HVAC Fundamentals & BMS Controls - Summary

Top HVAC course in Udemy

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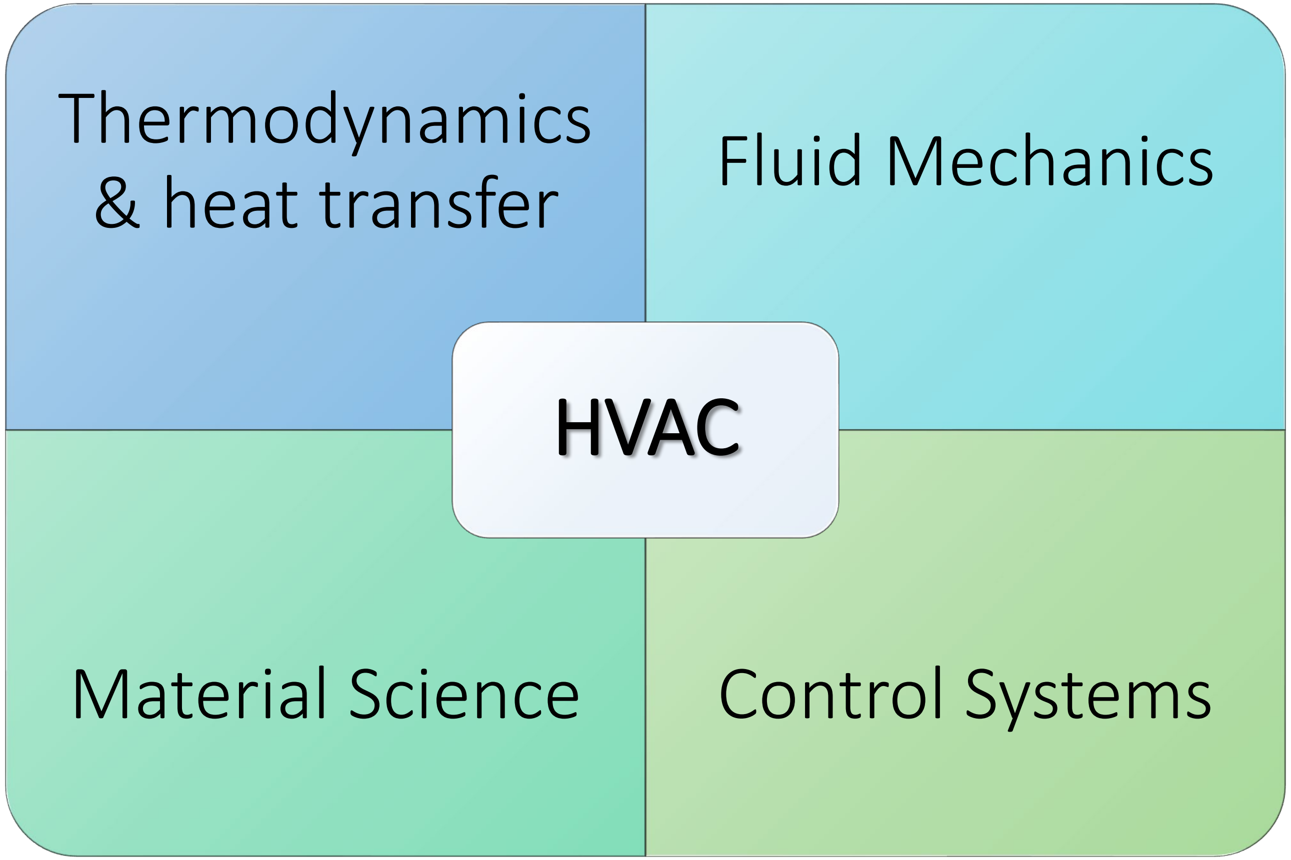
Section 1

Introduction to HVAC

Heating Ventilation and Air Conditioning (HVAC)



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Laws of Thermodynamics

What is thermodynamics?

The branch of physical science that deals with the relations between **heat** and other forms of energy.

Thermodynamics

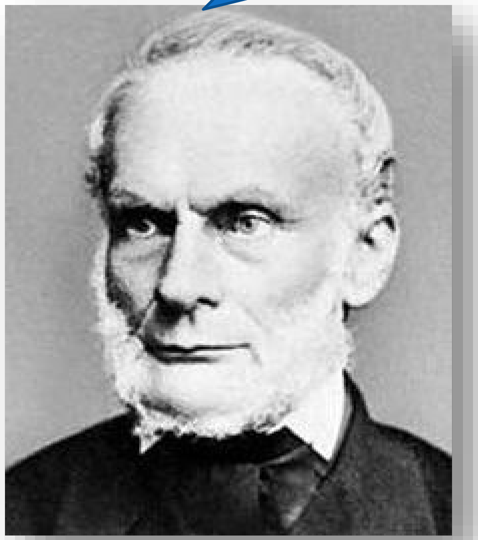
> Classical thermodynamics... is the only physical theory of universal content which I am convinced... will never be overthrown.
>
> — *Albert Einstein* —

First Law of Thermodynamics

First Law of Thermodynamics:
Law of Conservation of Energy

Energy cannot be created or destroyed, only converted from one form to another.

There is a state function E, called 'energy', whose differential equals the work exchanged with the surroundings during an adiabatic process.

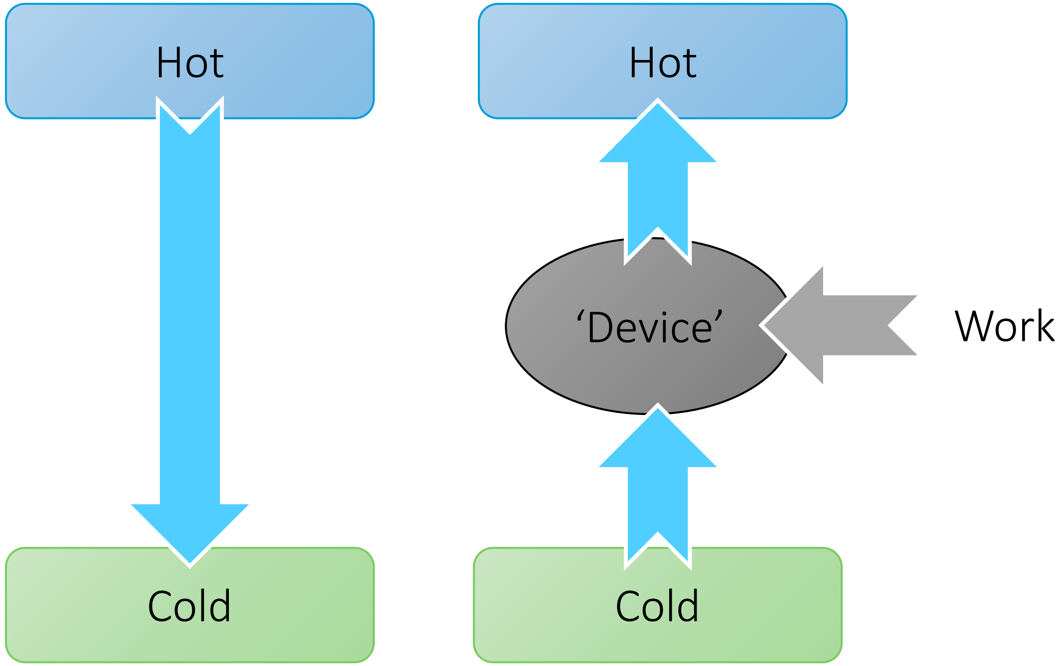


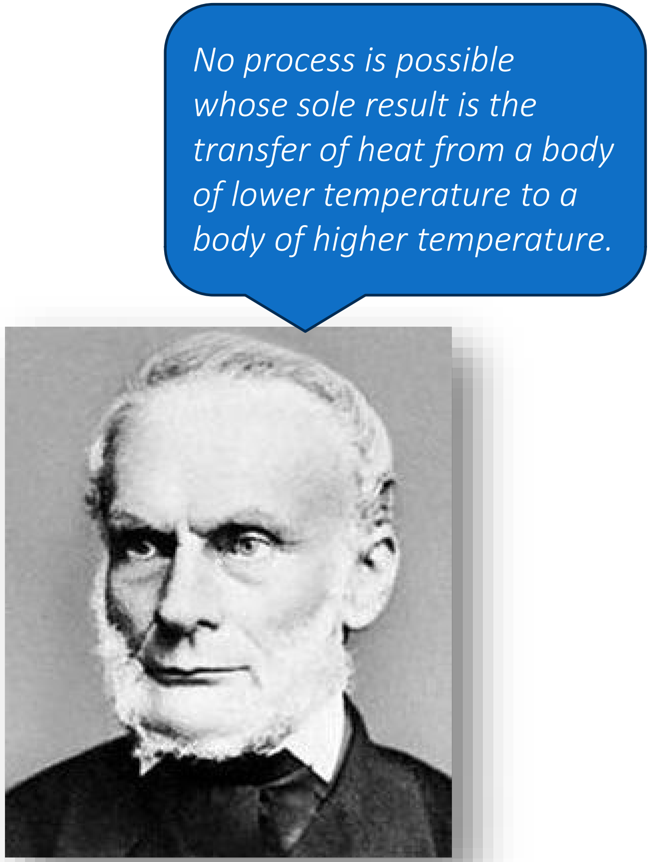
Rudolf Clausius

Second Law of Thermodynamics

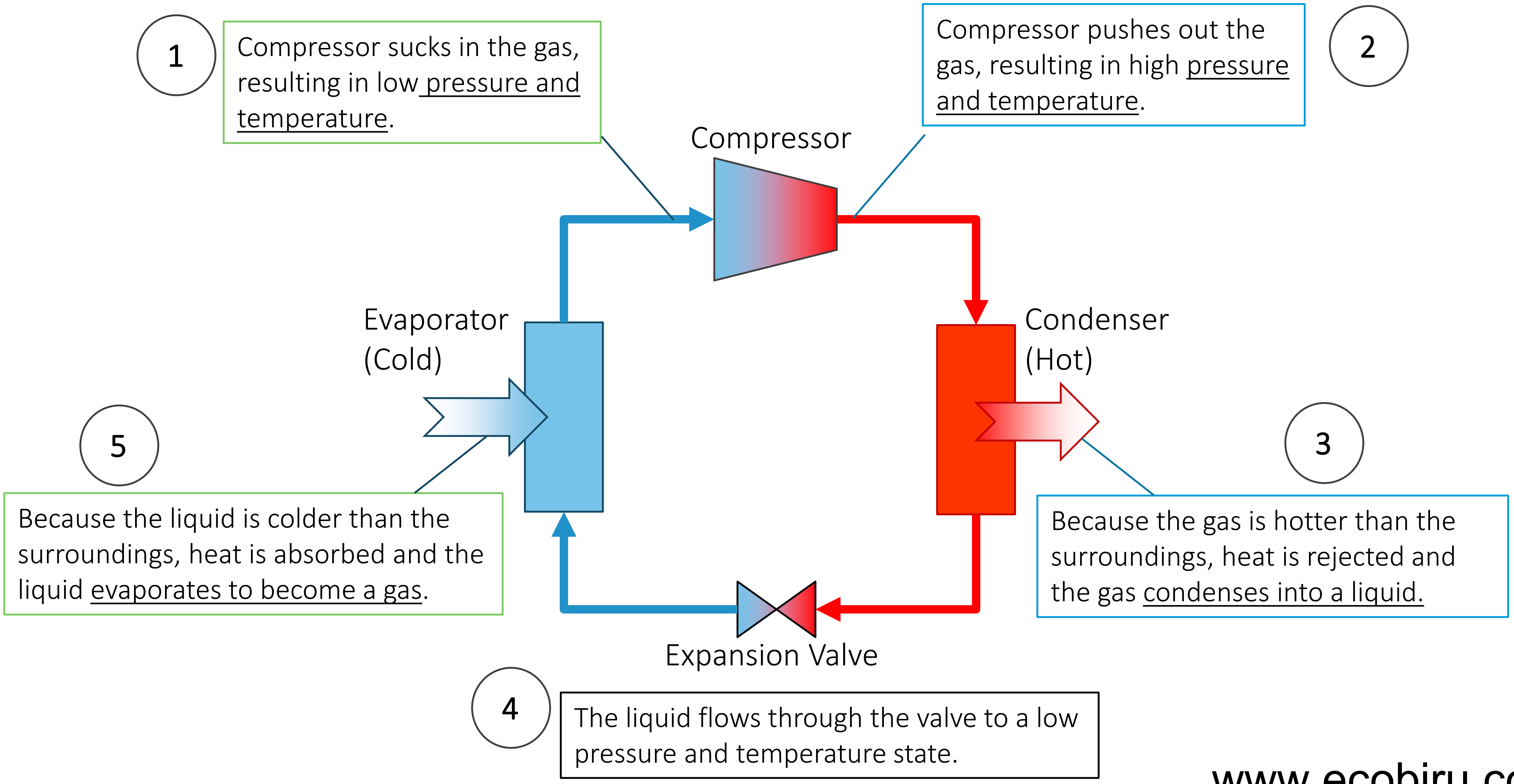
Heat *naturally* flows from a hotter to colder body

If the opposite is desired, external work is inevitably required





Vapour-Compression Cycle



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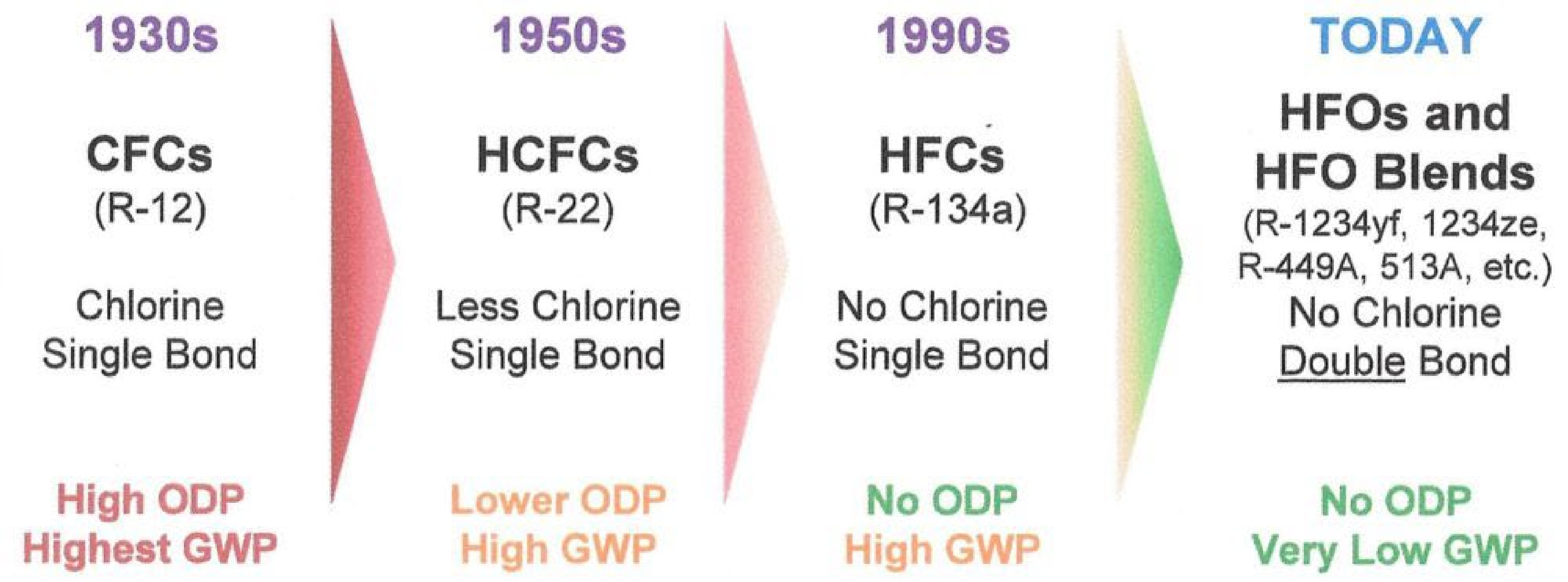
ODP and GWP of Refrigerants

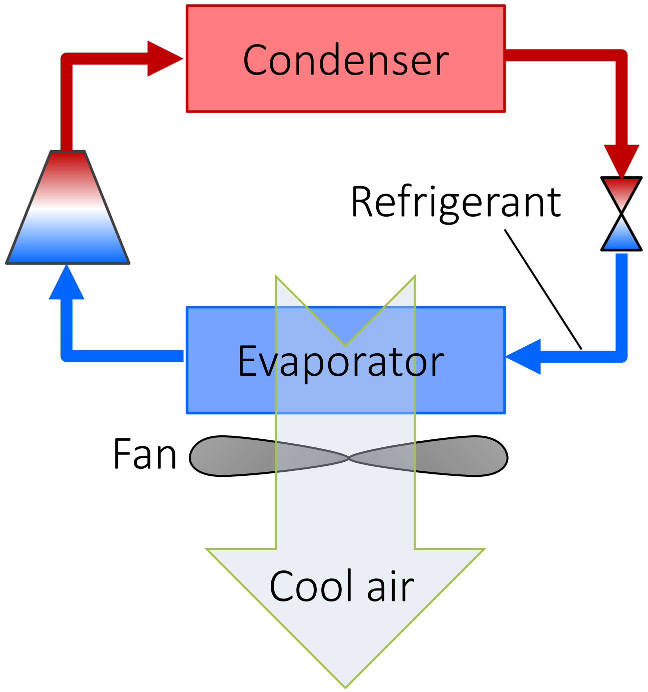


Section 2

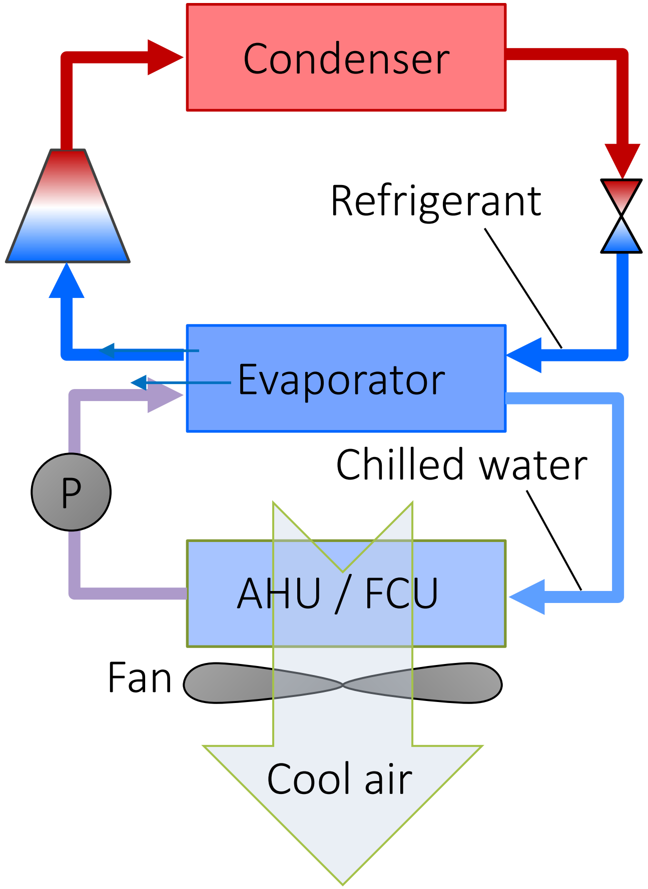
Cooling System Major Components

Types of Air-Conditioning Systems

Broadly, there are 2 types of AC systems– direct-expansion (DX) and chilled-water systems



Direct-expansion (DX) System



Chilled-water System

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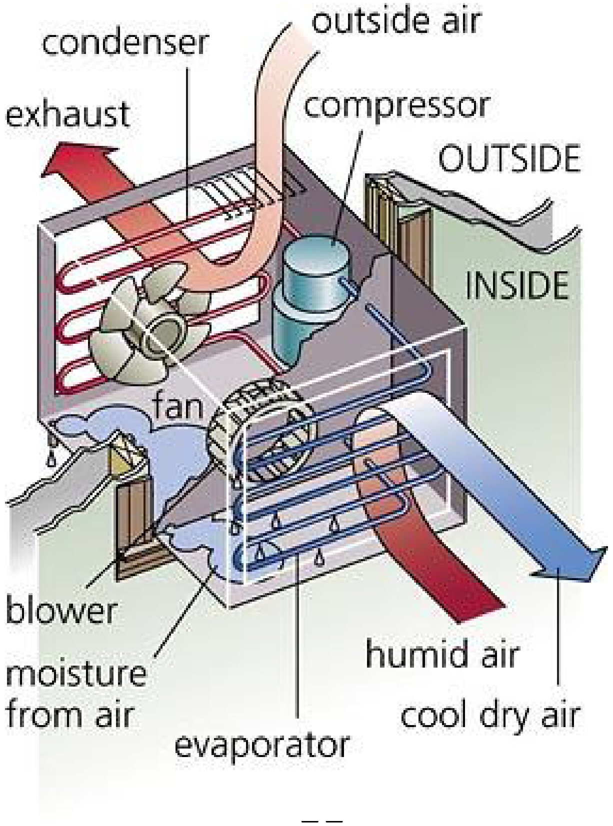
Unitary System (DX)

All components of the vapour-compression system are contained in a ‘unit’.

- Low-cost and ease of installation
- Noisier than split systems due to close proximity to cooled space
- Commonly used for temporary facilities such as at construction sites


Condenser


Evaporator



Chilled-Water Systems

Cooling of air is achieved by heat transfer from air to chilled-water

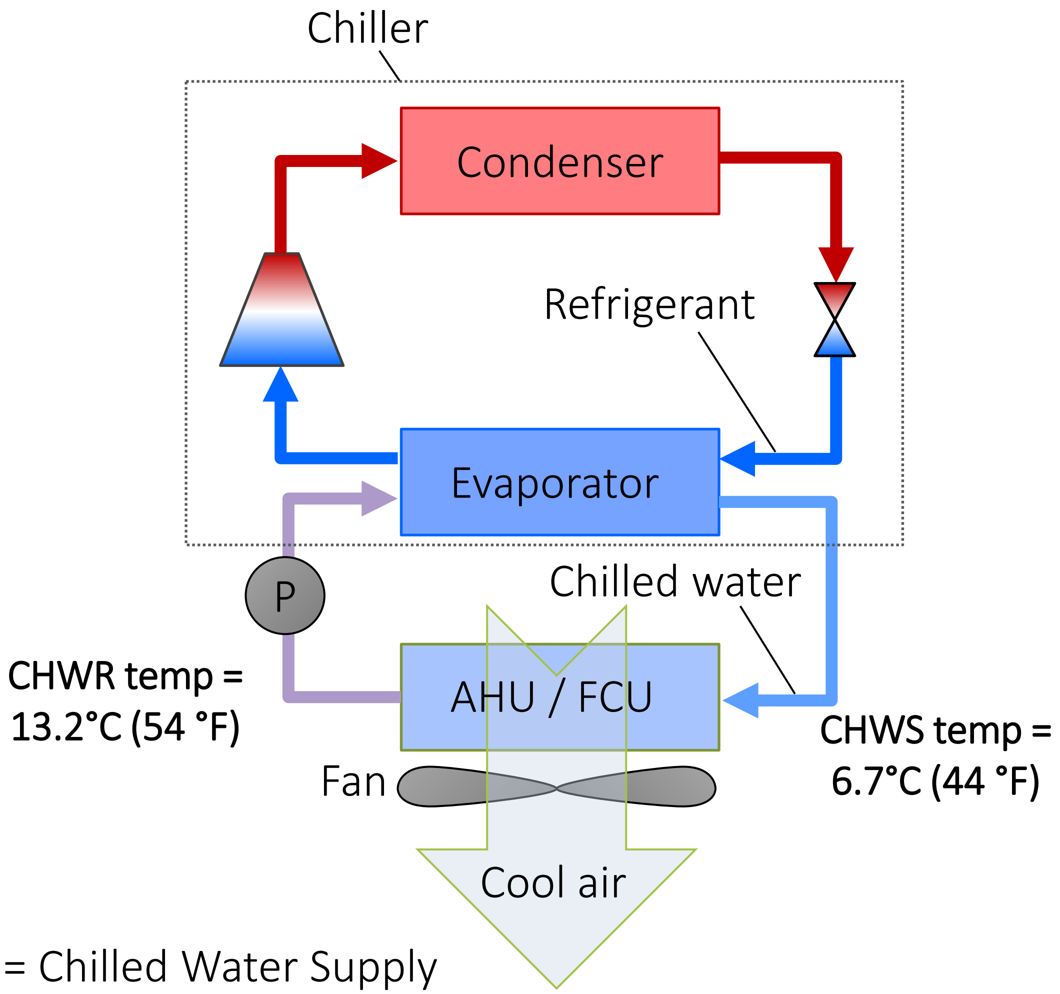
Evaporator 'chills' the circulating medium, i.e. water

A <u>**lower**</u> evaporator temp. is required as compared to DX systems

Commonly used for medium to large spaces

The vapour-compression system is contained in a unit known as the <u>**'chiller'**</u>

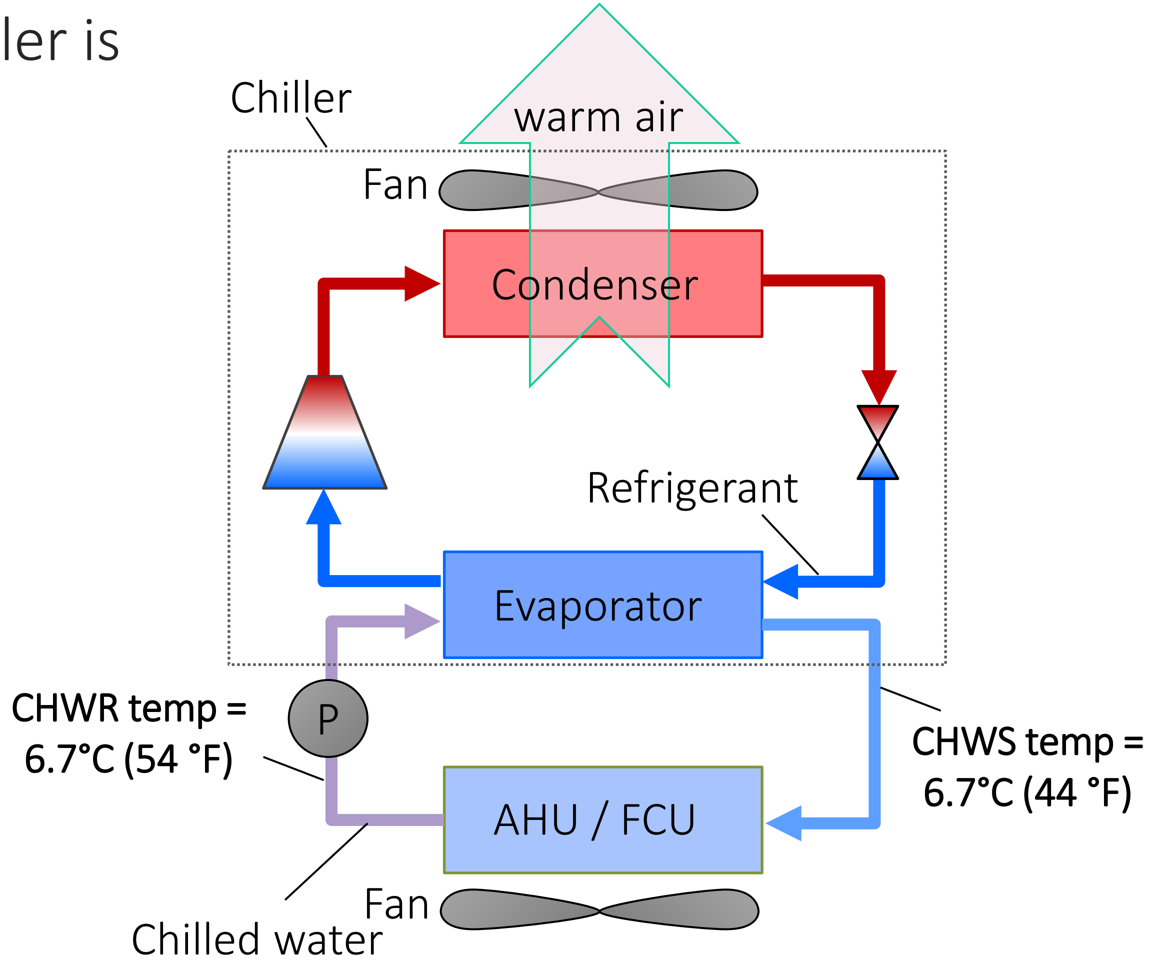
The condenser can be cooled by <u>**air or water**</u>



CHWS = Chilled Water Supply
CHWR = Chilled Water Return

Air-cooled Chiller

When the condenser is cooled by air, the chiller is commonly referred as an air-cooled chiller



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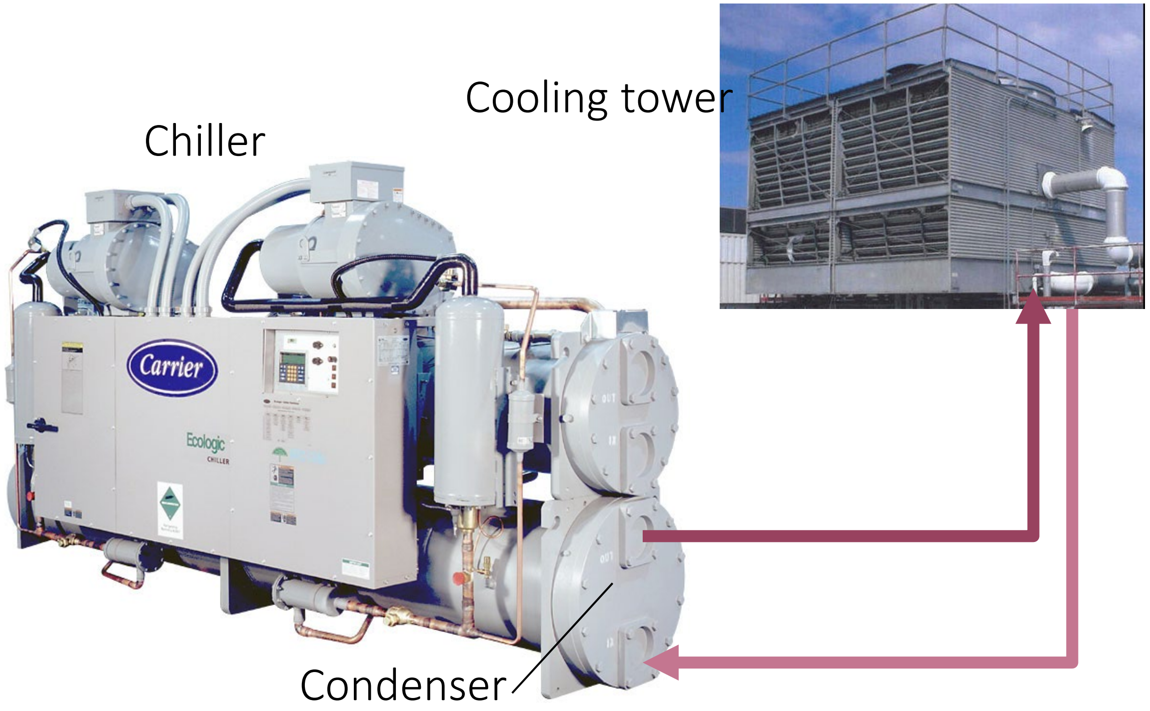
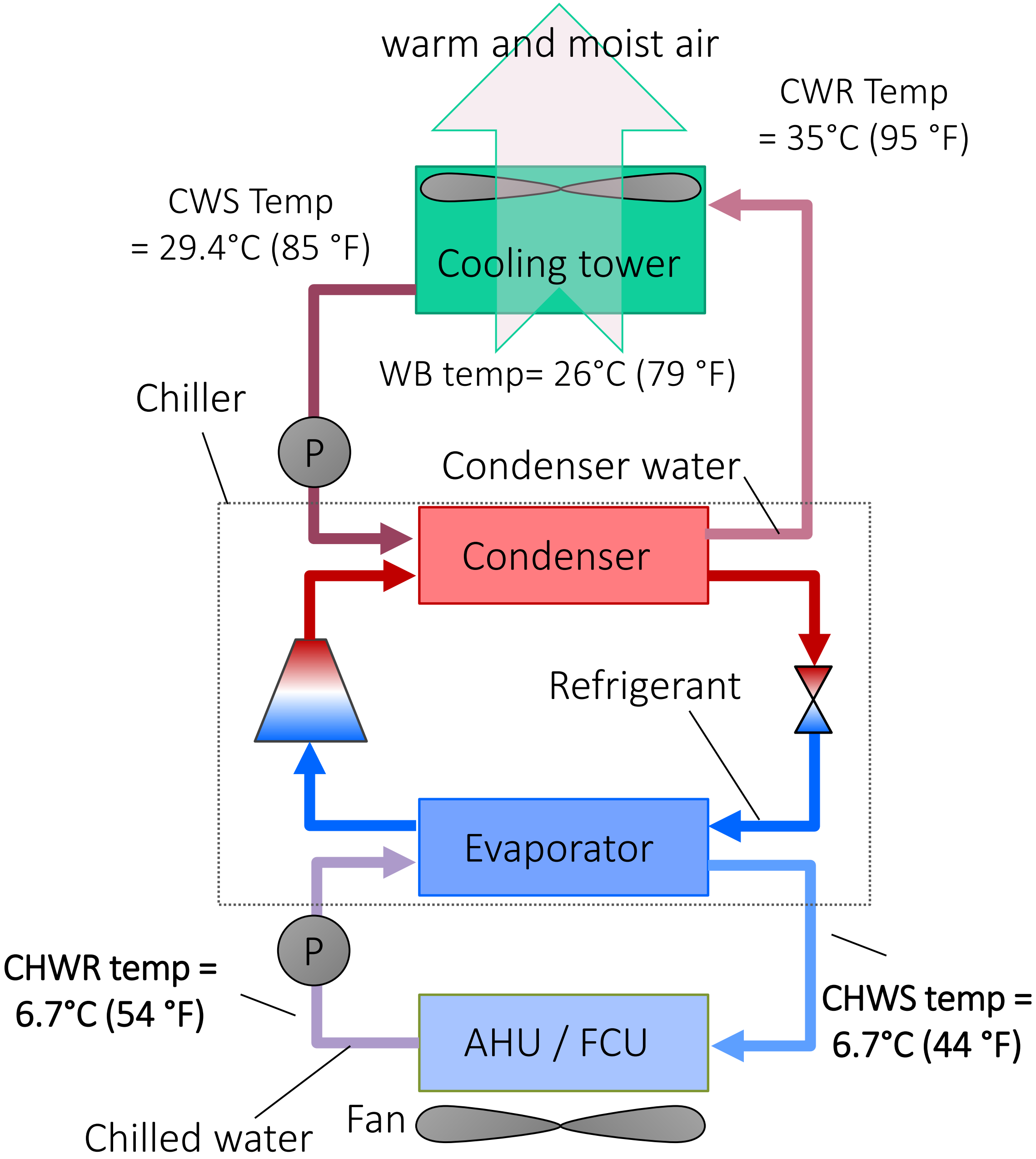
Water-cooled Chiller

If the condenser is cooled by water, the chiller is referred as a water-cooled chiller

CWS = Condenser Water Supply
CWR = Condenser Water Return





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Chilled water and Condenser water pump

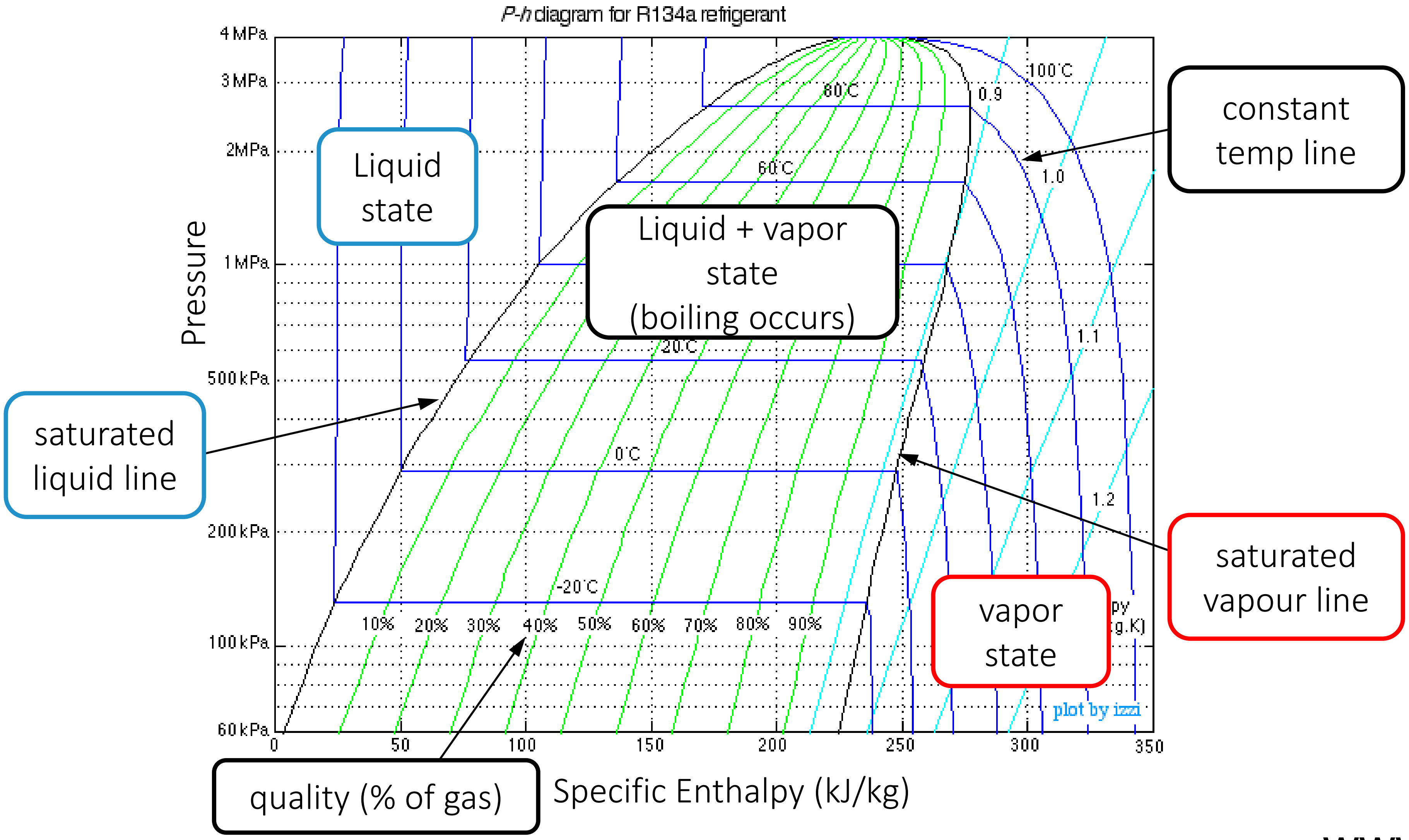
End Suction Centrifugal Pumps

Horizontally Split Case Centrifugal Pumps

Section 3

Cooling Load and Efficiency

Pressure-Enthalpy (P-h) Diagram



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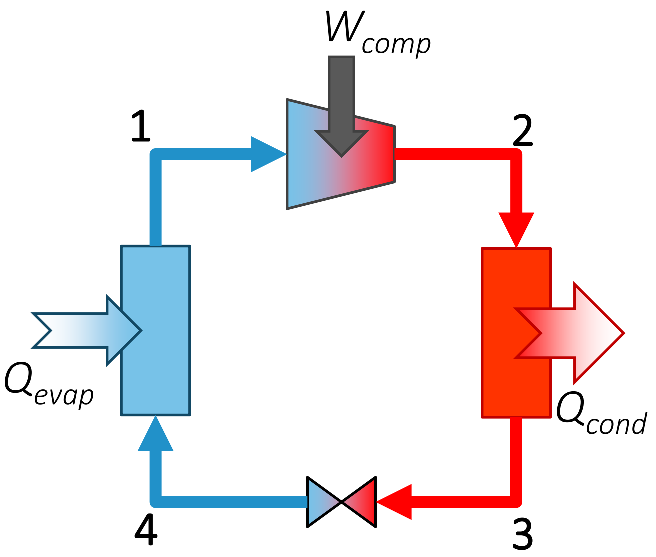
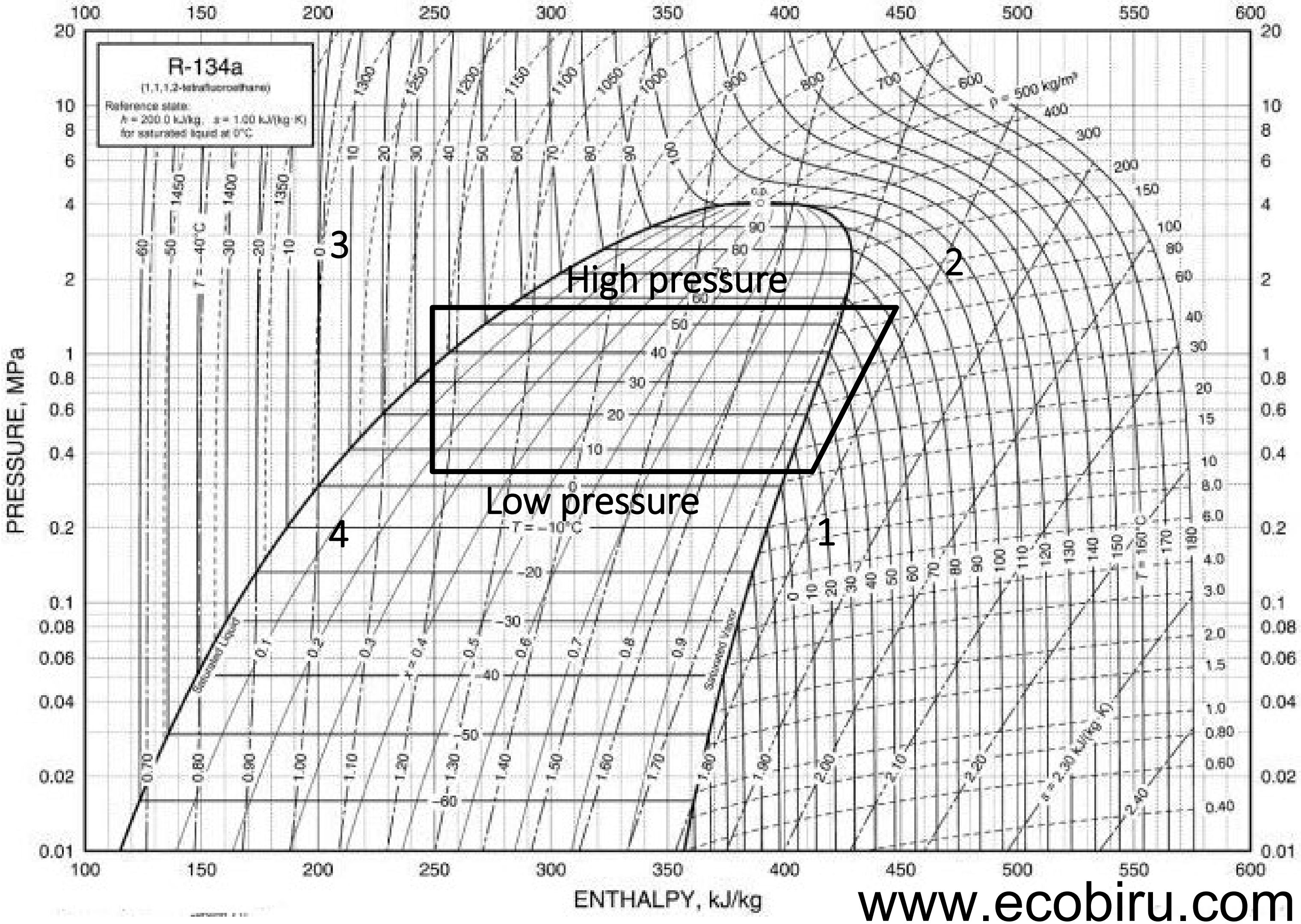
P-h Diagram for Vapour-Compression Cycle



What is the changes in thermodynamic properties between each of the two points?



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P-h Diagram for Vapour-Compression Cycle

The cooling capacity is the heat absorbed by the refrigerant at the evaporator.

The cooling capacity is given by: $Q_{evap} = \dot{m}(h_1 - h_4)$ (kW)

The compressor work is the useful work done <u>on</u> the refrigerant to increase its enthalpy.

The compressor work is given by: $W_{comp} = \dot{m}(h_2 - h_1)$ (kW)

The heat rejected at the condenser is the heat removed from the refrigerant at the condenser.

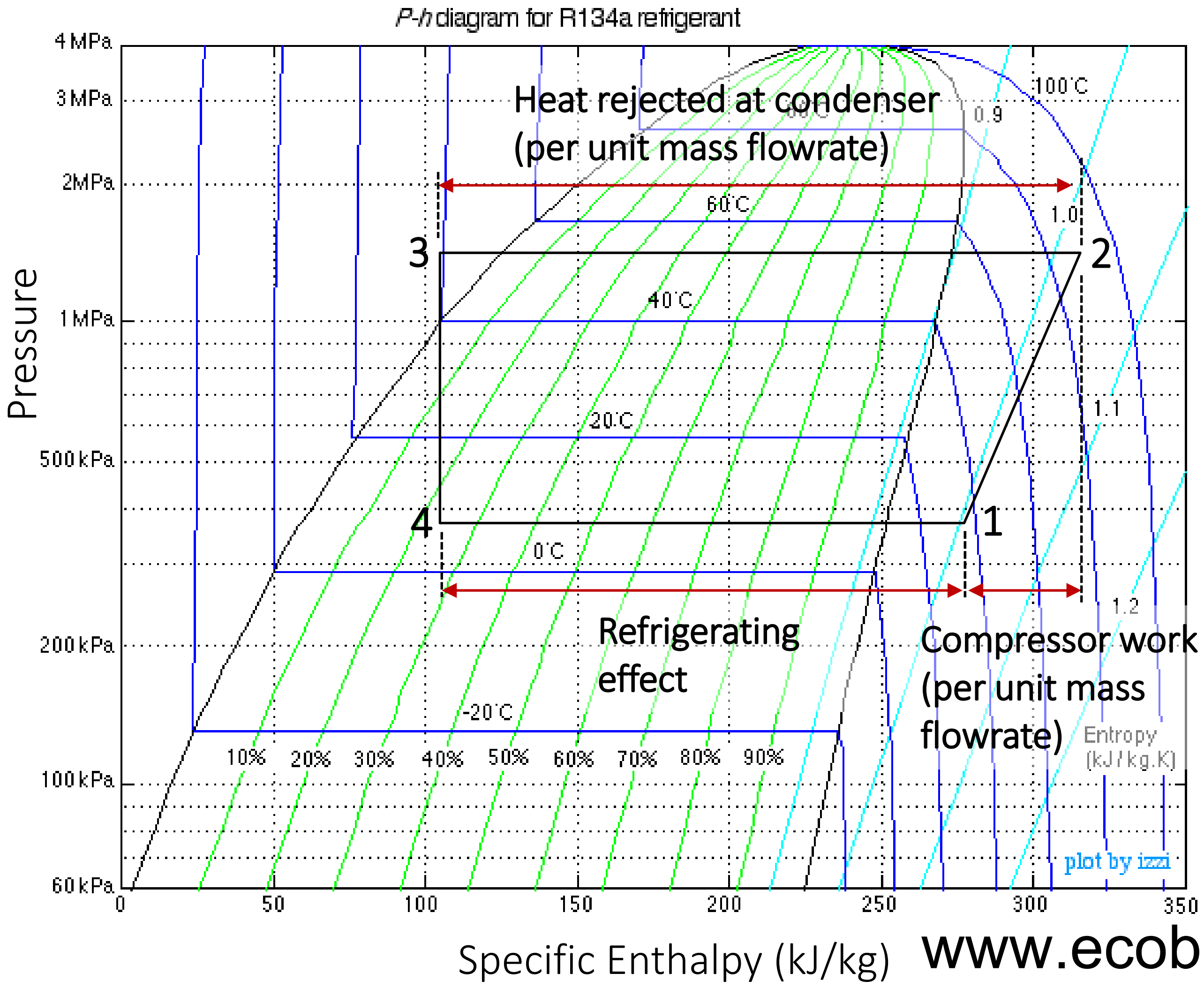
The condenser heat rejection is given by: $Q_{cond} = \dot{m}(h_2 - h_3)$ (kW)

Cycle Heat Balance

From the P-h diagram, it can be deduced that:

$$Q_{cond} = Q_{evap} + W_{comp} \quad \text{(kW)}$$

The above equation states that the heat rejected at the condenser is the sum of the heat absorbed at the evaporator and the compressor work.



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Coefficient of Performance (COP)

A measure of 'heat moving' effectiveness of the AC system

The higher the COP, the more efficient is the AC in moving heat

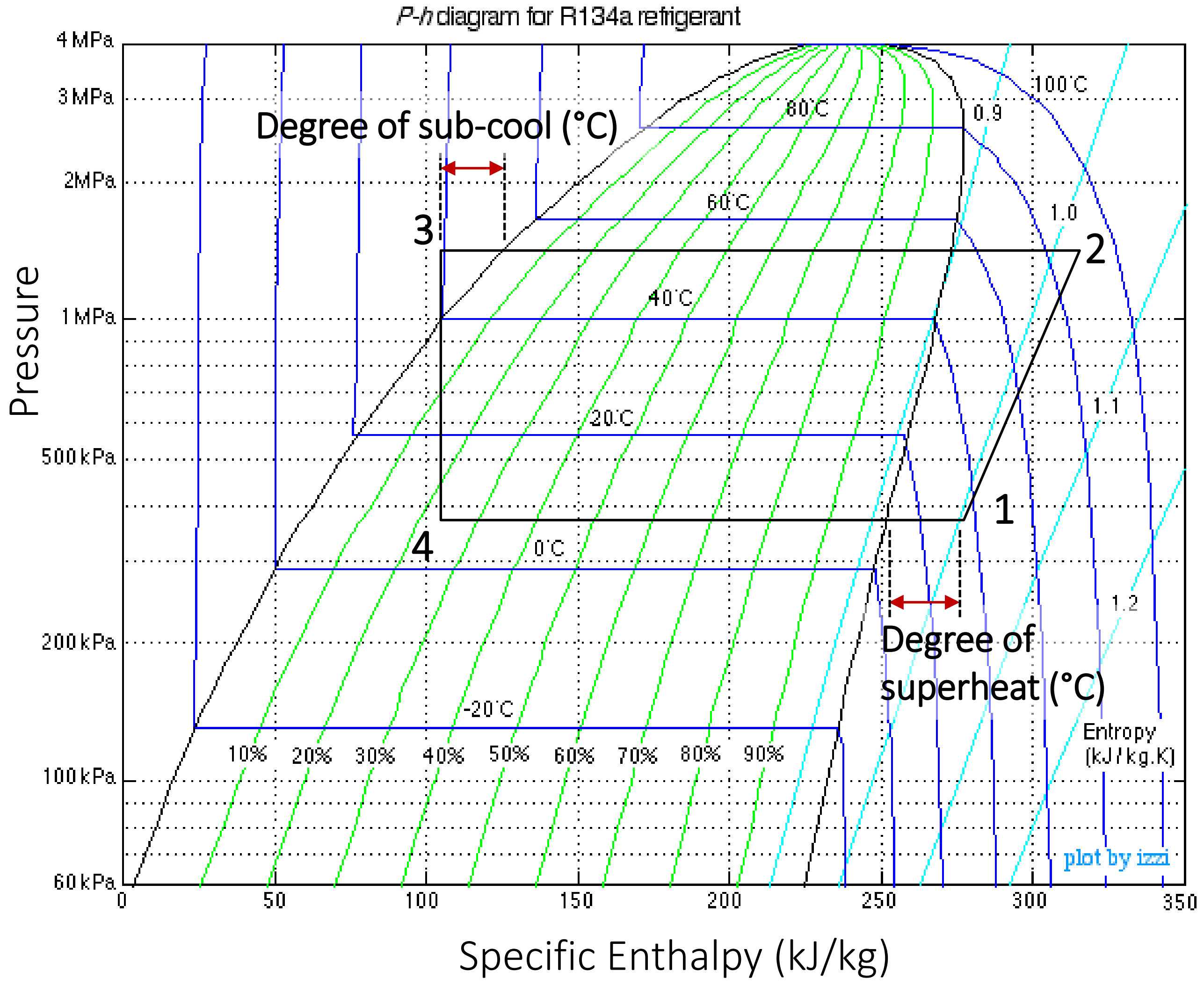
Note that COP can be greater than 1, but it does not mean that the efficiency is more than 100%

The COP of an AC system is defined as:

$$COP = \frac{Q_{evap}}{W_{comp}}$$

where Q_{evap} = cooling load (W)
W_{comp} = Work done by compressor (W)

Degree of Superheat & Subcool



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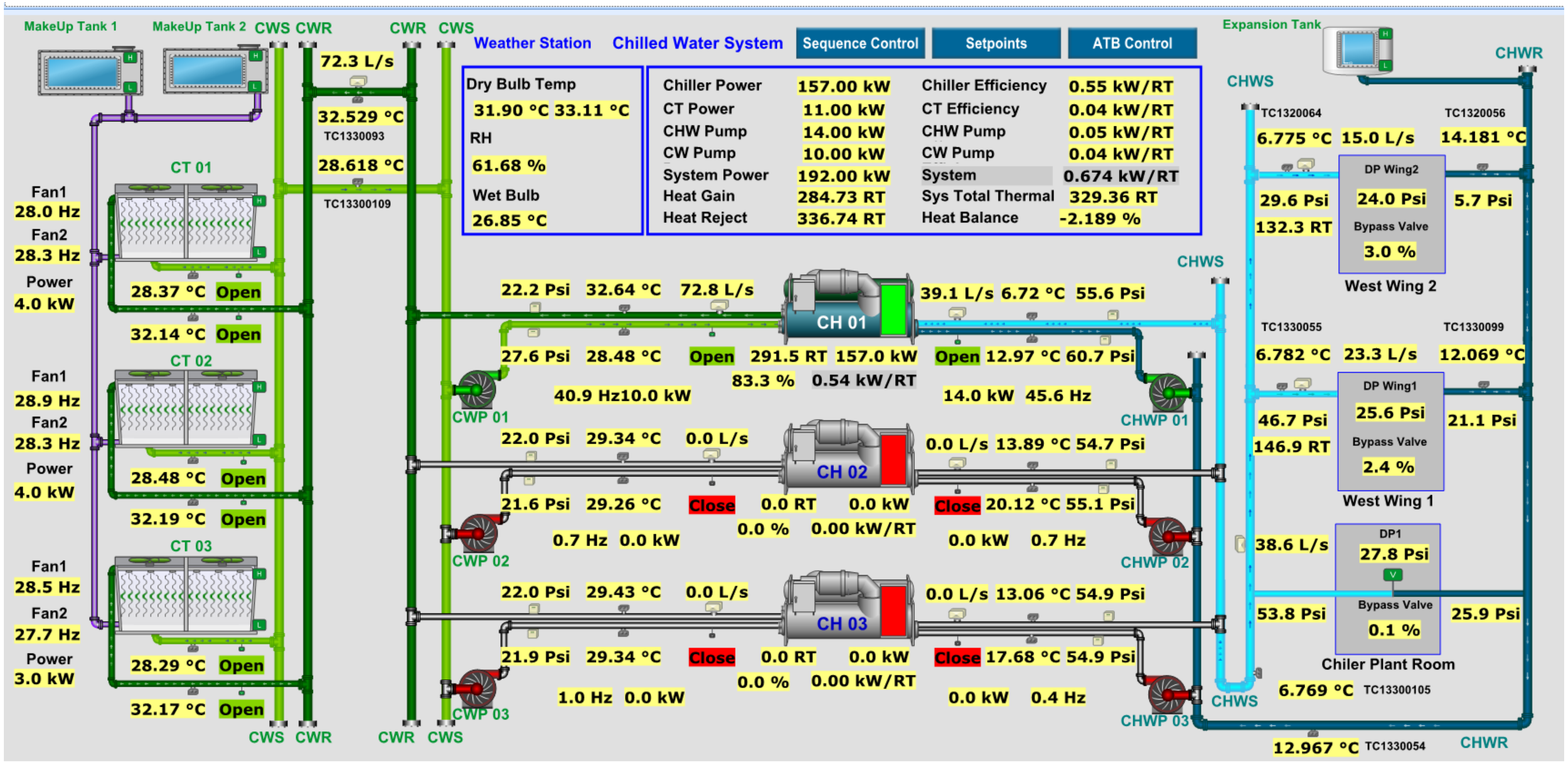
Building Cooling Load Calculation



What are the “header” parameters?

Building Management System (BMS) Chiller Plant Schematic

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Chiller load

There is a common measurement unit used in the industry for HVAC

<u>Units of Cooling</u>

1 x Refrigerant Ton (RT) = 12000 x BTU/hr = 3.517 kW

A ton is the amount of heat removed by an air conditioning system that would melt *1 ton* of ice in *24 hours. It is the one of the most commonly used unit to represent cooling load.*

BTU – British Thermal Unit

Evaporator Load (Chiller load) Calculation

Heat gained at evaporator (chiller load) = Heat rejected by the chilled water

$$Q_{gain} = \dot{m} \times c_w \times \Delta T_{evap}$$
$$= \dot{m} \times c_w \times (T_{CHWR} - T_{CHWS}) \quad \text{(kW)}$$

From sensors

$\dot{\mathrm{m}}$ = mass flow rate of chilled water in kg/s

$\mathrm{c_w}$ = specific heat capacity for water in kJ/kgK

$\Delta\mathrm{T_{evap}}$ = Difference in temperature in °C

For water:
kg/s = l/s since
1 litre of water = 1 kg

C_w= 4.19 kJ/kgK

Condenser Load Calculation

Heat rejected at condenser = Heat absorbed by the condenser water

$$Q_{reject} = \dot{m} \times c_w \times \Delta T_{cond}$$

$$= \dot{m} \times c_w \times (T_{CWR} - T_{CWS}) \quad \text{(kW)}$$

From sensors

$\dot{m}$ = mass flow rate of condenser water in kg/s

c_w = specific heat capacity for water in kJ/kgK

ΔT_{cond} = Difference in temperature in °C

For water:
kg/s = l/s since
1 litre of water = 1 kg

C_w = 4.19 kJ/kgK

Heat Balance Equation

Heat rejected at condenser = Heat gained at evaporator + Compressor power input

Heat balance equation:

$$Q_{reject} = Q_{gain} + W_{in}$$

Compressor power input is taken from the power meter or chiller panel.

Section 4

Chiller Efficiency and Selection

Chiller load and efficiency

To determine the performance of a chiller, we can either compare the COP value or the kW/RT value.

$$COP = \frac{\textbf{Cooling capacity (kW)}}{\textbf{Input power (kW)}}$$

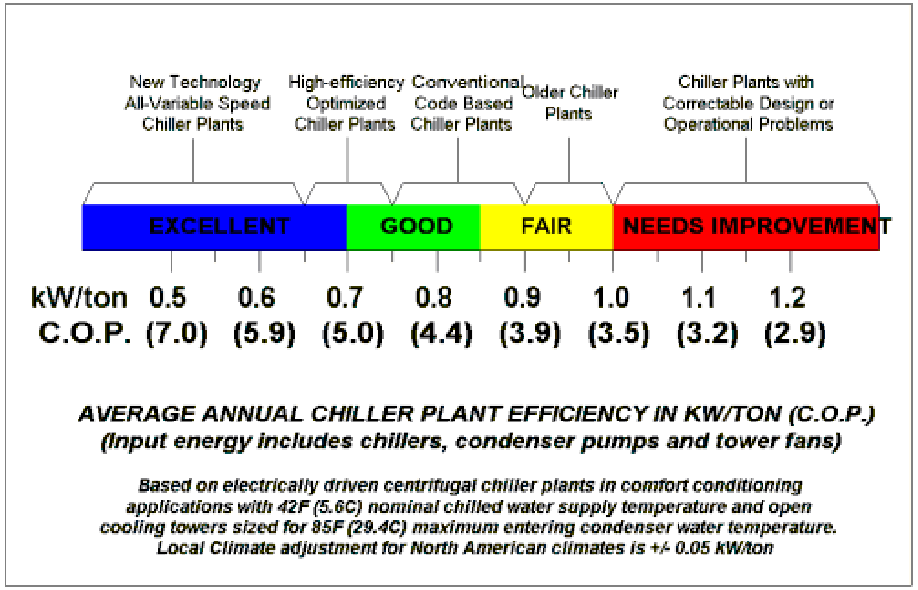
Output/Input -> amount of cooling provided with 1 kW of input

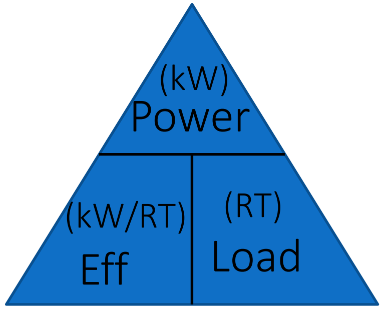
Bigger value = more efficient

$$\textbf{Chiller efficiency} = \frac{\textbf{Input power (kW)}}{\textbf{Cooling load (Rton)}}$$
$$= 3.517/COP$$

Input/Output -> amount of power required to provide 1 RT of cooling

Smaller value = more efficient





EER and SEER

Energy Efficiency Ratio

Used to evaluate the efficiency of cooling systems

Efficiency of cooling system operates under specific conditions, typically at peak load

$$EER\left(\frac{BTU}{Wh}\right) = \frac{Cooling\ Capacity\ \left(\frac{BTU}{hr}\right)}{Power\ Input\ (W)}$$

$$COP = \frac{EER}{3.41214}$$

Calculated under standardized conditions:

- Outdoor temperature of 95°F (35°C)
- Indoor temperature of 80°F (26.7°C)
- 50% relative humidity

IPLV and NPLV

<u>IPLV (Integrated Part Load Value)</u>

IPLV is a metric used to evaluate the efficiency of cooling systems, particularly chillers, under various part-load conditions.

Uses standard conditions defined by AHRI (Air-Conditioning, Heating, and Refrigeration Institute) and assumes typical operating scenarios

It reflects how well a system performs when it is not operating at full capacity, which is more representative of typical usage patterns in many applications.

IPLV Calculation:
12% of the time at 25% load (D in the equation)
45% of the time at 50% load (C in the equation)
42% of the time at 75% load (B in the equation)
1% of the time at 100% load (A in the equation)

IPLV = 0.01A + 0.42B + 0.45C + 0.12D

<u>NPLV (Non-Standard Part Load Value)</u>

- Similar to IPLV (Integrated Part Load Value), but uses non-standard conditions specific to the installation or operational requirements

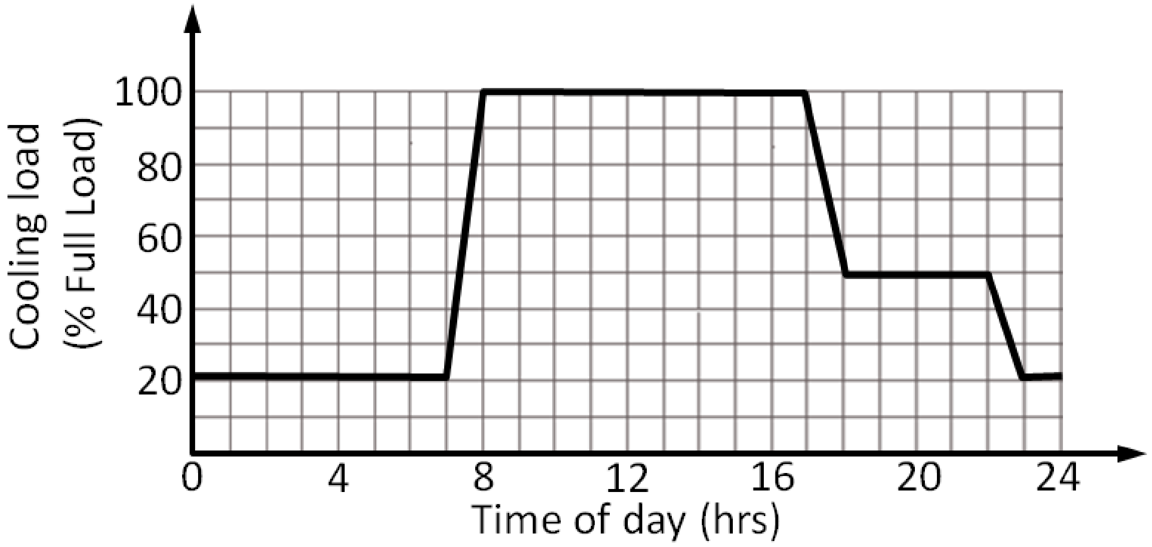
- Considers efficiency at multiple part-load points: 100%, 75%, 50%, and 25%, but uses customized weighting factors or conditions

Measurement	Full Name	Unit
COP	Coefficient of Performance	Dimensionless
kW/ton	Kilowatts per Ton	kW/ton
SEER	Seasonal Energy Efficiency Ratio	BTU/Wh
EER	Energy Efficiency Ratio	
HSPF	Heating Seasonal Performance Factor	
IPLV	Integrated Part Load Value	Depends
NPLV	Non-Standard Part Load Value	Depends

HVAC Efficiencies Summary

Cooling Load Profile

Time (hrs)	Cooling Load	Activity
0800 - 1700	100 % full load	Working hours, with high heat gain from external conditions
1800 - 2200	50 % part load	Off-office hours, but some staff work overtime (OT)
2300 - 0700	20 % part load	Minimum OT staff, cooling still required for servers



Section 5

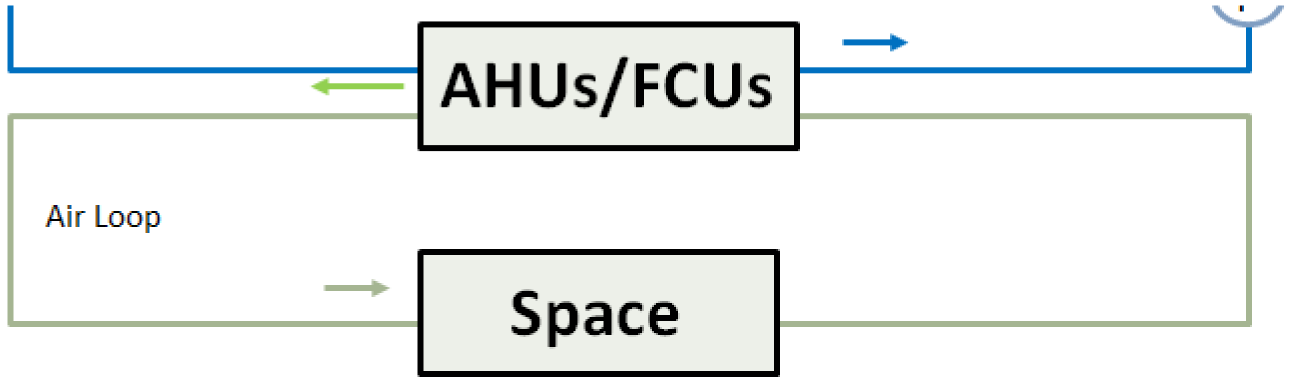
Building Management System Controls

Air Distribution Systems

For a central AC system providing cool air to several spaces, an air distribution system is required

The main “driver” of the cooled air is

1. Air Handling Unit (AHU)
2. Fan Coil Unit (FCU)



AHU vs FCU major differences

AHU	FCU
1. AHUs are located in <u>**AHU room**</u> separate from or outside the occupied space that they serve.	1. FCUs are located in the <u>**ceiling**</u> of the occupied space(s) that they serve.
2. Since the chilled water coil (ie. AHU) is located <u>**outside**</u> the occupied space to be cooled, the space is cooled by the cold air produced outside the space.	2. In an all-water system, the chilled water coil (ie. FCU) is located <u>**within**</u> the space to be cooled, so the space is cooled by the cold air produced within the space.
3. Maintenance of AHU can thus be carried out without interfering with the tenant's business or operations.	3. Maintenance of FCUs may only be carried out at possible risk of interfering with the tenant's business or operations.
4. A single AHU can serve a reasonably <u>**large zone**</u>, so a larger fan operated at a lower speed can be provided, resulting in lower sound power level.	4. Several FCUs may be required to serve the same size of zone, so <u>**multiple**</u> fans operating at various speeds may result in higher sound power level.
5. Fan noise can be largely confined to the AHU room.	5. Fan noise in occupied space may be significant, especially at MED & HI speed.
6. Intake of outdoor air at AHU can be achieved so long as the AHU room has at least 1 external wall for fixed louvres.	6. A separate outdoor air intake system is usually required to distribute OA to the multiple FCUs serving the zone(s).

Controls in Air Handling Systems

There are 4 main control loops in a typical AHU. They are:

- Space temperature control
- Static pressure control
- CO_2 control
- Supply Air temperature control

Sensor

Actuator
Output device

Desired
Set Point

Controls in the Chiller plant

There are three basic configuration of chilled-water piping in a chiller plant. They are

1. Constant primary flow
2. Constant primary/Variable secondary flow
3. Variable primary flow

Controls in the Chiller plant – Building Cooling load variation

Considering the constant primary/variable secondary piping configuration under a decreasing load condition

Control method	Field devices involved	Control process
Modulating Chilled water flow	• Chilled water flow rate • VSD control of CHWP • DP Sensor	Cooling load low -> AHU chilled water valve throttle close -> Chilled water DP increases above set point -> VSD reduces secondary pump speed -> chilled water flow rate and DP decreases
Modulating Bypass valve	• DP sensor • Bypass valve	If DP is still higher than set point despite operating at minimum speed (30Hz) -> bypass valve throttle open -> DP and CHWR temperature reduces
Start/Stop of additional chiller	• CHWS temp • Start/Stop command	If DP is still higher than set point despite bypass valve is 100% open and Delta T is low -> One chiller and pump switched off

Controls in the Chiller plant – Condenser water loop

There are a few different control methods in the condenser water loop depending on the chiller plant design.

Consider the cooling tower fan speed control

Control method	Field devices involved	Control process
Using Condenser Water Supply (CWS) temperature	• CWS temp sensor • VSD for cooling tower fans	CWS temp increases above set point -> VSD increases cooling tower fan speed
Using approach temperature between CWS temp and ambient wet bulb temperature	• CWS temp sensor • Ambient wet bulb temp • VSD for cooling tower fans	Approach temperature increases above set point -> VSD increases cooling tower fan speed

Chiller Sequencing

At any stage where the condition is not met, the sequence is aborted and the next chiller set will be commanded to start

Condenser water Pump → Cooling Tower → Chilled water pump → Chiller

Chiller Staging

How to determine when to start or stop a chiller?

Different strategies are used for by different buildings

3 common methods are:

1. Based on building cooling load calculation
2. Based on chilled water Return temperature
3. Based on chilled water Flow rate

Whichever method is used, the first chiller is always started by time schedule.

The start/stop of subsequent chillers will be based on 1 of the 3 methods.

Section 6

Building HVAC Maintenance and Troubleshooting for Facility Management

Common Air side issues

How to resolve?

Design problem:
- Relocation of sensors or equipment

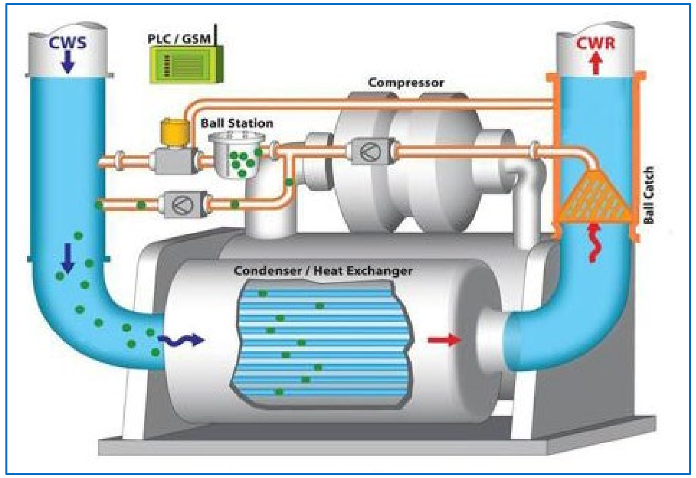
Settings problem:
- Reset the settings on site or via BMS

Equipment problem:
- Calibrate or replace the faulty equipment
- Offset the sensor readings via BMS

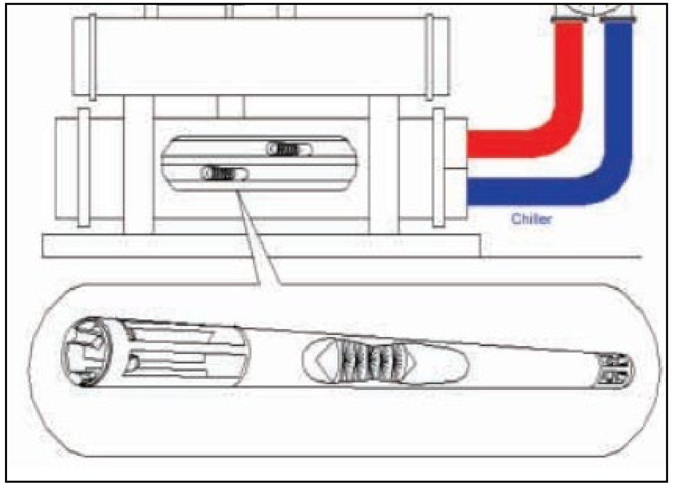
Condenser water heat transfer

Automatic Tube Cleaning System (ATCS)

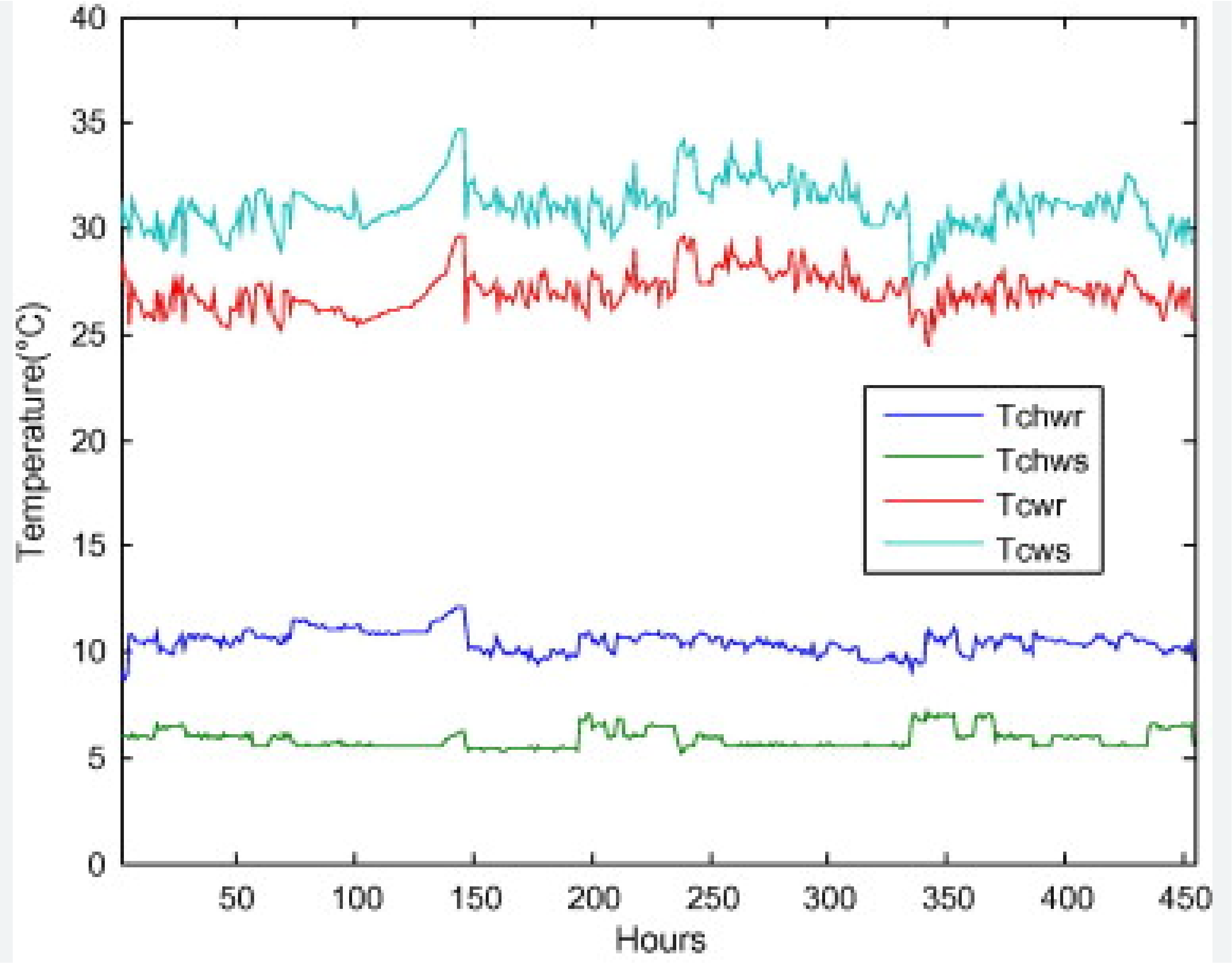
- Periodic manual cleaning of chiller's condenser requires equipment shut down, and expensive maintenance staff time.
- Automatic tube cleaning system are available commercially that can consistently "clean" the tubes surface and prevent scale from forming.
- Two common types of ATCS:
  - ➢ Ball
  - ➢ Brush



Ball Type

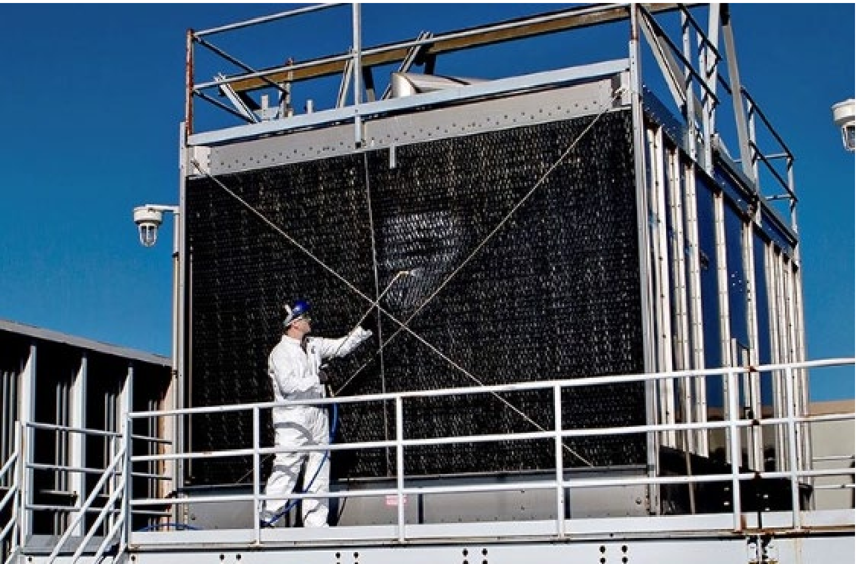


Brush Type



Low Delta T Syndrome

- Low Delta T syndrome is a common issue in chilled water systems
- The temperature difference (Delta T) between the chilled water supply and the return water is lower than the design specifications.
- This condition can significantly reduce the efficiency and effectiveness of the chilled water system.



Cooling Tower Maintenance

Regular Inspection
Water Treatment
Cleaning and Disinfection
Check and Maintain Fans

Section 7

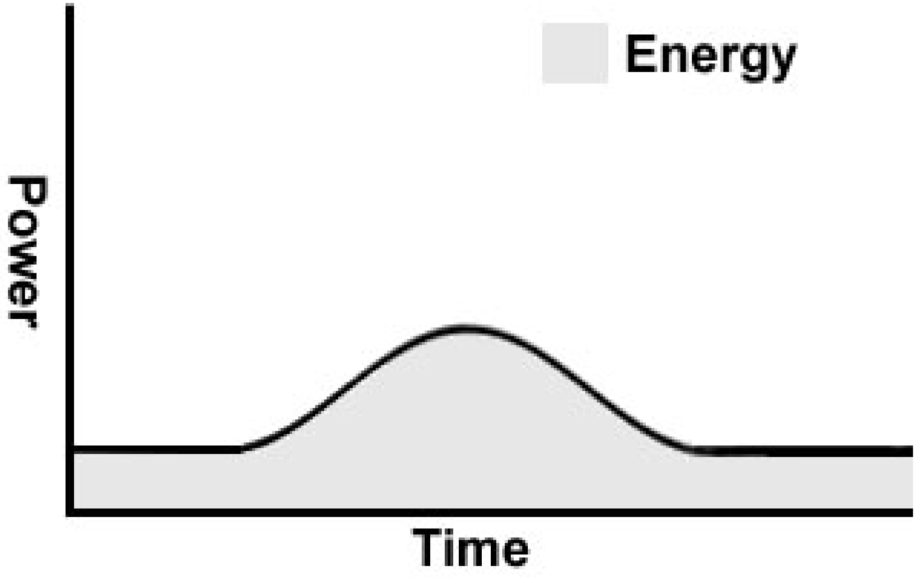
HVAC Optimisation strategies

Energy Savings in Air Handling Systems

To reduce energy consumption of the AHU fan:

1. Reduce power consumption of the fan
2. Reduce running hours

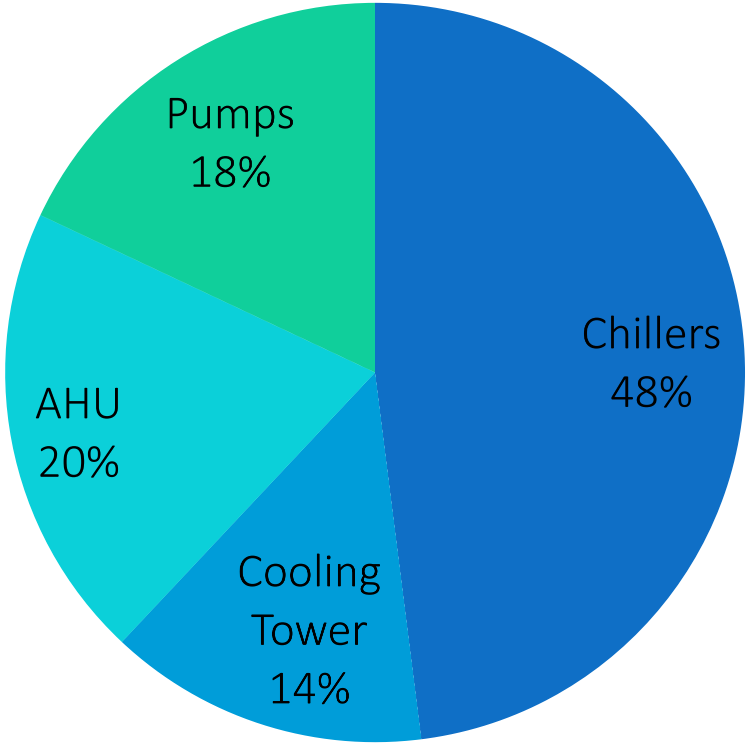
$$Energy = Power \times Time$$



Chiller plant Optimization

- The main bulk of energy is consumed by the chillers.

- Any modification to the parameters of chillers will have a drastic effect on the energy consumption.

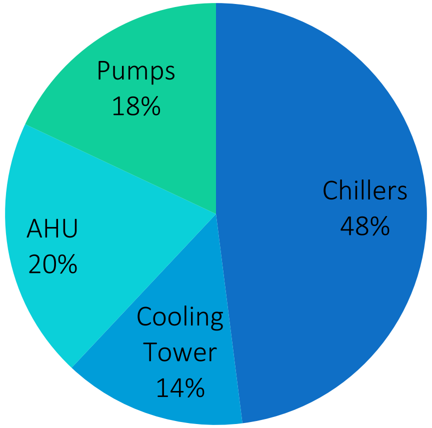


Energy consumption distribution for a typical building

Optimization Strategies – Pump/Fan Systems

Although the chiller is the main energy consumer in an HVAC system, there are other components that consume substantial energy:

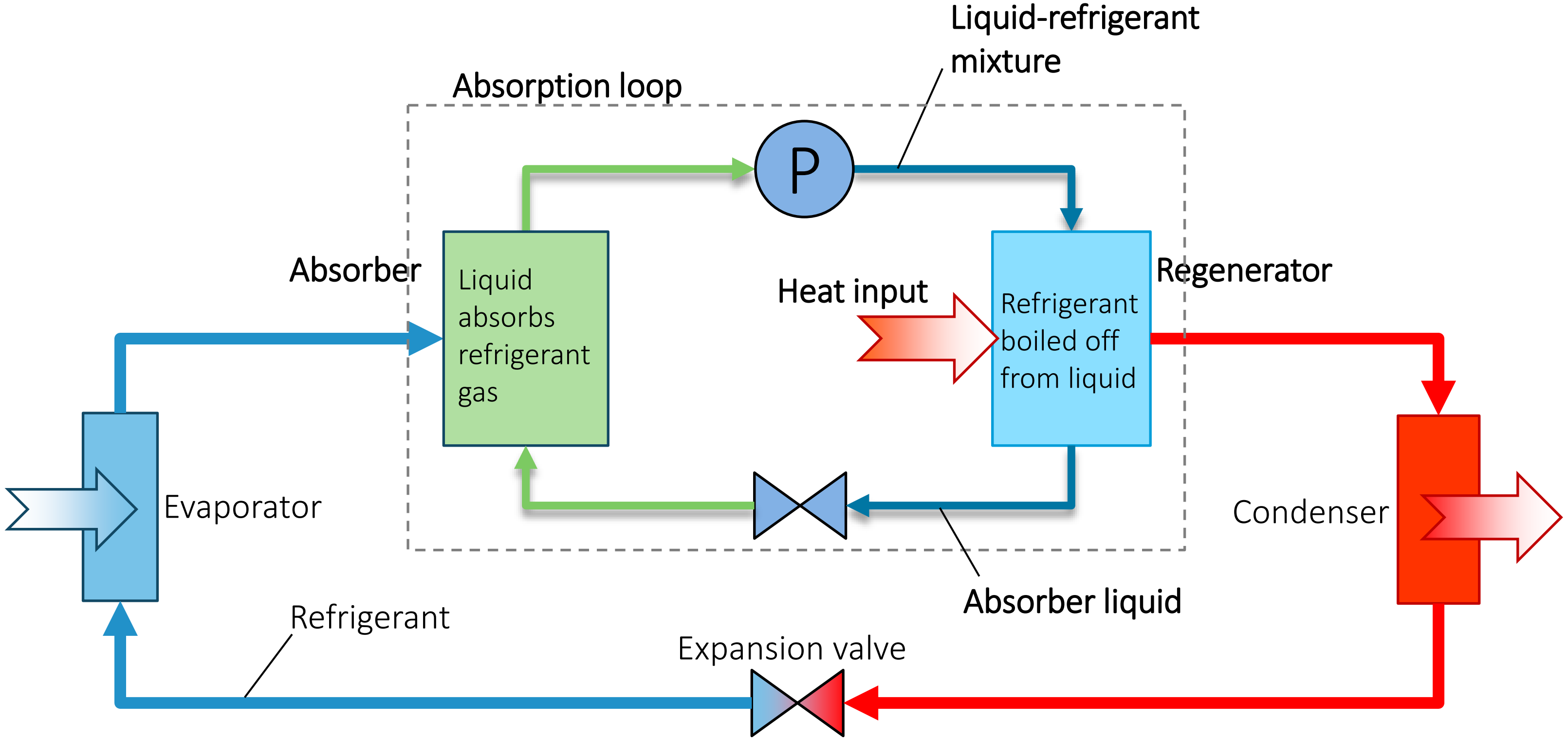
- Chilled-water pumps
- Condenser water pumps
- Cooling towers
- AHU/FCU fans



As compared to a compressor, a pump or fan require much less energy to operate. However, **due a large number of them**, the energy consumption can be significant.

Working Principle of Absorption Cycle

In principle, the absorption cycle makes use of a liquid to absorb the refrigerant and a pump to change the pressure of the refrigerant.



Absorption Cycle

Artificial Intelligence in HVAC