Air Cooled Chillers

A Review of the Refrigeration Cycle and a Discussion of Potential Measures

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Review

First, let's review:

- The pressure/enthalpy diagram
- The chiller's refrigeration system

Pressure-Enthalpy Diagram

'The dome':

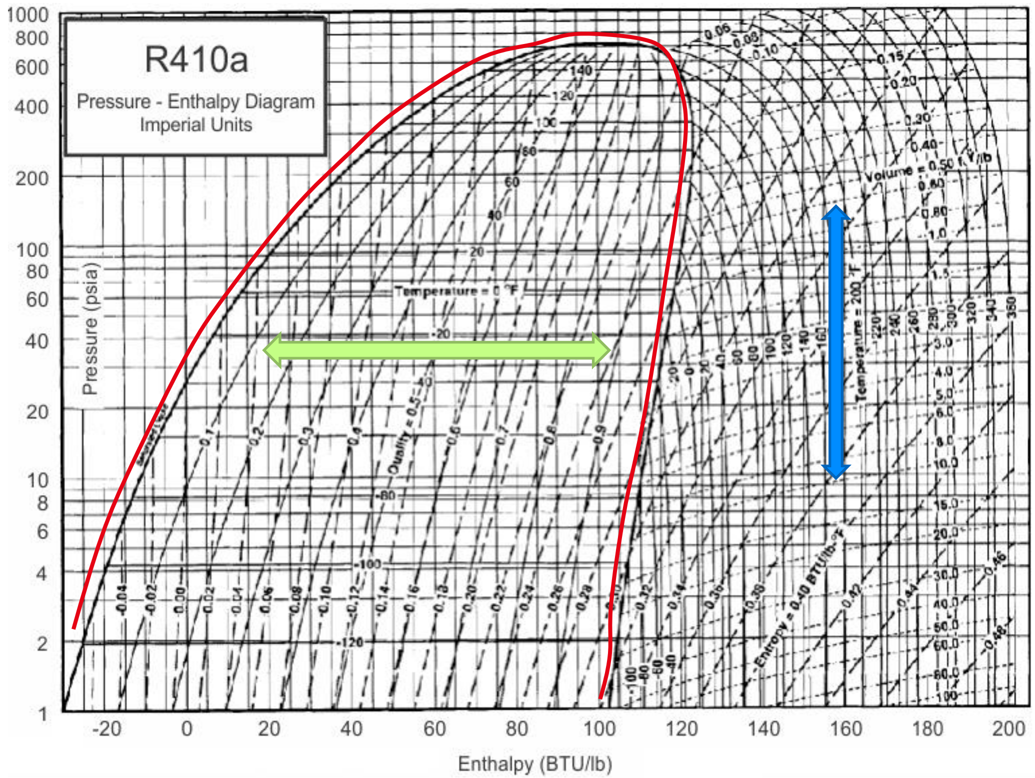
- The area to the left is liquid
- The area to the right is vapor
- Within the dome is a liquid/vapor mix

Left ←→Right

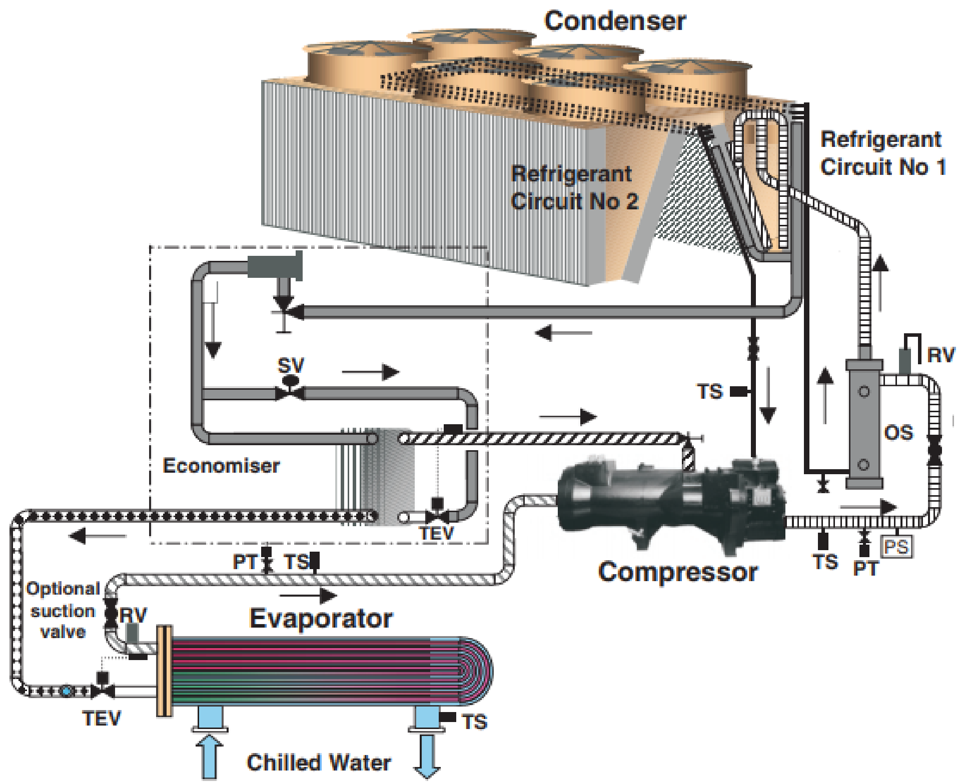
- Energy is absorbed or released by refrigerant

Up / Down

- Increase or reduction in pressure



An Air-Cooled Chiller with Economizer Cycle



Oil

Low Pressure Liquid

High Pressure Subcooled Liquid

High Pressure Further Subcooled Liquid

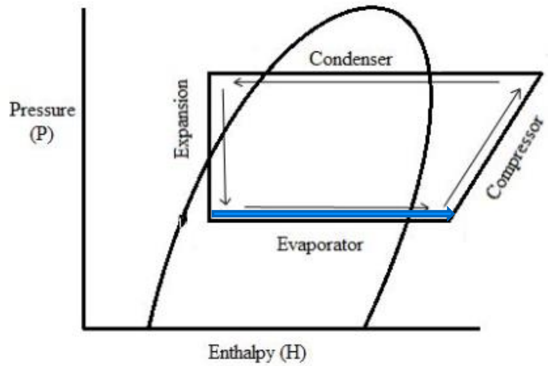
Low Pressure Superheated Vapour

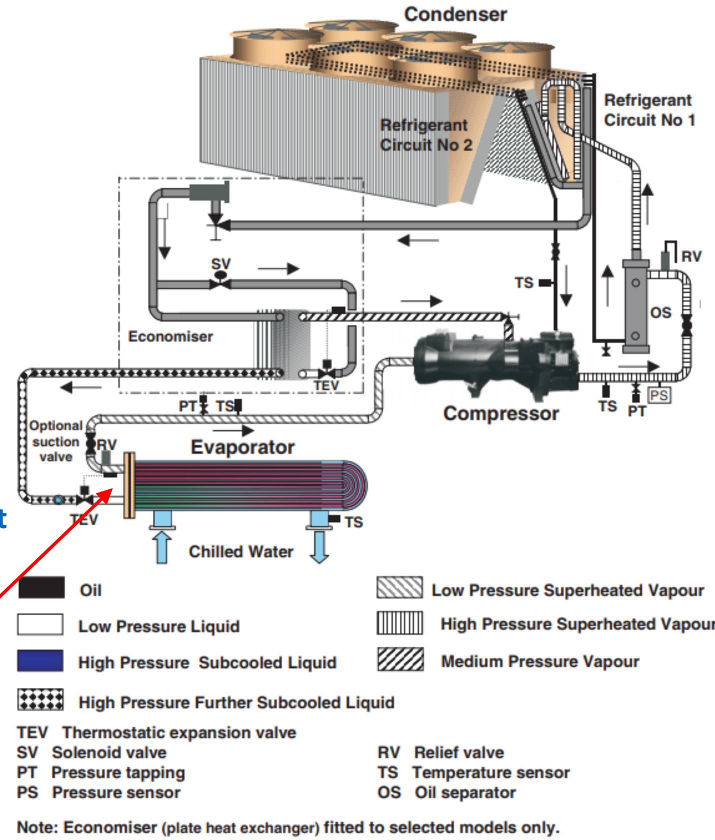
High Pressure Superheated Vapour

Medium Pressure Vapour

TEV Thermostatic expansion valve
SV Solenoid valve
PT Pressure tapping
PS Pressure sensor
RV Relief valve
TS Temperature sensor
OS Oil separator

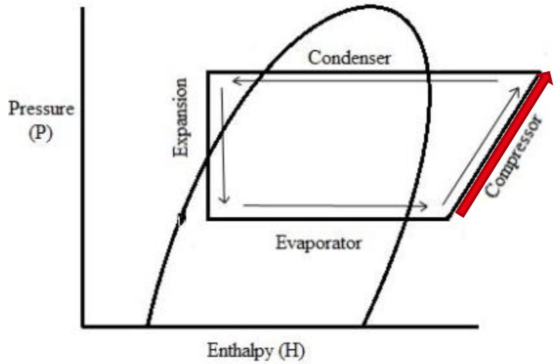
Note: Economiser (plate heat exchanger) fitted to selected models only.

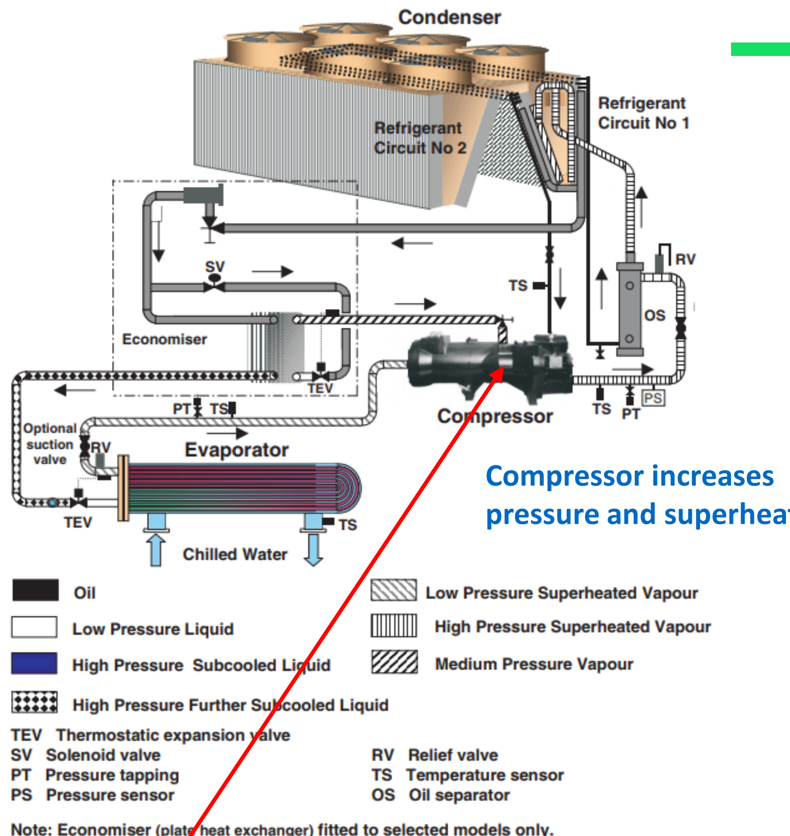




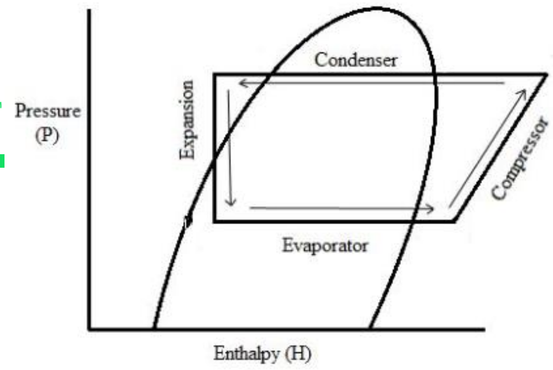
Evaporator absorbs heat from chilled water

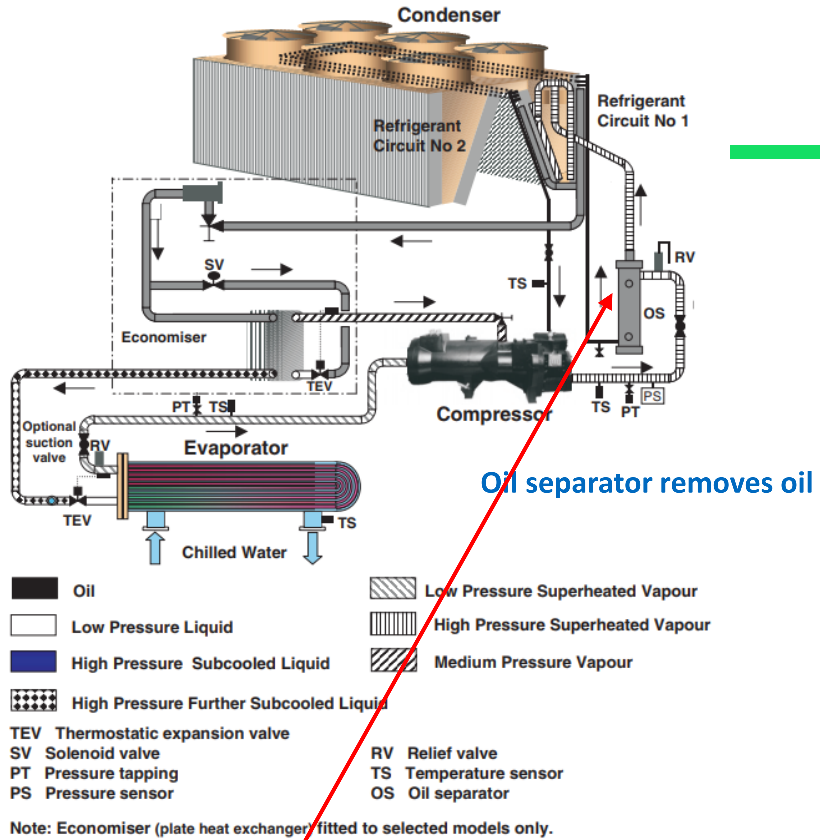
Low pressure liquid refrigerant enters the evaporator and is evaporated and superheated by the heat energy absorbed from the chilled water passing through the evaporator shell.



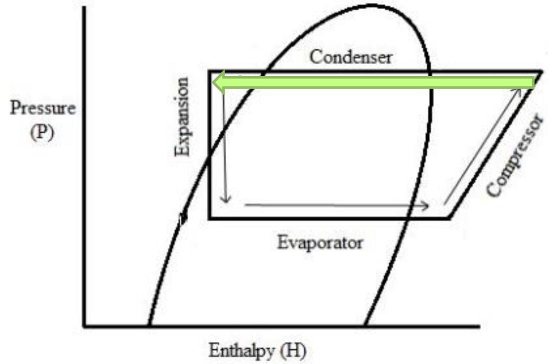


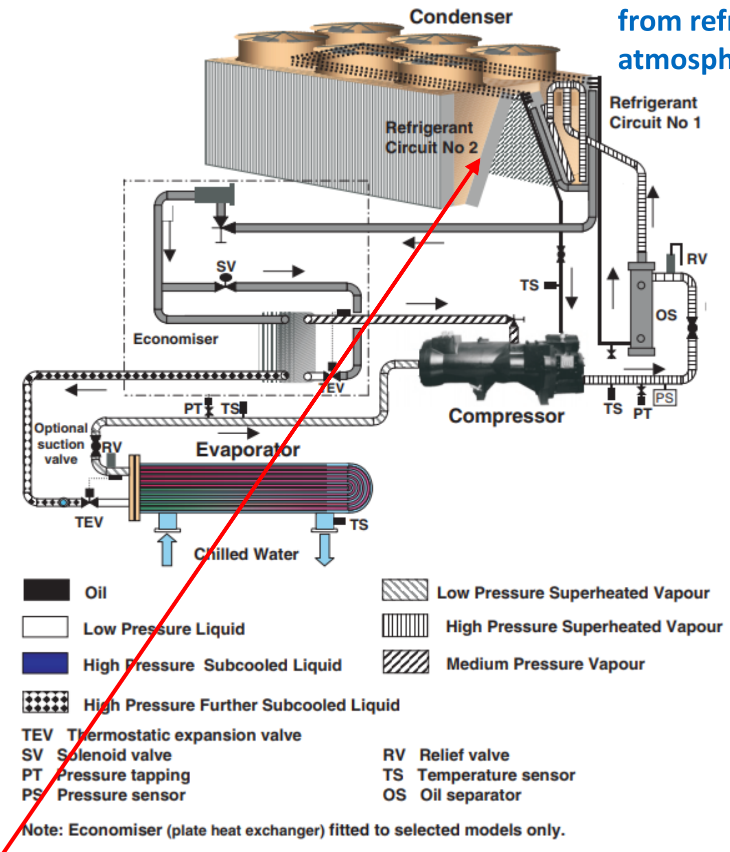
Low pressure vapor enters the compressor where pressure and superheat are increased.





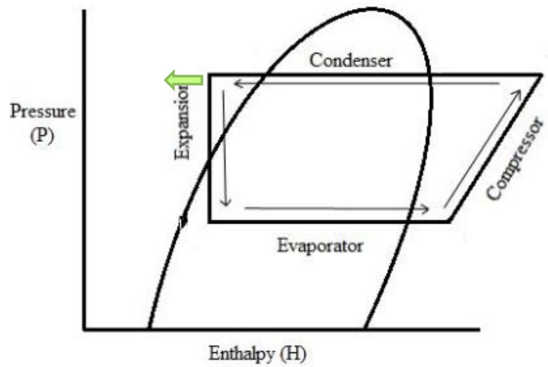
High pressure vapor is passed through the oil separator where compressor oil is removed and recirculated to the compressor via the oil cooler.



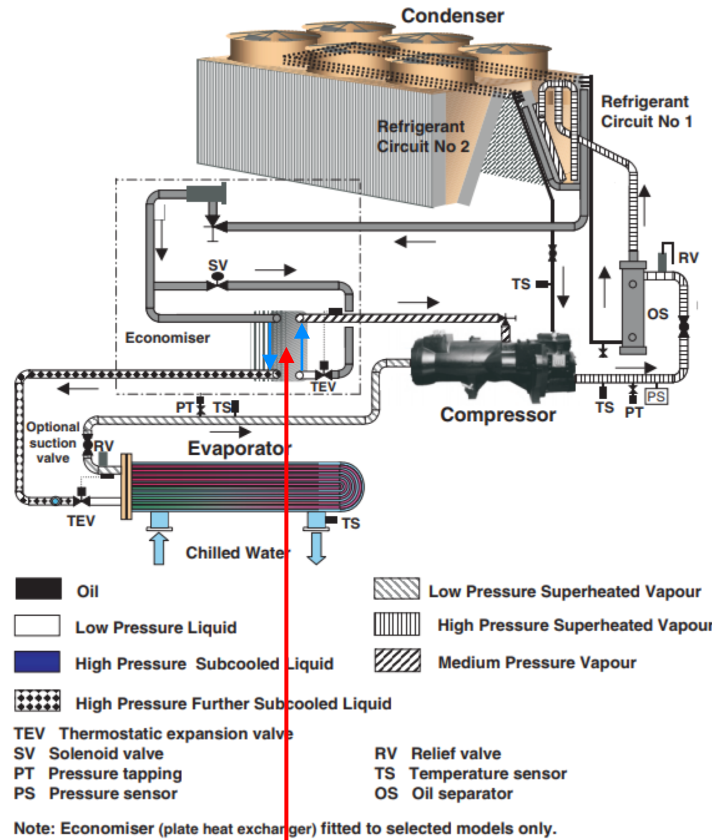


Condenser rejects heat from refrigerant to atmosphere

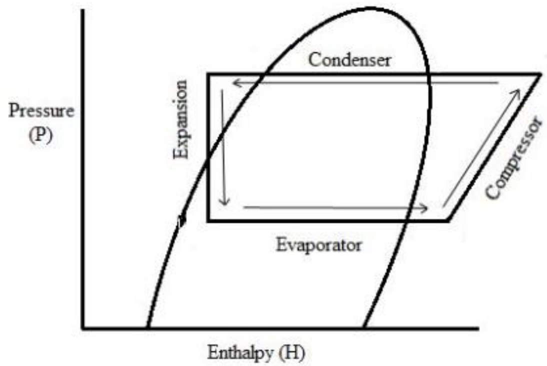
The high pressure oil-free vapor is fed to the air-cooled condenser coil and fans where the heat is removed.

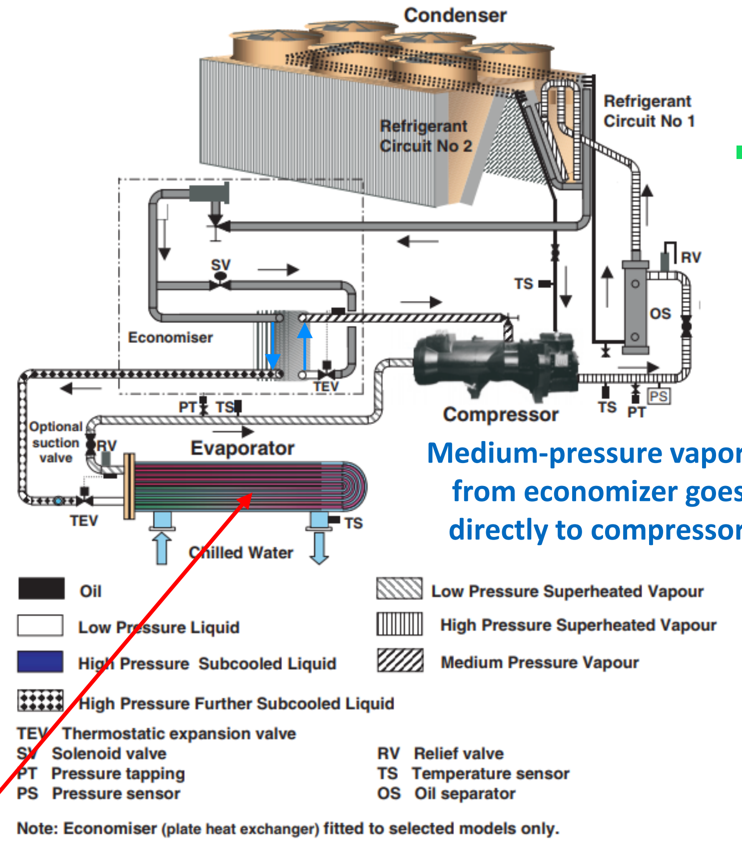


refrigerant flashes to vapor in economizer, subcools liquid refrigerant



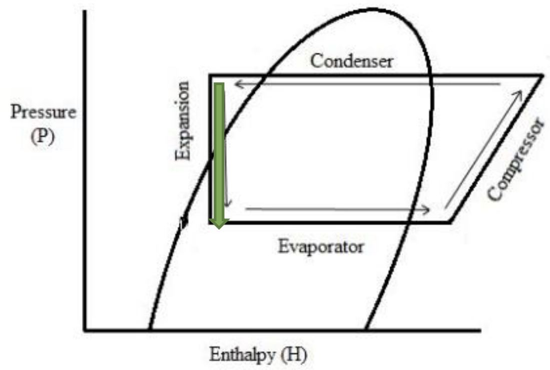
The fully condensed liquid enters the economizer. A small percentage of the liquid passes through an expansion valve, into the other side of the economizer where it is evaporated. This low pressure liquid sub-cools the rest of the refrigerant.



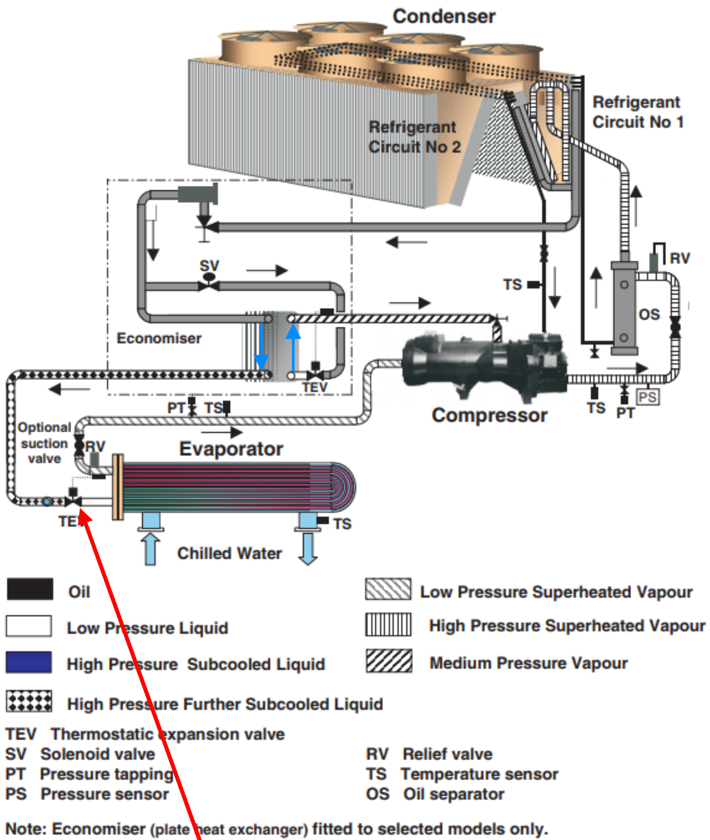


Medium-pressure vapor from economizer goes directly to compressor

Medium pressure vapor then returns to the compressor.



Subcooled liquid enters evaporator



The subcooled refrigerant then passes through the expansion valve where pressure is reduced, and further cooling takes place before returning to the evaporator.

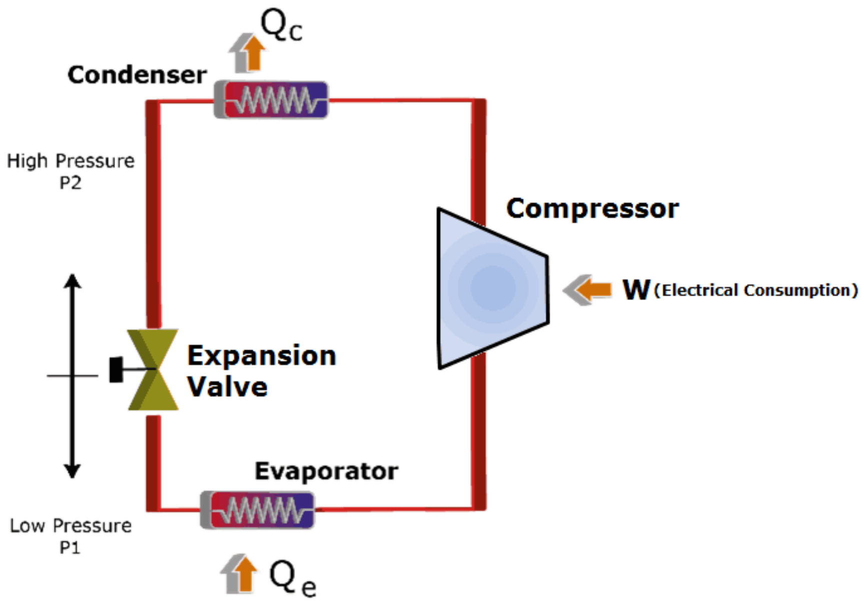
Additional Resources

(VIDEOS RE: REFRIGERATION CYCLE)

Basic Refrigeration cycle - How it works
https://www.youtube.com/watch?v=Uv3GfEQhtPE

Refrigeration Cycle Tutorial: Step by Step, Detailed and Concise!
https://www.youtube.com/watch?v=XscHn6GPWO0

How Does A Chiller Work?



(evaporator)

Cold, low-pressure refrigerant absorbs heat from chilled water.

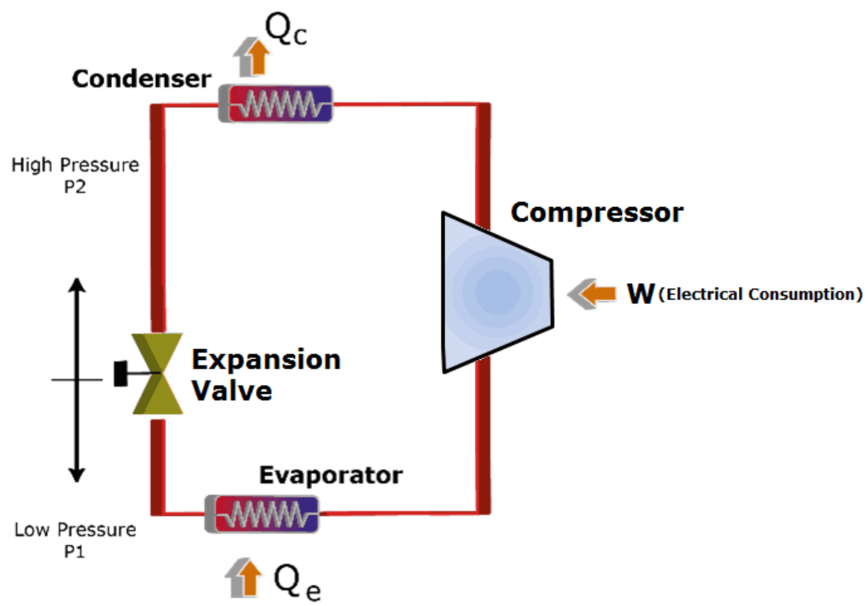
(compressor)

The compressor increases the refrigerant from low pressure to high pressure.

(condenser)

The high-pressure refrigerant is hot and rejects heat to the outdoors.

Chiller Energy Usage

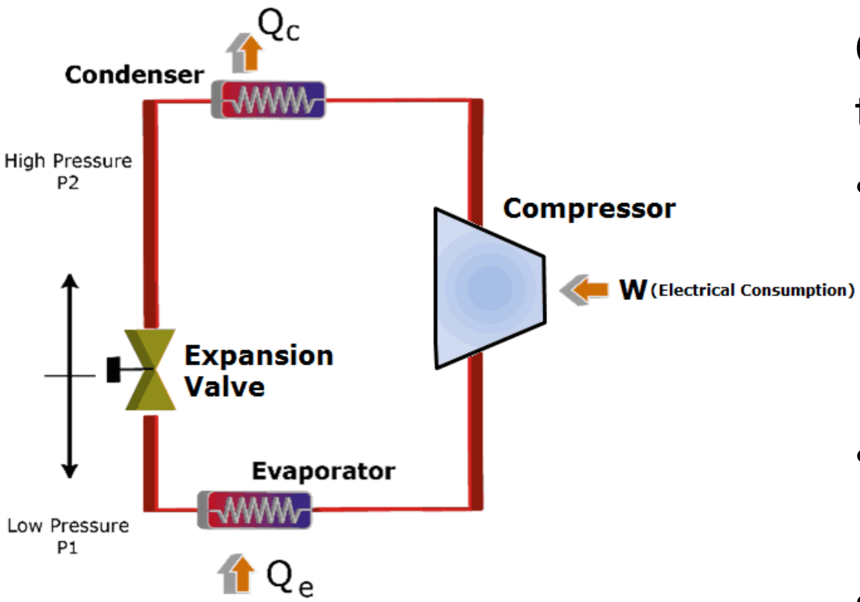


Nearly all the energy of a chiller is consumed by the compressor

(and compressors use a *lot* of power.)

How do we reduce the work done by the compressor?

Reducing Compressor Work



Compressor work depends on two things:

- Pressure (and therefore temperature) difference between evaporator and condenser
- Amount of refrigerant flow

So, we can decrease compressor work by:

- raising evaporator pressure
- lowering condenser pressure
- Reducing refrigerant flow

Raising Evaporator Pressure

Raise Chilled Water Supply Temperature Setpoint

The lower the pressure, the colder the chilled water temperature.

Raising the chilled water supply temperature

- raises the evaporator pressure
- decreases compressor work
- **improves system efficiency by around 1.5% per degree F**
  - Example: raising chilled water supply temperature by 10 degrees would reduce compressor energy by roughly 15%

Raising Evaporator Pressure *(cont'd)*

Reduce Evaporator "Approach" Temperature

(CHWS – evaporator temperature) = "approach" temperature.

An approach temperature of <1°F is ideal.

- (e.g. if CHWS is 45°F, evaporator should be no colder than 44°F)

What causes high approach temperatures?

- Fouling in Refrigerant tubes
- System is low on refrigerant

Either of these conditions will require colder refrigerant temperatures (i.e. lower evaporator pressures) to achieve the same chilled water temperature.

So . . .

Raising Evaporator Pressure *(cont'd)*

<u>**Reduce Evaporator "Approach" Temperature**</u>

1. Clean Evaporator tubes
   - This improves heat transfer, which reduces the approach temperature. With a lower approach temperature, the refrigerant doesn't need to be quite as cold to provide the same CHW temperature.
2. Add Refrigerant
   - If the system is low on refrigerant, adding refrigerant will help reduce the approach temperature.

Lowering Condenser Pressure

<u>What determines condenser temperature?</u>

The condenser temperature setpoint for air-cooled chillers (often around 115°F) is usually set in the factory. This temperature is intended to ensure that:

1. The condenser is hot enough to reject heat to atmosphere
2. There will be enough system pressure to push refrigerant through the expansion valve at the evaporator

This is the *minimum* condenser temperature. On hot days, the preset temperature may be insufficient to reject heat to atmosphere, in which case the compressor pressure (and temperature) rises in response.

Lowering Condenser Pressure *(cont'd)*

How Can We Lower Condenser Pressure?

Lower the minimum condenser temperature setpoint

- This can often be done at the on-board controller; most technicians don't know how to do this.
- This is *especially* effective in mild climates where the factory-default temperature is much warmer than needed to reject heat to atmosphere

However, be careful not to reduce the pressure too far! Check with the chiller manual or the vendor to learn what this minimum is. Otherwise, there won't be enough pressure for the refrigerant to push through the expansion valve into the evaporator.

(But stay tuned! We can maybe affect this!)

Lowering Condenser Pressure *(cont'd)*

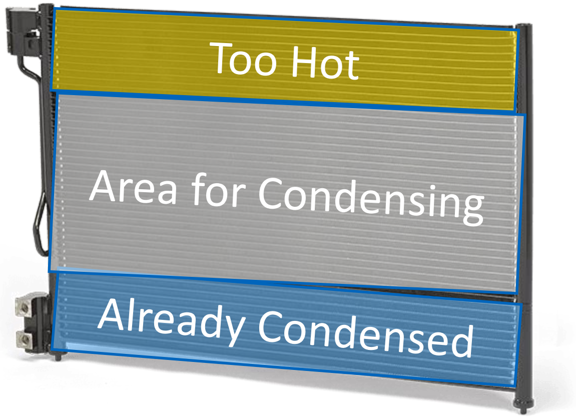
How Can We Lower Condenser Pressure?

Use a bigger condenser.

- A bigger condenser has longer to reject heat, so it doesn't need to be as hot.

Unfortunately, upsizing the condenser is rarely an option. So, *can we more effectively use the existing condenser?*

Lowering Condenser Pressure *(cont'd)*



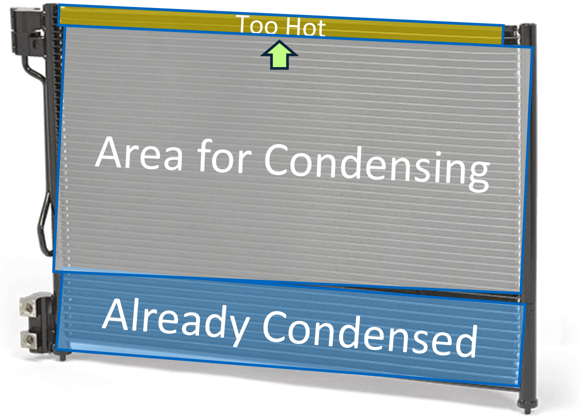
<u>How Do We Use the Condenser More Effectively?</u>

A condenser's job is to condense refrigerant vapor as it flows through the coils. However,

- on the 'entering' side of the condenser, much of the surface area is used to cool hot refrigerant vapor down to condensing temperature (called de-superheating)
- on the 'leaving' side of the condenser, some of the coils are filled with liquid refrigerant which has already condensed.

Both of these conditions reduce the area available for "condensing" the refrigerant.

Lowering Condenser Pressure *(cont'd)*

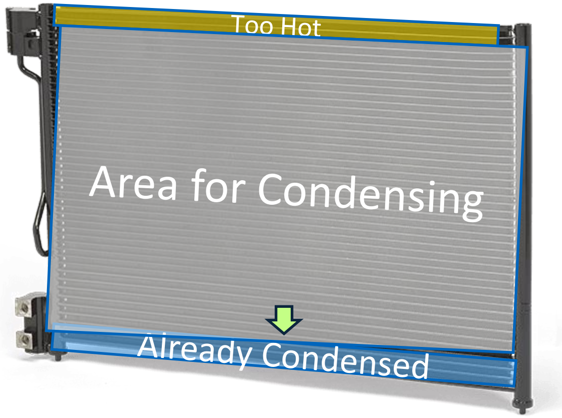


How Do We Use the Condenser More Effectively?

By flashing a small amount of liquid refrigerant at the condenser inlet, you can reduce the heat of the entering refrigerant.

Although this causes a small decrease in overall system capacity, it has the same effect on efficiency as installing a larger condenser.

Lowering Condenser Pressure *(cont'd)*



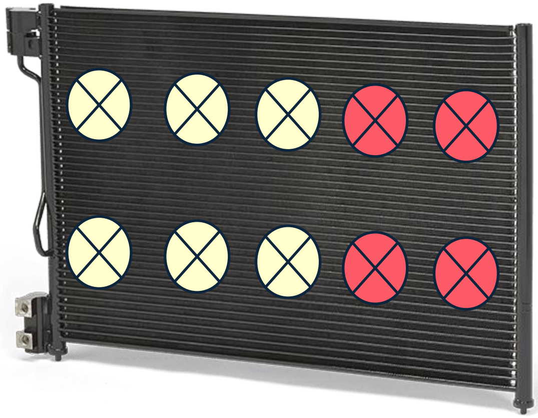
How Do We Use the Condenser More Effectively?

By controlling to a lower high-side system pressure (and thus, temperature), you reduce the temperature difference between the condenser and the ambient air, so it takes longer for the refrigeration to condense.

Air-cooled systems commonly have a 'floor' temperature of 115 degrees, which is MUCH higher than needed at non-design conditions.

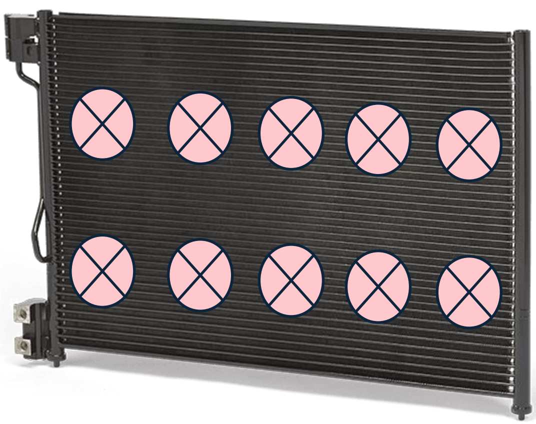
A **receiver tank** with a level-sensor can be added after the condenser. A low liquid level will stop the condenser fans.

Lowering Condenser Pressure *(cont'd)*



Also

Most condenser fans stage sequentially, meaning that air only blows across a small part of the condenser surface – until peak conditions when *all* fans are running.



If instead, the condenser fans can be controlled in parallel, condenser fan energy will decrease. But more importantly, all condenser surface area can be used for condensing refrigerant - including at non-peak conditions, so the surface doesn't need to be as hot. (this will likely require a different controller)

Which means the 'high pressure' side of the system can operate at a lower pressure, reducing compressor work.

How Low Can You Go?

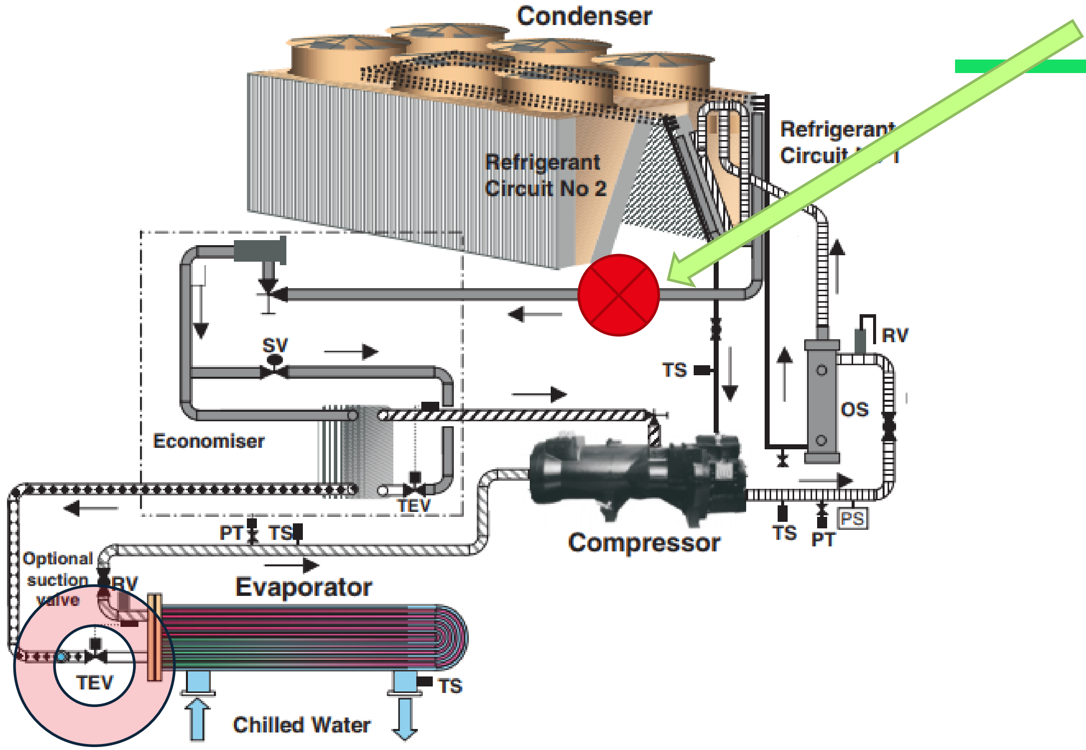
Be careful not to reduce the pressure too far! Check with the chiller manual or the vendor to learn what this minimum is. Otherwise:

1) there won't be enough pressure for the refrigerant to push through the expansion valve into the evaporator.

   (An electronic expansion valve has less resistance and may help with this!)

2) or the lift might be too low for the compressor

Liquid Pressure Amplification



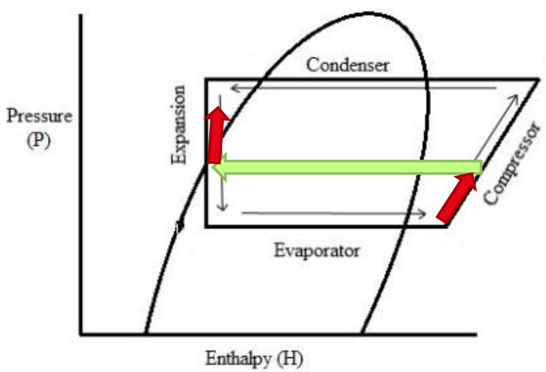
Oil
Low Pressure Liquid
High Pressure Subcooled Liquid
High Pressure Further Subcooled Liquid
Low Pressure Superheated Vapour
High Pressure Superheated Vapour
Medium Pressure Vapour

TEV Thermostatic expansion valve
SV Solenoid valve
PT Pressure tapping
PS Pressure sensor
RV Relief valve
TS Temperature sensor
OS Oil separator

Note: Economiser (plate heat exchanger) fitted to selected models only.

Add a Liquid Pump

The pump ensures the expansion valve has adequate pressure. Boosting pressure with a pump is more efficient than with the compressor.



Caveats

- Not all systems lend themselves to this.
- An engineered solution is needed! The ideas presented here are not ‘off the shelf’ solution.
- Much depends on the type of refrigerant! Some operate at higher temperatures and pressures than others.

Recap

- Compressor savings result from reducing Lift (i.e. bringing low-side and high-side pressures closer together)
- Most air-cooled condenser pressures are set for hot climates
- Reduce required high-side pressure by maximizing condenser area used for condensation. For example:
  - Add a de-superheater
  - Add condenser receiver
- Enough pressure is required for expansion valve to work correctly. Minimum pressure can be reduced by:
  - Installing a liquid pump
  - Replacing TX valve with EX valve
- This is not an ‘off the shelf’ solution. Many variables should be considered.