condenser to use more energy.

By implementing improved freezer defrost controls, the defrost cycles can be initiated only when needed.

This reduces the amount of excess heat developed from the cycle that would need to be removed and reduces the amount of energy consumed by the heaters.

Improved Freezer Defrost Control

- Best fit for low temp applications
- Requires controller and temperature sensors
  - Uses coil temperature to initiate and end cycle
- Can be integrated into Building Automation System or operate standalone

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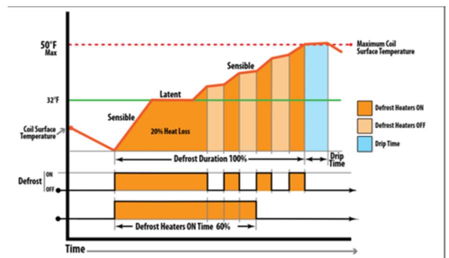
Improved defrost controls are best suited for low temp categories such as walk-in freezers where frost can develop more often.
Walk-in coolers do not see enough energy savings to warrant installing this control method.

To implement this measure, there are specific controllers that use temperature sensors on the evaporator coil to determine when defrost cycles should be initiated and for how long.
The figure on the slides shows a common controller from KE2 Therm Solutions.
They are rather simple to install and can be used on all evaporators with electric defrost.

The controller can be integrated into a Building Automation System if the building has one.
This is often done in industrial refrigeration where an automation system is already in place
This allows for easy access and the ability to change setpoints, if needed, remotely.
In grocery store applications, these controllers will normally operate standalone.

Improved Freezer Defrost Control

- Benefits:
  - Eliminates unneeded cycles
  - Reduces heat generated into space and compressor energy
  - Reduces energy consumed from electric heaters
  - More consistent product/space temperatures



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By implementing improved freezer defrost controls the customer will see many benefits.

First, it eliminates unneeded defrost cycles.
Cycles will now occur only when the controller determines one is needed.

A result of this is that less heat is generated into the space.
The refrigeration system doesn't have to remove as much excess heat from the electric heaters or the hot gas.
The figure on the slide shows a typical operation of an evaporator with electric defrost that is utilizing improved freezer defrost controls.
The coil temperature is much lower, 50°F, and the defrost heaters cycle on and off during the cycle. Reducing the amount of energy they consume.

Another benefit is there will be more consistent product and space temperatures.
The space temperature won't rise as much during the defrost cycle. Ensuring the product always remains at a safe temperature.

This is a very common measure implemented for walk-in freezer evaporators that can provide great benefits for an easy implementation.

Review Questions

1. True or False: The evaporator fan cycling measure can only be implemented for new evaporators.

2. Which air cooled condenser fan speed provides the most energy savings compared to a standard 1140 rpm condenser?
   a. 830 RPM
   b. 1140 RPM w/ ECM
   c. 540 RPM

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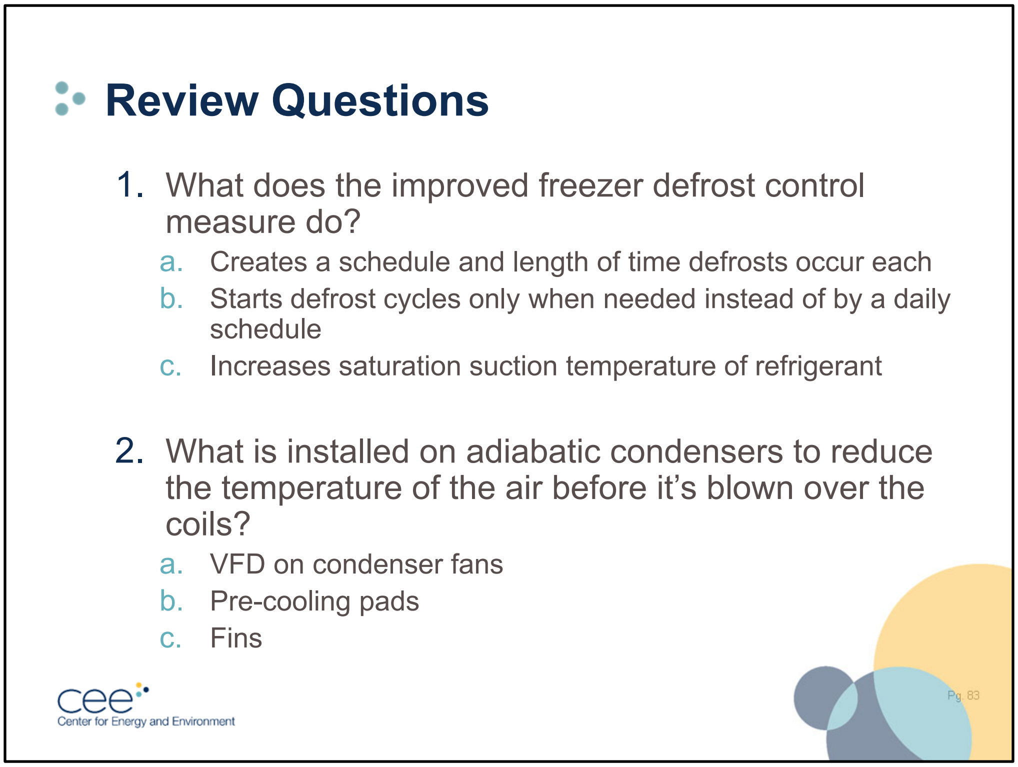
1. False

2. c

These questions will be asked in the google poll and participants will put there answer in the poll prompt.



1. b

2. b

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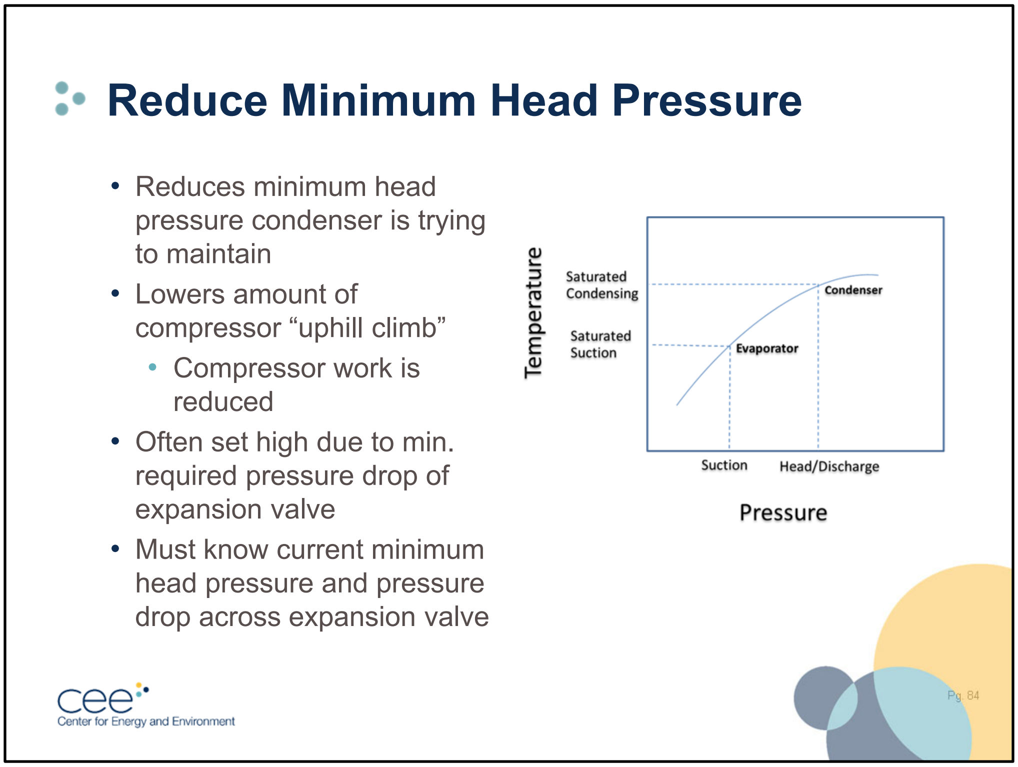


The next two measures we will discuss involve changing parameters in the refrigeration system that help reduce the amount of uphill climb the compressor performs when increasing the pressure of the refrigerant.

The first measure looks at reducing the minimum head pressure setpoint at the condenser. This can be implemented for any type of condenser at any of the three applications.

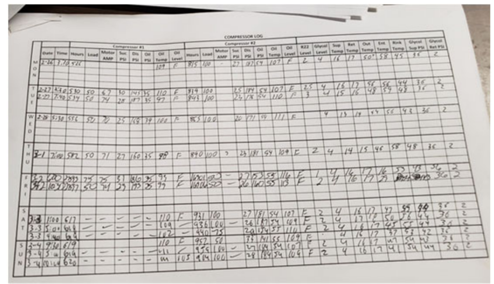
If the minimum head pressure setpoint can be reduced we lower the amount of "uphill climb" the compressor must do to increase the refrigerants suction pressure to the systems head pressure.
This can be visualized in the figure on the slide. The top of the hill is reduced, and the compressor consumes less energy on its climb.

The minimum head pressure is set high in many systems due to the expansion valve as we learned earlier in the presentation.
For the expansion valve to work correctly, it requires a minimum pressure drop across it.
When the minimum head pressure at the condenser is reduced, the pressure drop across the valve is also reduced.
If the pressure drop becomes too low, this can cause poor metering of the refrigerant into the evaporator.

Before this measure can be implemented, the current minimum head pressure and minimum pressure drop required across the expansion valve must be known.

Reduce Minimum Head Pressure

- How to identify min. head pressure setpoint
  - Locate condenser control panel and cut out pressure switch or system controller
  - Compressor logs
- Verify minimum required pressure drop of existing expansion valve
- Contact contractor to assist in verifying current setpoint and making changes



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To identify what the current minimum head pressure is for a system, you will need to locate the mechanical room that houses either the condenser control panel and pressure switch or a system controller.

For many older systems, there will be a condenser control panel.
Typically, on the panel there are pressure switches that set when the condenser fans will turn on and off based on the head pressure setpoints.
For example, if a pressure switch shows a fan starting pressure of about 235 psig.
This means when the refrigerants pressure in the condenser rises above 235 psig, the fans will turn on.
The pressure corresponding to when the fans turn off is the cut in pressure minus the differential.
In this case the differential is about 35 psig.
When the refrigerant pressure falls below 200 psig the fans turn off.
This will be the minimum head pressure for the system.

New or renovated systems may have a central controller that controls the refrigeration system.
In this control panel, you can cycle through different menus for each component of the system.
There may be a page for the condenser like the picture shown.
For this system, the minimum head pressure was 235 psig as shown in the brackets and the current head pressure was 246 psig.

Another way to confirm the minimum head pressure is to review compressor logs.
Most facilities will record daily temperature and pressure readings for maintenance and operation checks.
You can find the compressor discharge pressure and calculate an average over a course of a couple of weeks.
This will give you an approximate value for the minimum head pressure setpoint.

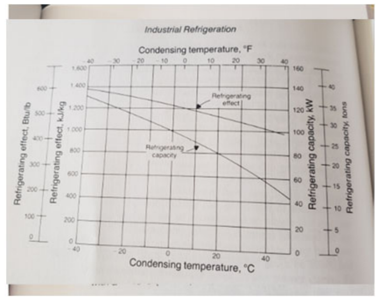
Once the minimum head pressure is known, the minimum required pressure drop across the expansion valve must be verified.
For ice arenas, the expansion valve can be found at the inlet of the chiller.

The model number of the valve is located on the top and the minimum pressure drop can be found from the manufacturers cut sheets.
For industrial and grocery store applications, there may be multiple expansion valves for the different evaporators making it a little more difficult to determine the minimum pressure drop for the system.
Discussions with facility maintenance staff or contractors can help determine what this pressure drop might be.

Once these pieces of information are known, a contractor should be contacted to assist in reviewing and verifying the information you found, and making the appropriate changes to the systems minimum head pressure setpoint.
There are multiple, complex items that need to be reviewed by a licensed contractor before changes are made that are out of the scope of this presentation.

Reduce Minimum Head Pressure

- Benefits:
  - Reduction in compressor energy consumption
  - Refrigeration capacity of compressor increases
  - Condenser fans may not cycle as often



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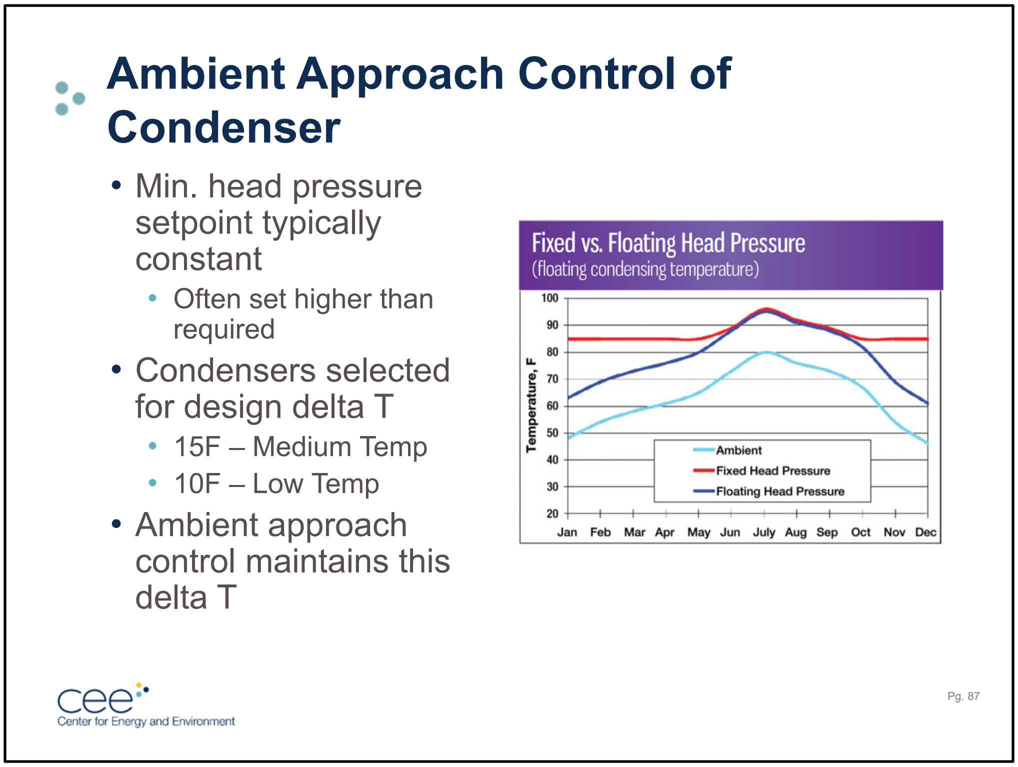
There are multiple benefits to reducing the minimum head pressure for the condenser.

First, the compressor will consume less energy.
There is less up hill climb for the compressor, reducing the amount of work it must perform.
The figure on the slide shows how the compressor power increases as the condenser saturation temperature increases.

Second, the refrigeration capacity of the compressor will increase, improving system efficiency.
The current figure on the slide shows the compressor's refrigeration capacity reacts to a change in condenser saturation temperature.
Refrigeration capacity is the amount of useful cooling the compressor can provide.

Finally, the condenser fans may not cycle as often due to the lower minimum head pressure setpoint.
If the pressure was set high and the fans were controlled as on/off, there is a strong potential they could cycle on/off quickly during milder weather.
This can decrease the life of the fans.



The next measure applies to all types of condensers and can be implemented at all three applications.

As we discussed earlier, the condenser fans are controlled to maintain a minimum head pressure.
Typically, this minimum is constant and often higher than what it needs to be for the system.
Remember this is due to the minimum pressure drop required across the expansion valve.

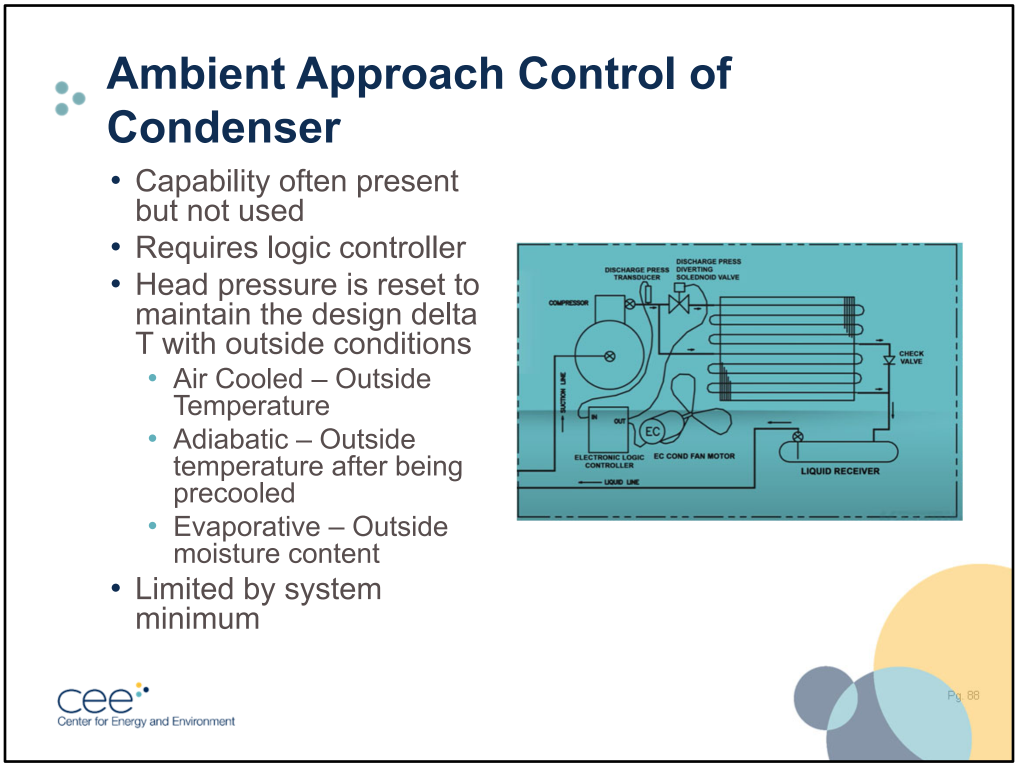
Depending on the temperature category the condenser is serving, it is normally selected based on a design temperature difference or delta T between the refrigerants condenser saturation temperature and the outside air temperature.
So when it’s 95°F outside, the design condenser saturation temperature for an air cooled condenser serving a medium temperature group would be 110°F in order to remove the required amount of heat.

As the outside air temperature decreases the condenser saturation temperature will naturally decrease until it reaches its constant minimum setpoint.
At lower outdoor air temperatures this high condenser saturation temperature is not required, and the compressors are consuming more energy to raise the refrigerant pressure higher than it needs to be.

The figure on the slide shows that with ambient approach control, the head pressure will decrease with the outdoor air temperature to maintain its design delta T instead of flat lining one it has reached its minimum.

In the figure, the Red line represents the condenser saturation temperature with a fixed minimum at 85F, the blue line is the condenser saturation temperature with ambient approach control and the light blue line is the outside air temperature.

There are quite a few months where the condenser saturation temperature can drop well below the original fixed setpoint of 85F, resulting in the compressors consuming less energy.



Many times the ability to modulate the head pressure at the condenser with outdoor air temperature is present in existing systems but not being utilized.
This can be verified by confirming what kind of controller, if any, is being used for the condenser.
Once that is known, you can determine if a control system needs to be added or if the existing controls can be modified.

The current figure on the slide, shows an example of a controller and the sensors it uses to modulate the condenser saturation temperature.
Each manufacturer may have different control methods to modulate the condenser saturation temperature, but they all achieve the same goal.

One thing to keep in mind is that air cooled, adiabatic and evaporative condensers use a different input to change the condenser saturation temperature.
Air cooled will modulate the head pressure based on outside air temperature.
Adiabatic will modulate the head pressure based on the outside air temperature after it has been precooled.
Evaporative will modulate the head pressure based on how much moisture is in the outside air.

As discussed earlier, an evaporative condensers capacity and ability to remove heat increases as the moisture content of the outside air decreases.
As the amount of moisture in the outside air decreases, the head pressure can be

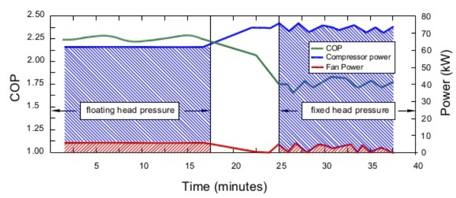
decreased to maintain its design delta T.

What limits the range of varying the temperature is the minimum pressure drop required by the expansion valve.
The expansion valve may need to be replaced with a valve that requires a lower pressure drop.
This should be verified by a contractor to ensure the system will operate correctly with ambient approach control.

Ambient Approach Control of Condenser

- Benefits:
  - Smaller hill for compressors to climb
    - Compressors consume less energy
  - Improved performance at lower outside air temperatures
    - Consistent head pressures
  - Can be combined with Reduced Min. Head Pressure and Condenser VFD measures for further energy savings

Measured COP, compressor power and fan power
for floating and fixed head pressure control
[ASHRAE JOURNAL]



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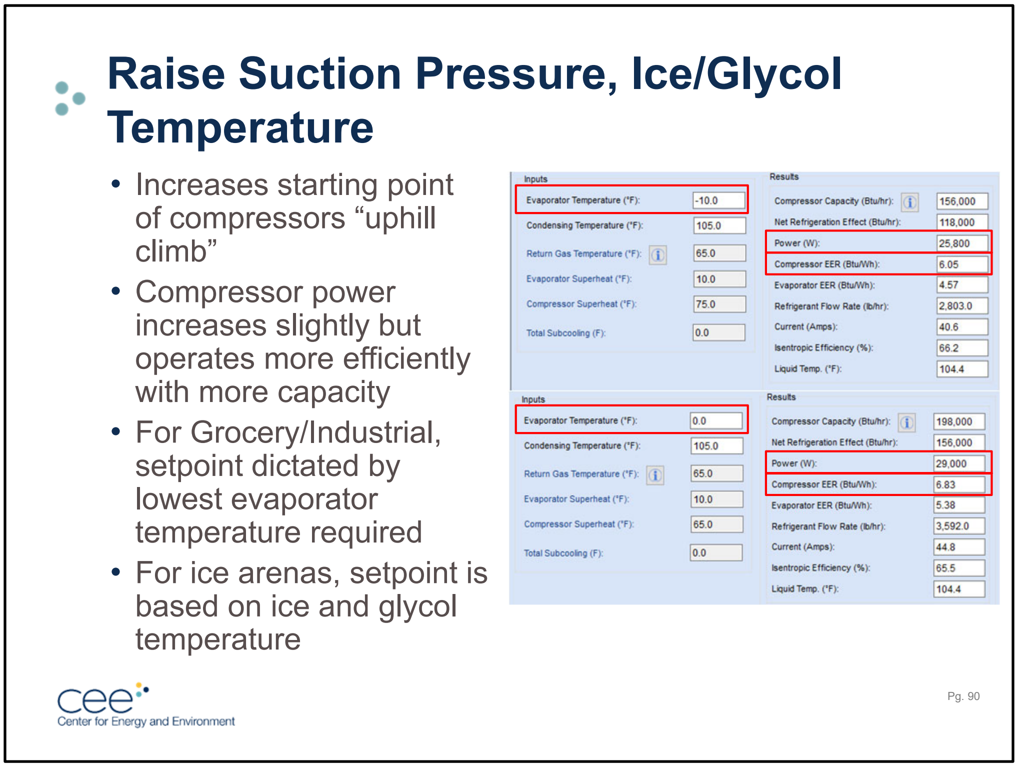
By implementing this measure, the compressors will climb a much smaller hill to increase the pressure of the refrigerant.
Allowing them to consume less energy.

As shown in the graph on the slide, the COP or efficiency of the system decreases, green line on the graph, and the compressor power, blue line on the graph, increases when the head pressure remains fixed.
The fans also cycle on and off much more.
With ambient approach control, the opposite will occur.
The efficiency of the system will increase and the compressors will consume less energy

An additional benefit of this ambient approach control is the condenser will provide more consistent head pressures as the fans are not cycling as often.

Further energy savings can be realized if this measure is combined with the Reduced Minimum Head Pressure or the Condenser VFD control measures.



The next measure we will discuss is looking at raising the saturated suction pressure setpoint for the compressors.
This measure can be implemented at any of the three refrigeration applications.

If we can increase the saturated suction pressure, the compressor will start at a higher point on its uphill climb to increase the refrigerants pressure.
The compressor will consume less energy overall with a higher starting point.

As shown in the current figures on the slide, there will be a slight increase in power due to an increase in the amount of refrigerant being compressed but the efficiency and capacity of the compressor will increase.
The top portion of the figure shows a compressor operating at a saturated suction temperature of -10F. Its power draw is 25,800 watts.
The bottom portion of the figure shows the same compressor operating at 0F. Its power draw is 29,000 watts.

This may seem problematic at first but we must compare the efficiency of the compressor as well.
At 0F its efficiency which is the term Compressor EER in the figure, is 6.83.
At -10F its EER is 6.05.

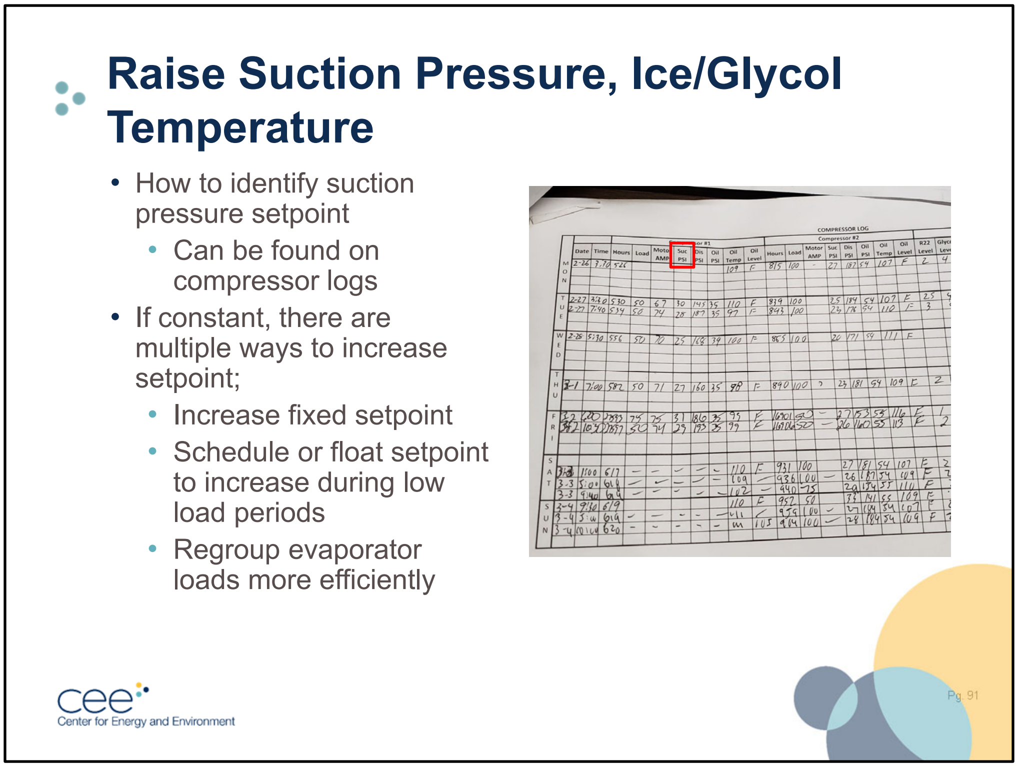
EER is the ratio between how much heat the compressor can remove and the amount of power to do it.

A higher EER means it can remove more heat for less power.
There is about a 13% increase in compressor efficiency meaning it will work more efficiently and have far fewer run-hours, reducing the annual energy consumption of the compressor.

For grocery store and industrial applications, the lowest evaporator refrigerant temperature on a compressor group dictates the suction pressure.
If you have 4 evaporators requiring 0F refrigerant but then have 1 evaporator requiring -10F, the suction pressure must be set for -10F.
Therefore it is critical to group evaporators efficiently based on their required temperatures.

For ice arenas, the suction pressure setpoint is based on ice temperature which then dictates the required secondary fluid temperature.
If we can increase the required ice temperature, even during low use periods, the suction pressure can be increased as we don't need to deliver as cold of secondary fluid to the ice sheet.

Before implementing this, we must first determine what the current saturated suction pressure is for the system.



To identify what the current suction pressure setpoint you can remove compressor logs, if available.
The current figure on the slide shows an example of a compressor log and the suction pressure that was recorded.
You can then calculate an average suction pressure over a couple of weeks from the recorded values.
This will provide a reasonable approximation of the suction pressure the compressors are operating to.

Once the current suction pressure setpoint is known there are few different ways to increase it.

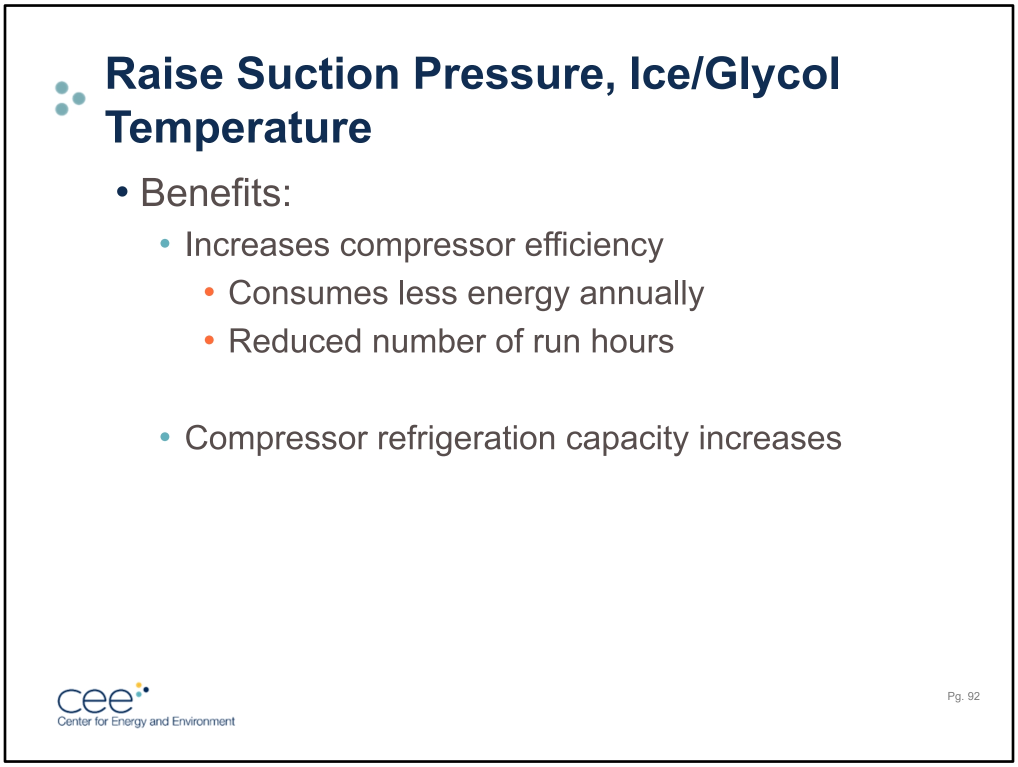
First, the setpoint can remain constant and be increased manually to a higher value that still allows the system to remove the required amount of heat.

Second, and the preferred method, is to implement electronic controls that can float the setpoint based on the refrigeration load.
As the load decreases, the setpoint could be increased and vice versa when the load increases.
This is a more efficient control method than a fixed setpoint as refrigeration loads can vary based on the season and time of day.
If floating suction pressure control is not preferred, electronic controls are still recommended even for constant setpoints as they are much more efficient, reliable and

can be easily changed compared to mechanical pressure controls.

A third option is to regroup the evaporators so that they share very similar saturated suction temperatures.
As mentioned earlier we don’t want evaporators grouped together that have a wide difference in required saturated suction temperatures.
By regrouping evaporators, compressor suction pressures can be increased and not driven by the lowest required saturated suction temperature from the evaporators that are part of that group.

Regardless of the control method implemented, a contractor should be contacted before any changes are made as there are additional detailed items that should be reviewed before making any changes to the system.



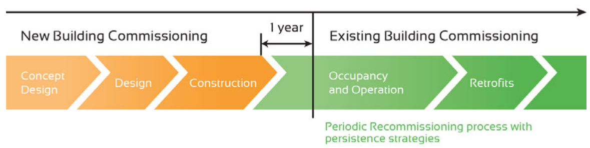
By increasing the suction pressure setpoint, the compressors efficiency will increase allowing it to remove more heat for less energy.
Because of this, the compressor will have a reduced number of run hours.

In addition, the compressors refrigeration capacity increases.

As can be seen, an increase in suction pressure can easily improve the operation of a refrigeration system.

Recommission Existing Controls

- Recommissioning (RCx): Optimizing the performance of existing buildings through low or no cost measures
  - Building “tune up”
- Many systems aren’t commissioned when installed
- Building owners deal with problems they shouldn’t have had



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This next measure, Recommission Existing Controls, can be implemented for all refrigeration applications and looks at the entre refrigeration system instead of one individual component.

First let’s define what Recommissioning is.
Recommissioning is optimizing the performance of existing buildings through low or no cost measures.
Essentially it is a building tune-up.
Recommissioning is recommended every 5 to 10 years to ensure the building and refrigeration system are operating correctly and as intended.

Many refrigeration systems aren’t commissioned to begin with when initially installed.
Setpoints, sensors and other operating parameters aren’t verified by a third party before the building is handed over to the customer.
The customer then may spend many months fixing problems that should not have been there in the first place.

Recommissioning can find these issues that may be increasing the refrigeration systems energy use and offer simple solutions to correct them.

Recommission Existing Controls

- Possible RCx opportunities:
  1. Reduce minimum head pressure
  2. Implement ambient approach control
  3. Raise suction pressure setpoint
  4. Implement floating suction pressure control
  5. VFD control optimization
  6. Reduce resurfacer water temperature

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The key principle of a recommissioning study is implementing opportunities that require little to no upfront costs.
Many of the measures we have discussed are potential opportunities and include the following;

Reduce minimum head pressure
Implement ambient approach control
Raise suction pressure setpoint
Implement floating suction pressure control

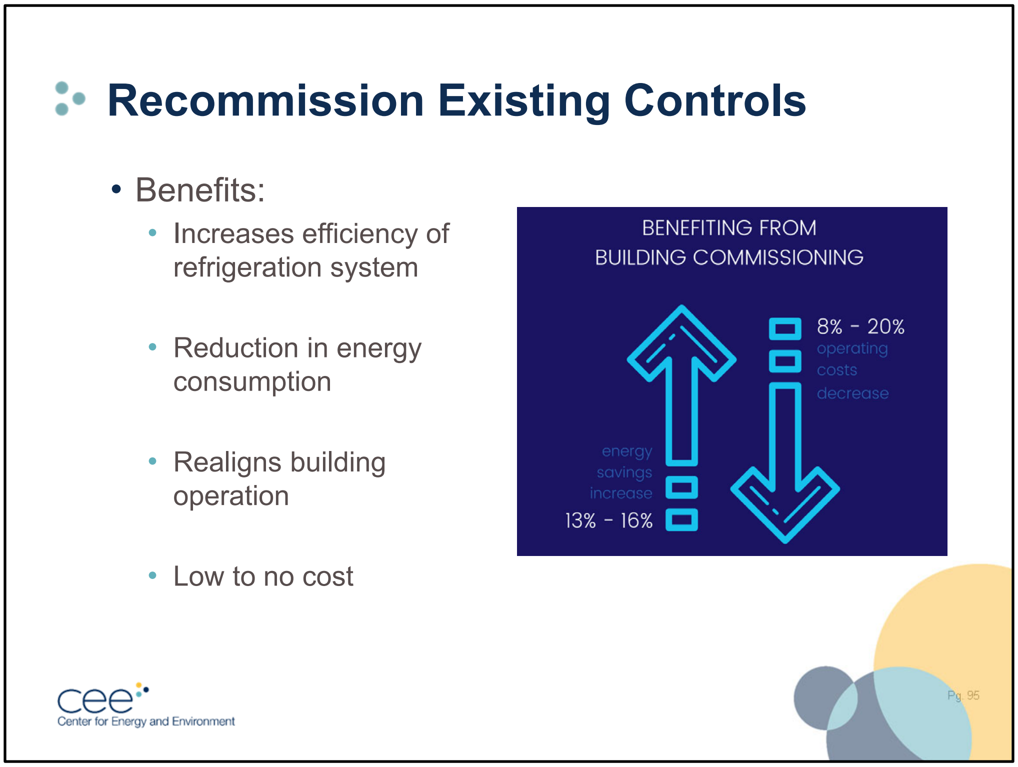
Additional opportunities outside of the measures we've discussed are VFD control optimization and reducing resurface water temperature for ice arenas.

VFD control optimization looks at how equipment with VFD's are operating.
Sometimes fans, compressors or pumps with VFD's are still operating at 100% instead of modulating or backing their speed down when able to.
This opportunity will look at correcting the operation of the equipment to ensure it is fully utilizing the capability of the VFD.

Reducing resurfacer water temperature is an opportunity specifically for ice arenas.
When resurfacing the ice, hot water is usually used as it contains less air bubbles than cold water.
Many times the water is much hotter than required and can be up to 140F.

Reducing this temperature can decrease the amount of energy used, whether gas or electric, to heat the water.
It also reduces the amount of heat that must be removed by the refrigeration system to create the ice.

There can be other specific building opportunities involved with a recommissioning study but these 6 are the most common.



Recommissioning an existing building and its refrigeration system can provide the following benefits to the owner.

It increases the efficiency of the refrigeration system.
Changing setpoints or improving the controls can greatly improve how the equipment will operate.
Which can lead to a reduction in energy consumption.

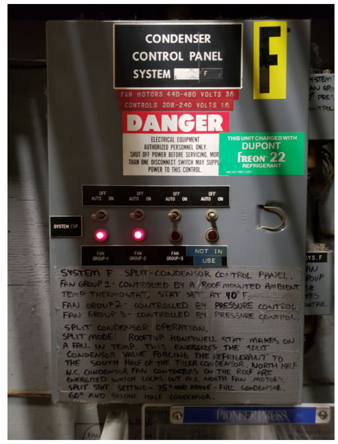
Recommissioning can realign the building and refrigeration system operation.
How the building was designed to operate may change over the years.
Renovations may occur or a change in how a space is being used.
Recommissioning reviews this with the owner in order to recommend appropriate changes to the system.

Finally, these opportunities are low to no costs with fairly short paybacks.
Large capital improvements are not part of a recommissioning study.

It's highly recommended any type of building is recommissioned periodically to ensure it's operating efficiently as possible.

Upgrade Controls

- Inefficient controls can cause higher energy consumptions
- Advancements in technology have improved system performance/operation
- Similar opportunities to RCx but includes additional items with higher capital costs



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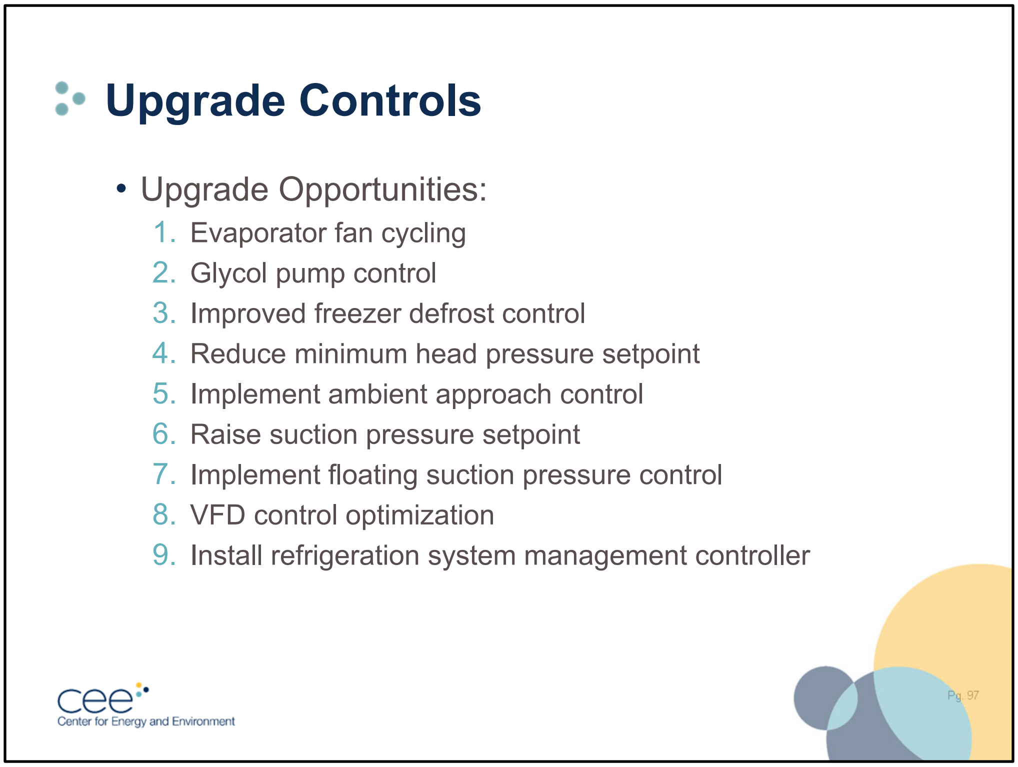
The final measure we will discuss applies to existing refrigeration systems for all three applications.

Upgrading a refrigeration systems controls can dramatically improve how it operates. Inefficient or outdated controls can produce higher energy consumption than normal.

Advancements in technology have improved and simplified how refrigeration systems perform and operate.

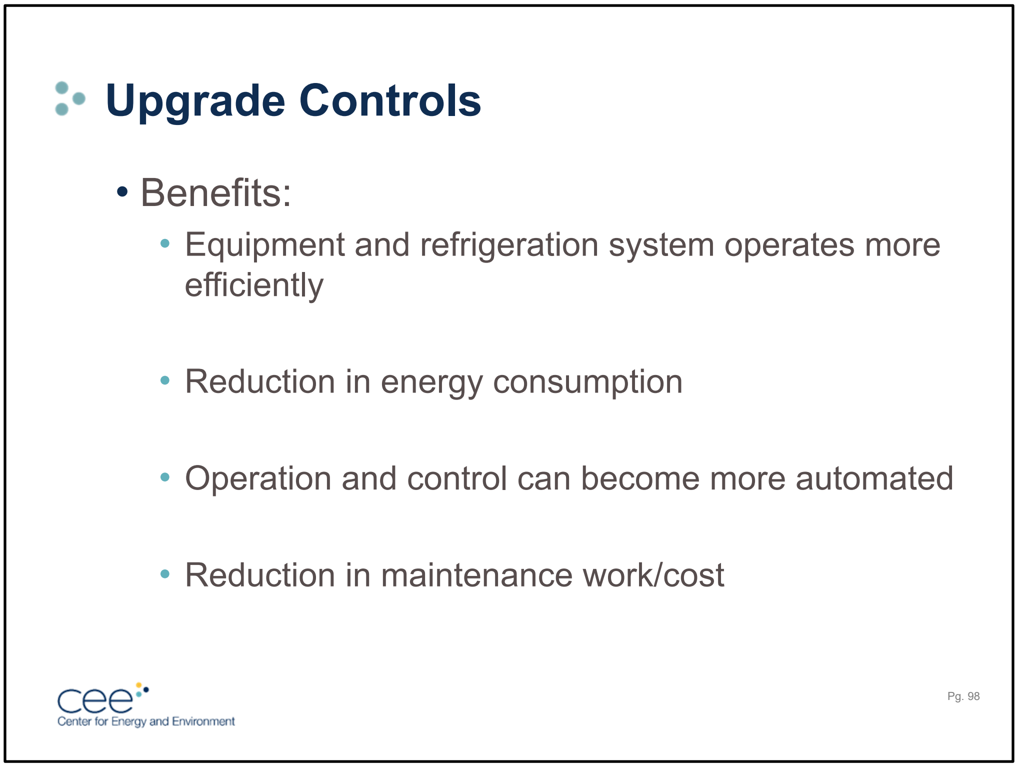
An upgrade to the controls of a refrigeration system is a good measure to recommend implementing for an existing refrigeration system where the controls may be 20 to 30 years old.
Many of the opportunities discussed for the Recommission Existing Controls measure are potential recommendations when upgrading the controls.
In addition to those low or no cost opportunities, an upgrade will also include items with higher capital costs.



The following are some of the opportunities, many being measures we've discussed, available when upgrading a refrigeration systems control.

Evaporator fan cycling
Glycol pump control
Improved freezer defrost control
Reduce minimum head pressure setpoint
Implement ambient approach control
Raise suction pressure setpoint
Implement floating suction pressure control
VFD control optimization
Install refrigeration system management controller

All of these we've discussed except for the installation of a refrigeration system management controller.
A system management controller provides total monitoring and control of all the components of a refrigeration system.
Setpoints and control methods be easily changed from a remote interface or through a Building Automation System.
This allows for maintenance staff to operate the system more efficiently and monitor it for any issues.



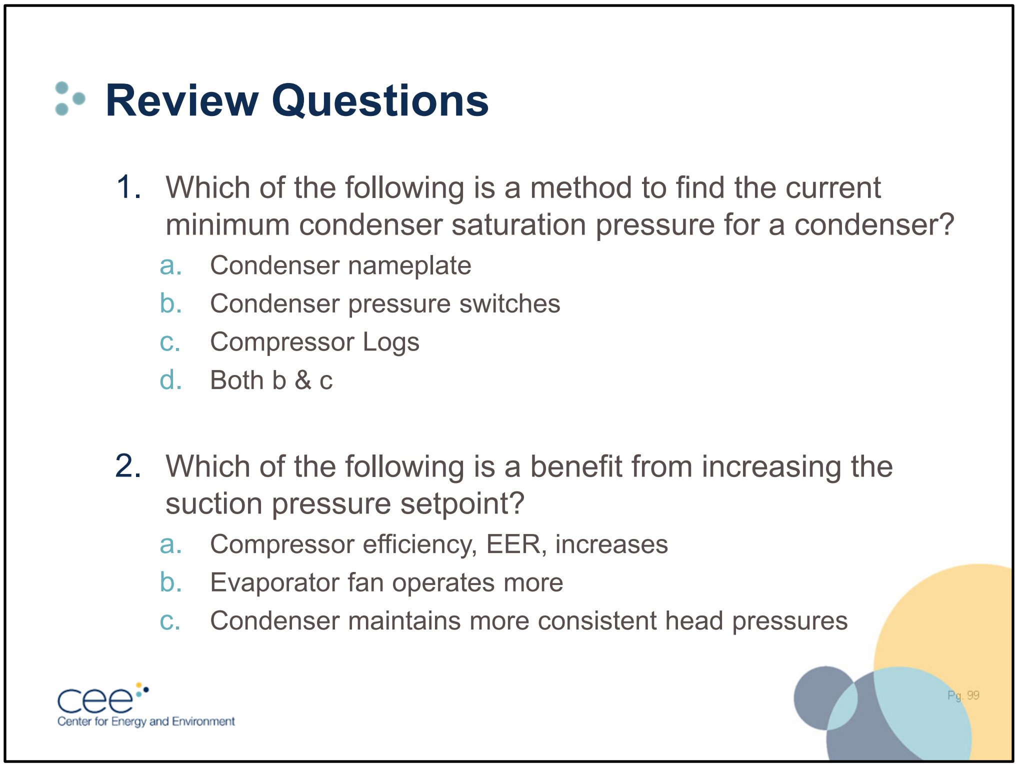
Upgrading an existing refrigeration systems controls can provide multiple benefits.

The components and refrigeration system as a whole can operate more efficiently.
This improvement in operation efficiency can provide a reduction in energy consumption and reduce the systems peak demand.

The operation and control of the system can become more automated.
Instead of going onsite to change a setpoint, the setpoint could be changed remotely.
This can provide a reduction in maintenance work and cost.

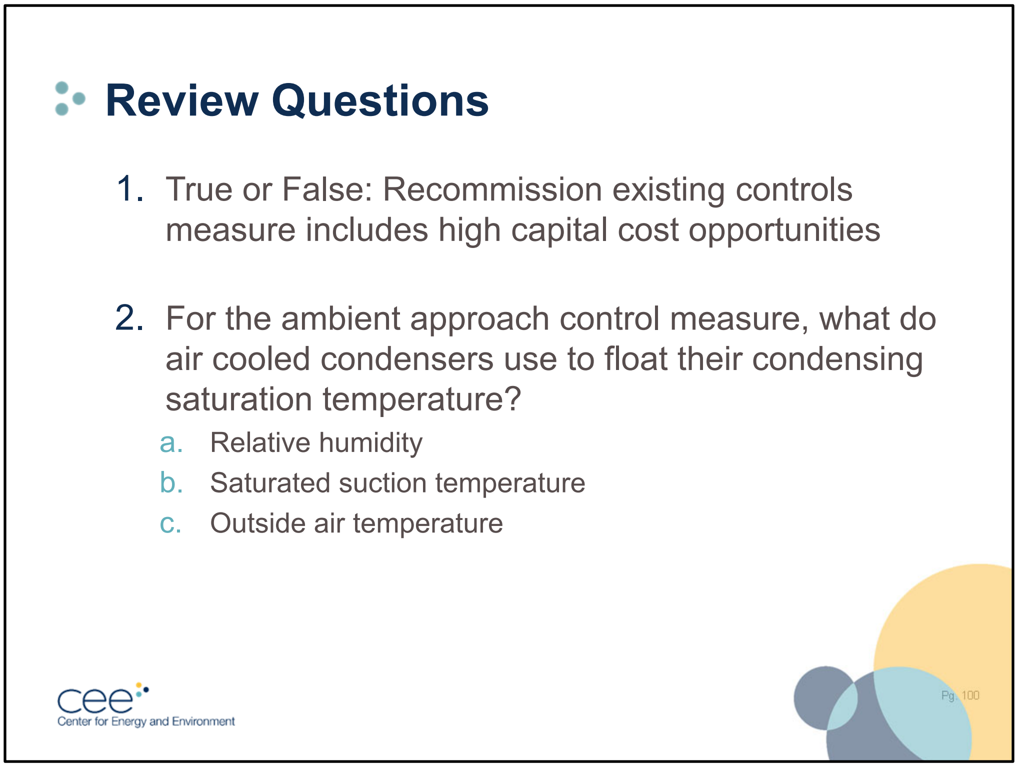
Upgrading a refrigeration systems controls should be a measure that is explored with building owners, especially for buildings that have their original controls.

Before we end, I have a couple more review questions on the measures we just discussed.



1. d
2. a

These questions will be asked in the google poll and participants will put there answer in the poll prompt.



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These questions will be asked in the google poll and participants will put there answer in the poll prompt.

Questions?