MECH 1905 Buildings for Contemporary Living

Air-Conditioning and Refrigeration

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How the Air Conditioner works

Outline

- Introduction
- What Is Comfort ?
- Air-Conditioning and Refrigeration
- Refrigeration Cycle
- Temperature Control
- Humidity Control

Functions of Air-conditioning and Refrigeration



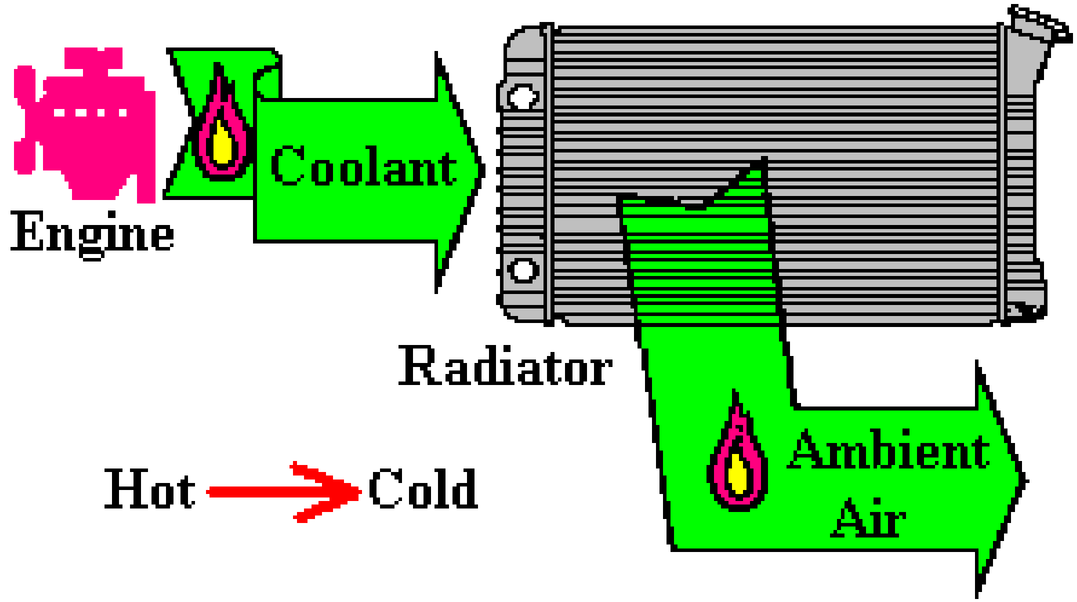



Air-conditioning in Hong Kong

- Air-conditioning accounts for 32% of the total electricity consumption in Hong Kong, of which 72% is taken up in non-domestic buildings
- Before 2000, air conditioning systems using fresh water heat rejection (cooling towers) were prohibited in Hong Kong because of a fresh water shortage in the territory
- Pilot Scheme on Wider Use of Fresh Water for Evaporative Cooling Towers was lunched in June 2000 by the EMSD of the Government of Hong Kong, SAR
- Aims not only to promote the energy-efficient water-cooled air conditioning systems, but also to assess the impacts on infrastructure, health and environmental effects with an ultimate aim to facilitate territory-wide implementation of water-cooled air conditioning systems in Hong Kong

Heat Movement

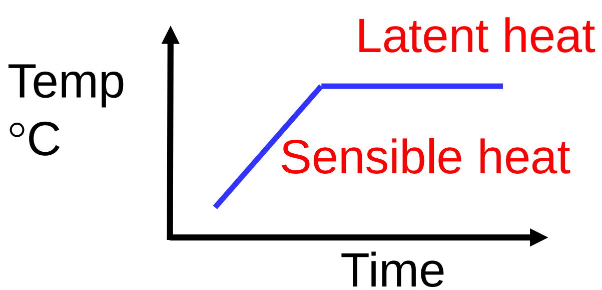
Heat always travels from ***Hot to Cold.***

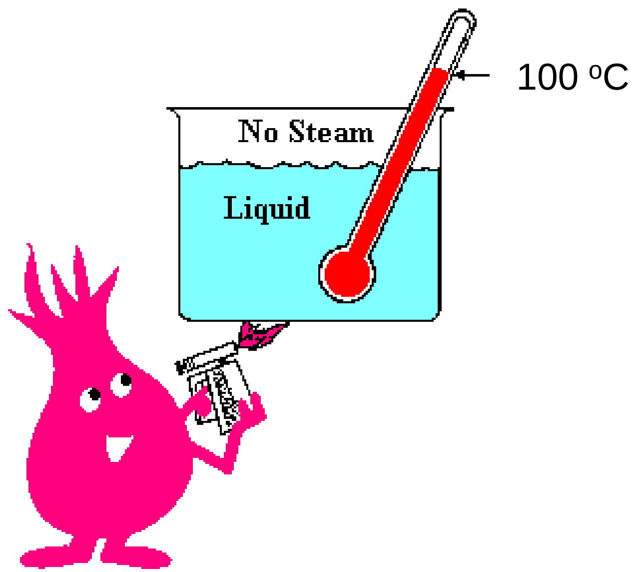


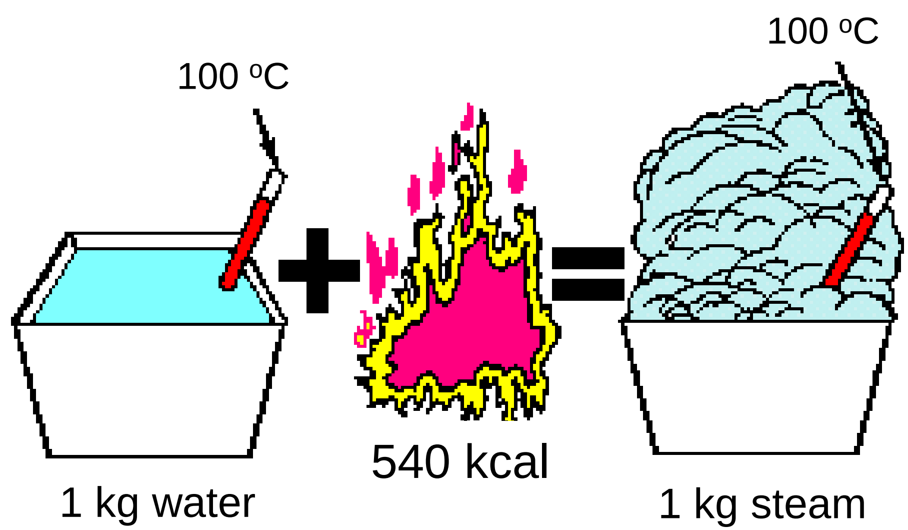
In the example of an automobile, heat within the engine will move from the very hot combustion chamber to the cooler coolant. After the coolant is moved to the radiator, the heat will move to the cooler air passing through it.

Sensible and Latent Heat

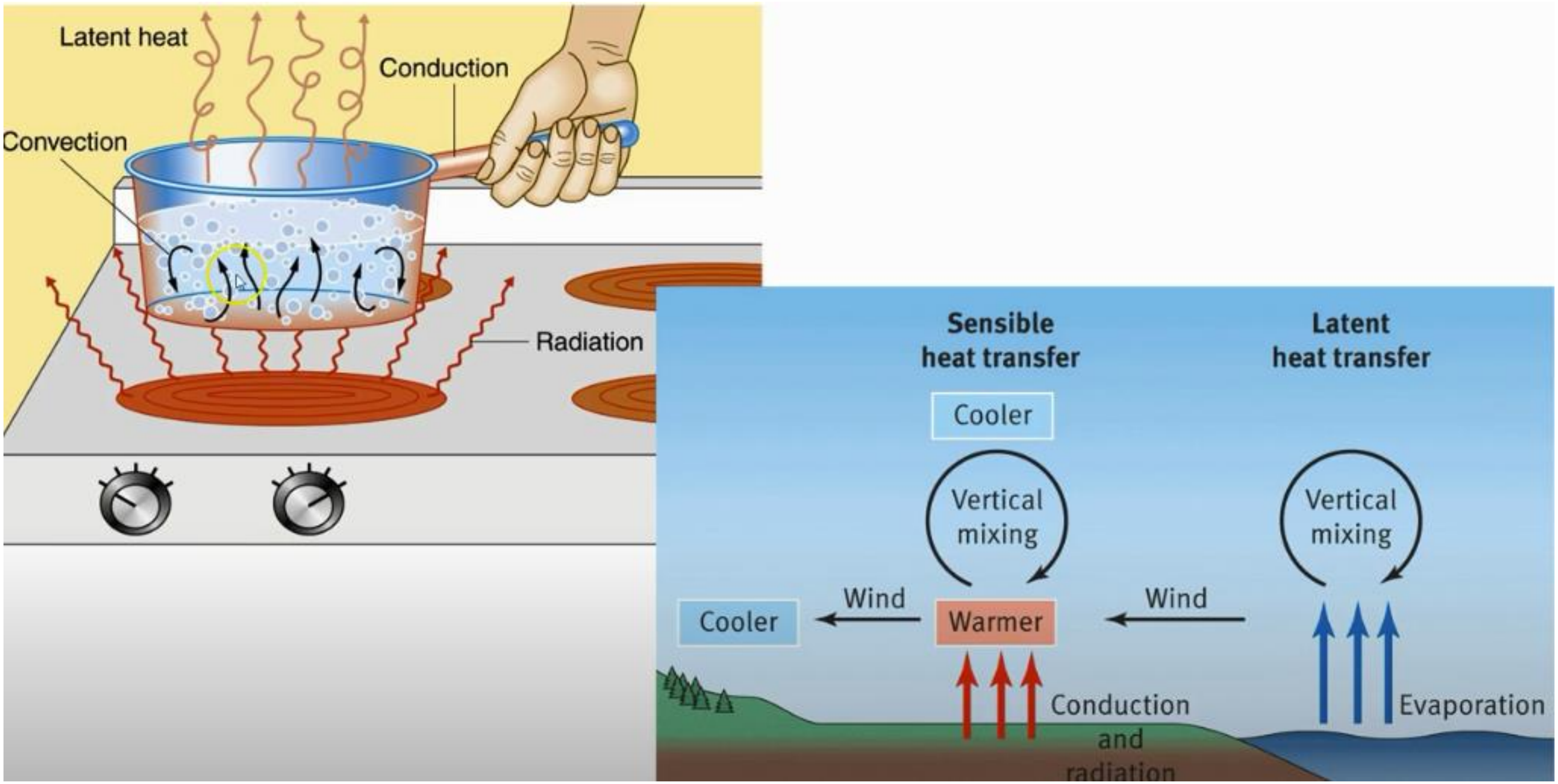
- **Sensible heat** causes a change in temperature
  - If we add heat to water, the temperature will increase, and this is called ***sensible heat.***
- **Latent heat** causes a change of state but no change in temperature
  - If we add heat to ice at 0 °C or to water at 100 °C, the temperature will not increase.
  - The added heat will melt some of the ice or boil some of the water.
  - This heat energy changes the molecular bond within the molecule.





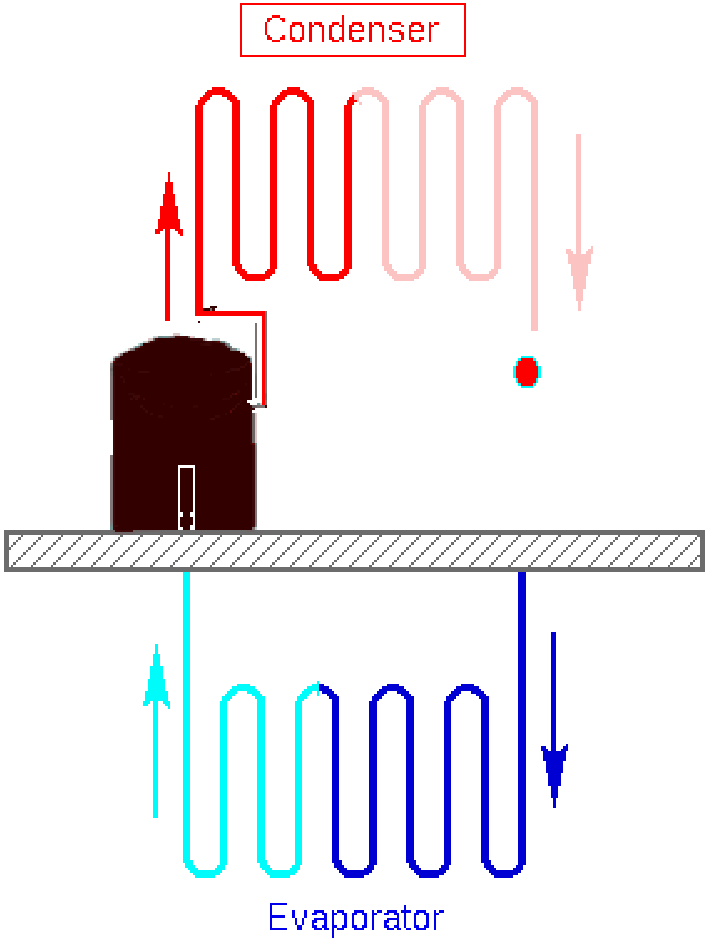


Sensible and Latent Heat



Latent Heat of Vaporization

- In an air-conditioning system, the refrigerant changes state and absorbs heat in the evaporator and releases heat as it changes state again in the condenser
- **Evaporator**: liquid changing to gas
- **Condenser**: gas changing to liquid



What Is Comfort ?
Subjective Feeling

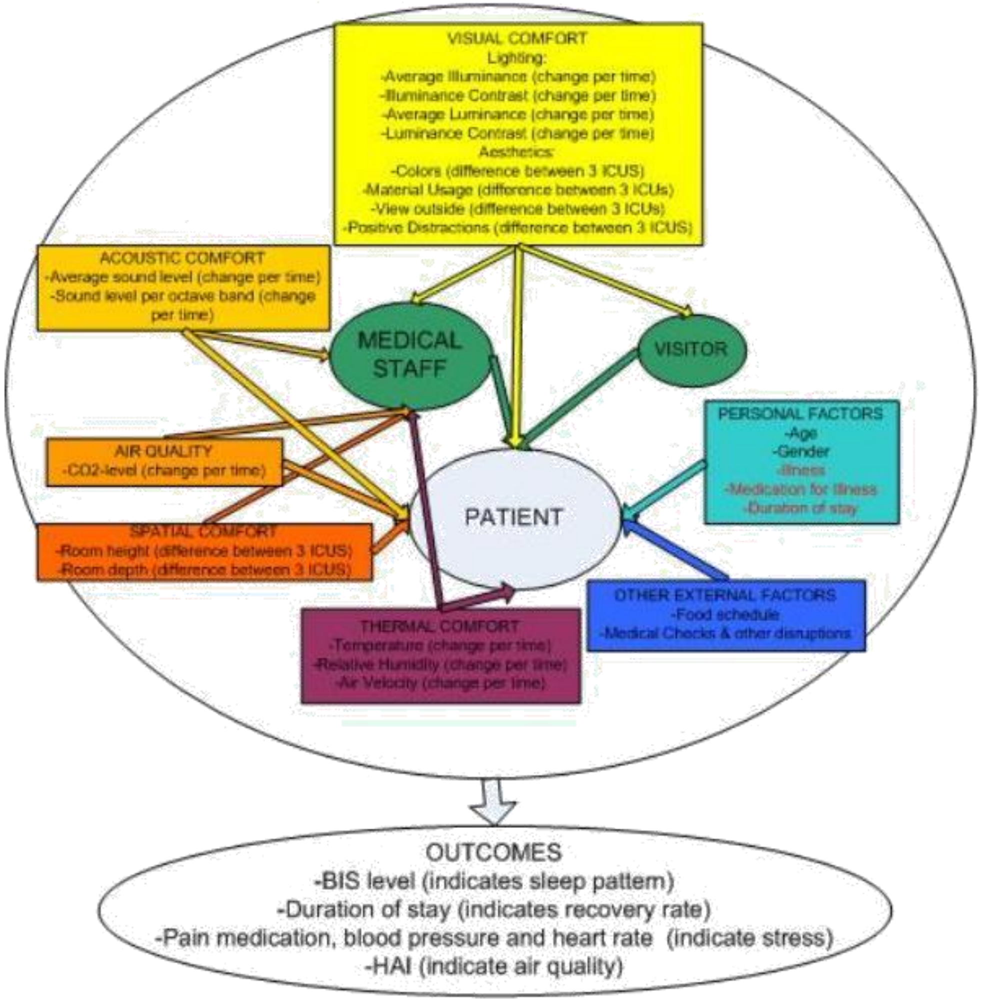
- Individual experience *vs.* public consensus
- Psychological
  - mood (state of mind)
  - situation and confrontation
  - subject to personal background
- Relative
  - sudden changes
  - length of duration
- Related to different human activities
  - human physiology
  - adaptation and habitual reconciliation

What Is Comfort ?
Objective measurements (1)

- Temperature
  - environmental measurements/air movement
  - body measurements
  - insulations/immediate contact
- Relative humidity
  - sticky feeling and wet floor on high humidity
  - skin cracks and discomfort on extremely low humidity

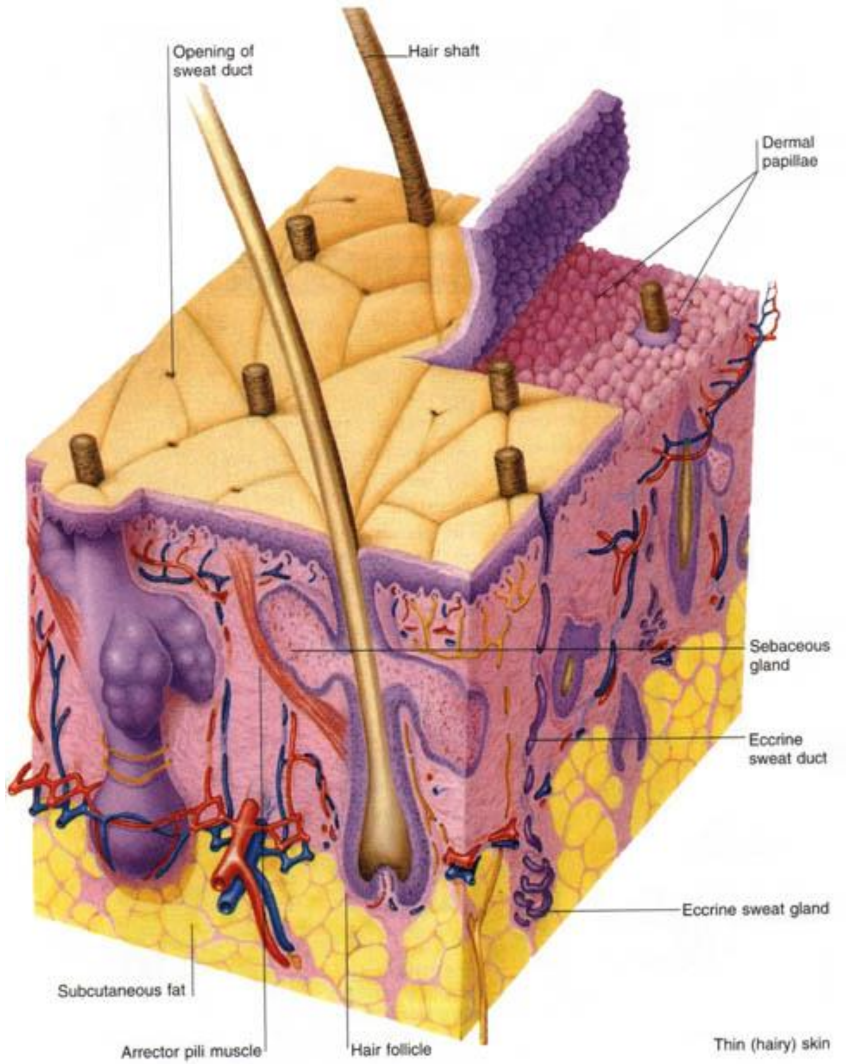
What Is Comfort ?
Objective measurements (2)

- Indoor air quality
  - Indoor environment - inadequate temperature, humidity
  - Indoor air contaminants - chemicals, dusts, moulds or fungi, bacteria, gases, vapors, odors
  - Insufficient outdoor air intake
- Lighting
  - natural light vs. artificial light
  - should be sufficient to enable people to work, use facilities and move about safely and without experiencing eye-strain
- Noise



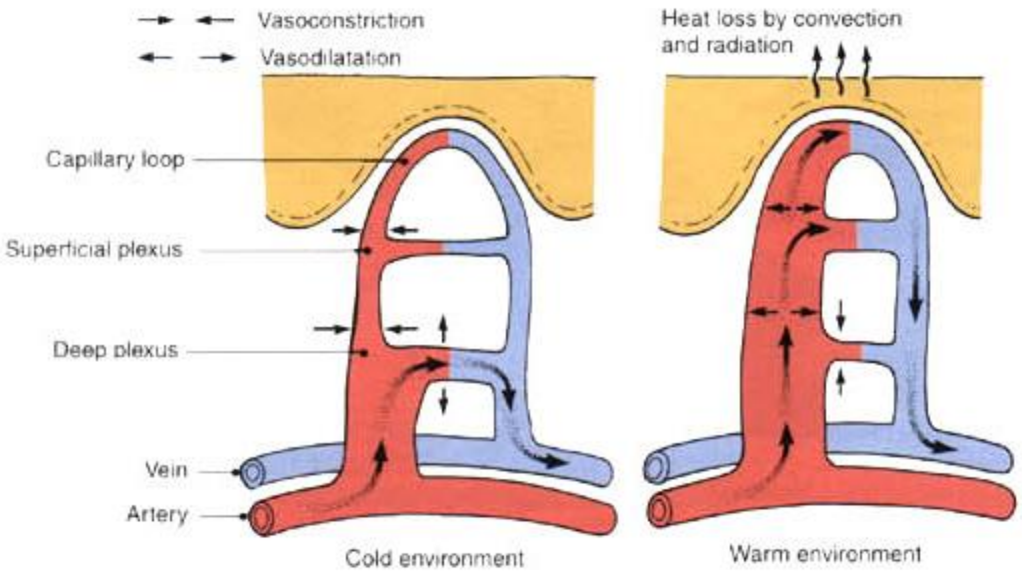
Physiology of Skin

- Skin has two main structural layers — the epidermis and the dermis
  - The epidermis is the outer layer of skin, which serves as the physical and chemical barrier to the interior body and exterior environment.
  - The dermis is the deeper layer providing the structural support of the skin.
- The sweat glands in the dermis layer produce sweat in response to heat and stress.
- Function of sweat from skin
  1. Excretion of excess of salts and water
  2. Evaporation of sweat causing a cooling effect and helping to maintain body temperature.



Temperature Regulation by Skin

- The homeostasis of our body temperature at 37°C is vital to many biochemical reactions
- Temperature regulation depends on metabolism and exercise
- The skin plays a crucial role in controlling temperature through the direct heat loss from its surface and by the evaporation of sweat



Variations in the blood supply to the skin under cold and warm conditions.

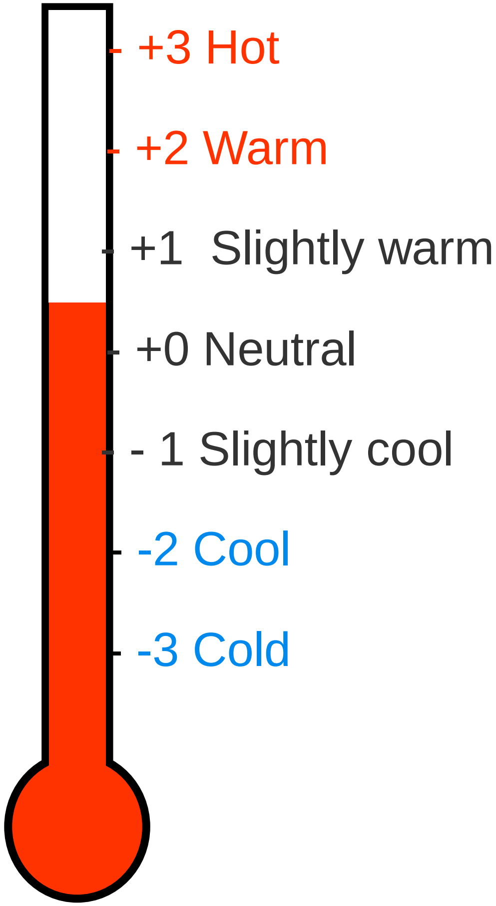
Two Conditions for Thermal Comfort

- The actual combination of skin temperature and the body's core temperature provide a sensation of thermal neutrality.
- The fulfillment of the body's energy balance: the net heat produced by the metabolism should be equal to the amount of heat lost from the body. The body's energy balance equation is written as follows:

$$\mathbf{M - W = H + E + C_{res} + E_{res}}$$

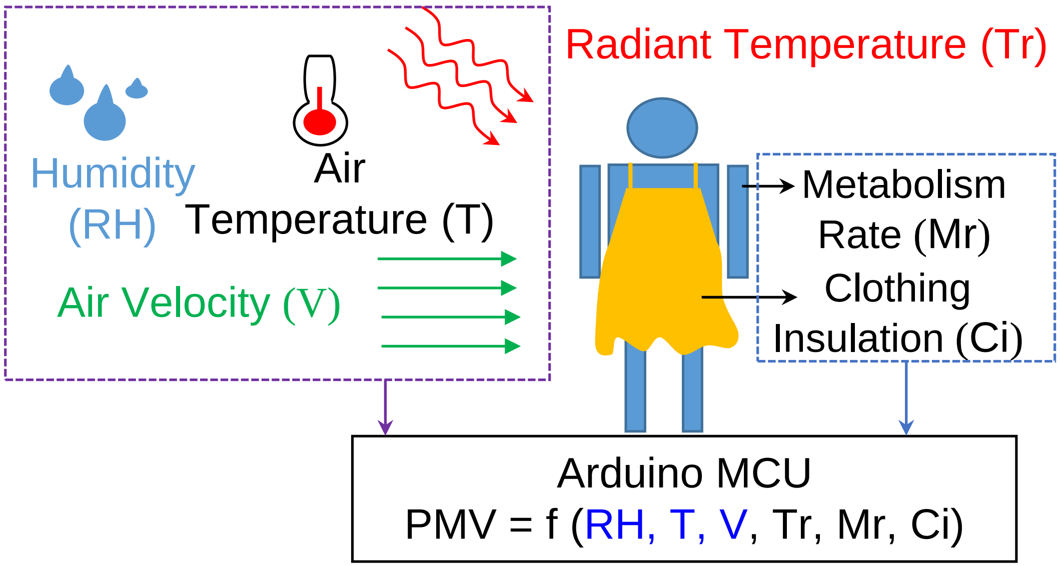
M	= metabolic rate (W/m^2)
W	= effective mechanical power (W/m^2)
H	= dry heat loss (W/m^2)
E	= evaporative heat exchange at the skin (W/m^2)
C_{res}	= respiratory convective heat exchange (W/m^2)
	$= 0.0014\, M \cdot (34 - t_a)$
E_{res}	= respiratory evaporative heat exchange (W/m^2)
	$= (1.72 \times 10^{-5}) \cdot (5867 - P_a)$
t_a	= air temperature (^oC)
P_a	= partial water vapor pressure in the air (P_a)

Predicted Mean Vote (PMV): ASHRAE Thermal Comfort Standard 55 / ISO 7730 Standard



Thermal comfort is defined as the mental condition that expresses satisfaction with the surrounding environment (ISO 7730)

ASHARE: 7-point scale of thermal sensation

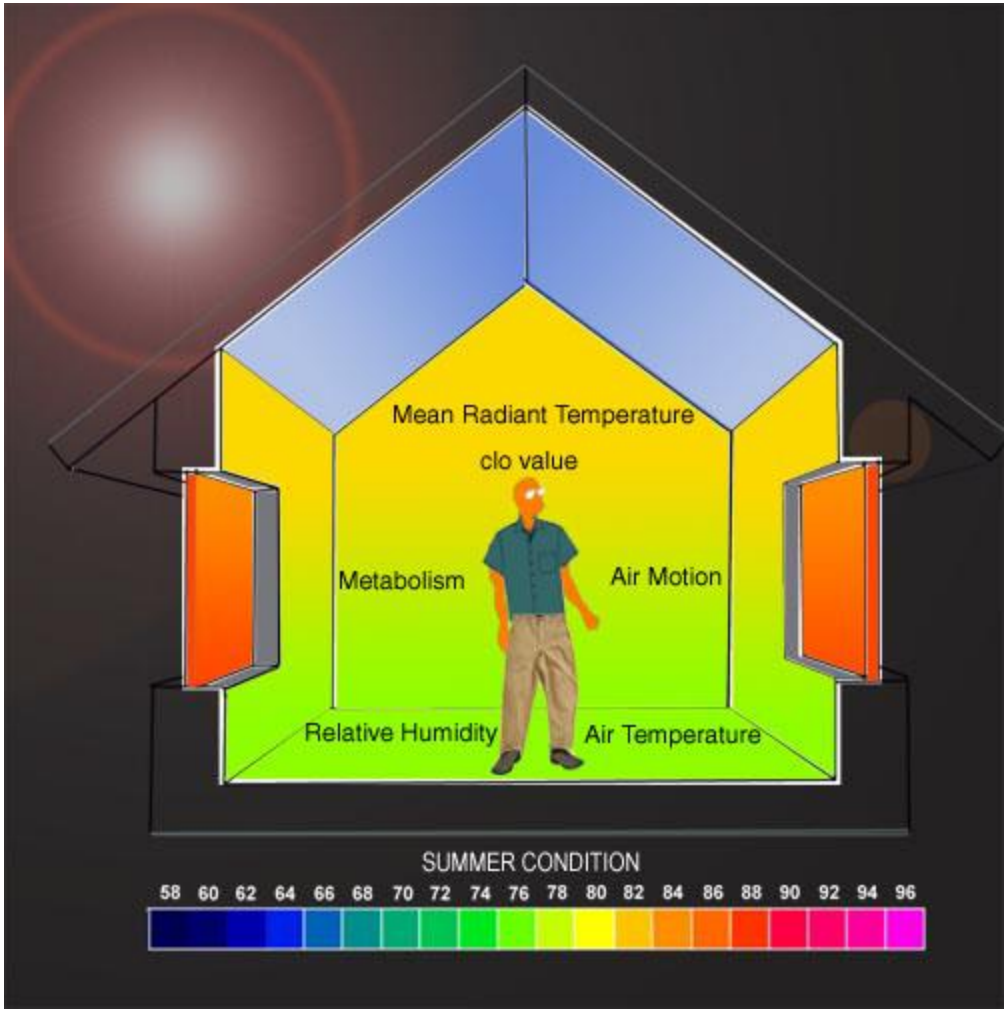


Control Target: -0.5 < PMV < 0.5 (10% PPD)

My UROP students made Android PMV app

Parameters Influencing Thermal Comfort

- Metabolism (Met value)
- Clothing level (Clo value)
- Various types of temperatures (operative temperature, equivalent temperature, effective temperature, mean radiant temperature)
- Humidity level
- Air speed
- Draught level
- Asymmetry of thermal radiation
- Vertical air temperature difference
- Floor temperature



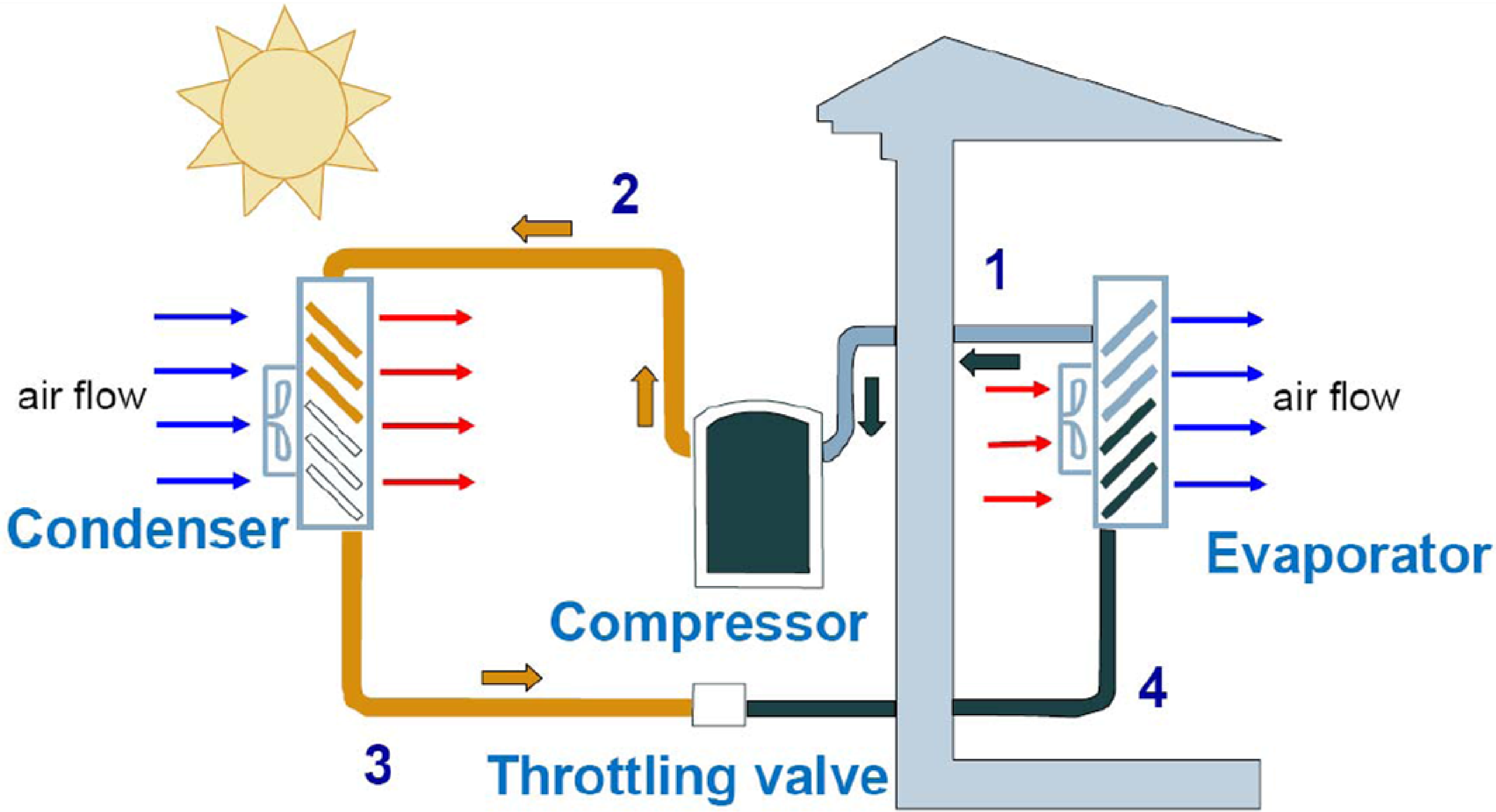
History of Refrigeration and Air-Conditioning

- The 19th century British scientist and inventor Michael Faraday discovered that compressing and liquefying ammonia could chill air when the liquefied ammonia was allowed to evaporate.
- In 1842, Florida physician Dr. John Gorrie used compressor technology to create ice, which he used to cool air for his patients.
- In 1902 the first modern electrical air conditioning was invented by Willis Haviland Carrier. The Carrier Air Conditioning Company of America was formed and residential sales expanded dramatically in the 1950s.
- Thomas Midgley, Jr. created the first chlorofluorocarbon gas, Freon, in 1928. The refrigerant was much safer for humans but was later found to be harmful to the atmosphere's ozone layer.
- Latest air conditioners usually have air sterilization effects, such as the recent air conditioners that have germicidal and neutralization benefits.

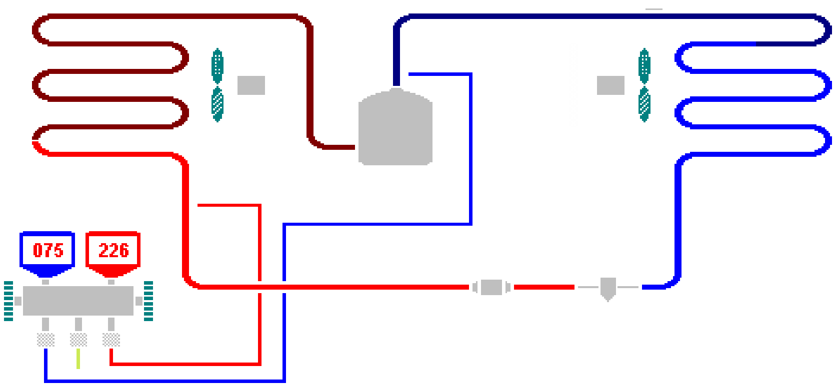
Refrigeration Basics

- Refrigeration is the removal of heat from a material or space, so that it's temperature is lower than that of it's surroundings.
- When refrigerant absorbs the unwanted heat, this raises the refrigerant's temperature ("Saturation Temperature") so that it changes from a liquid to a gas — it evaporates. The system then uses condensation to release the heat and change the refrigerant back into a liquid. This is called "Latent Heat".
- This cycle is based on the physical principle, that a liquid extracts heat from the surrounding area as it expands (boils) into a gas.
- To accomplish this, the refrigerant is pumped through a closed looped pipe system.
- The closed looped pipe system stops the refrigerant from becoming contaminated and controls its stream. The refrigerant will be both a vapor and a liquid in the loop.

Air-Conditioning in Buildings



Refrigeration System



- There are 4 main components in a refrigeration system:
  1. Compressor
  2. Condensing Coil
  3. Metering Device (or throttling valve)
  4. Evaporator

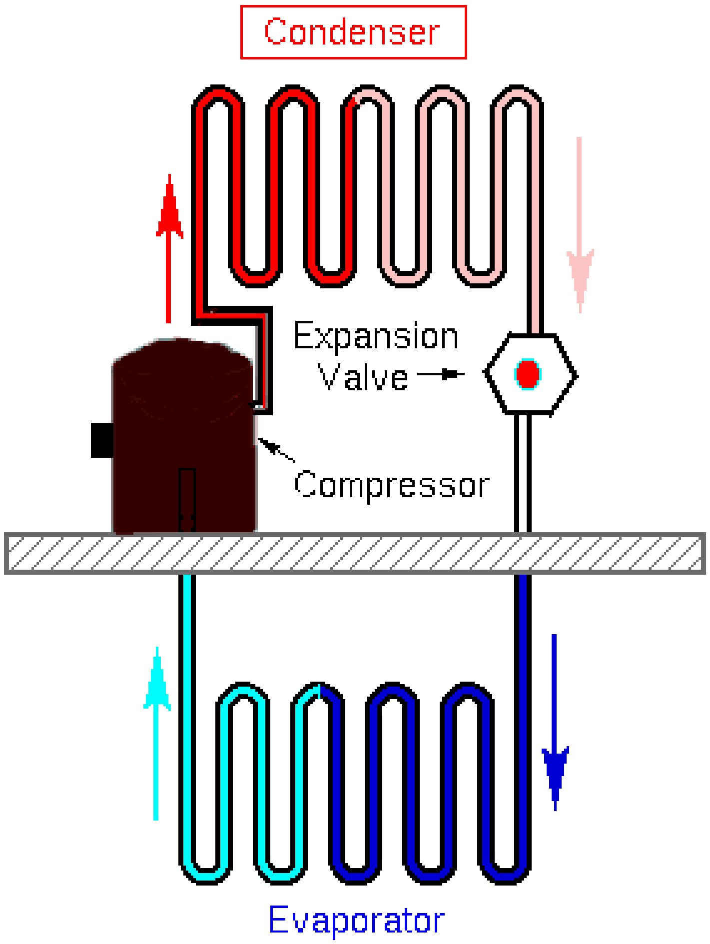
- Two different pressures exist in the refrigeration cycle.
- The evaporator or low pressure, in the "low side" and the condenser, or high pressure, in the "high side".
- These pressure areas are divided by the other two components.
- On one end, is the metering device which controls the refrigerant flow, and on the other end, is the compressor.

Compressor

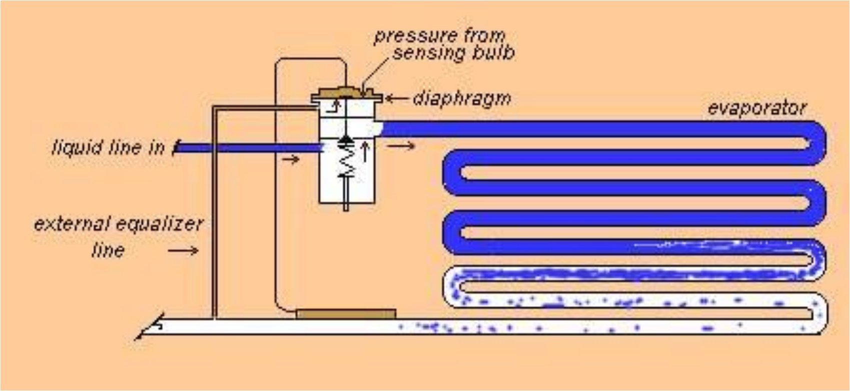
- The compressor is the heart of the system. The compressor does just what it's name is. It compresses the low pressure refrigerant vapor from the evaporator and compresses it into a high pressure vapor.
- The inlet to the compressor is called the "Suction Line". It brings the low pressure vapor into the compressor.
- After the compressor compresses the refrigerant into a high pressure Vapor, it removes it to the outlet called the "Discharge Line".

Condenser

- The "Discharge Line" leaves the compressor and runs to the inlet of the condenser.
- Because the refrigerant was compressed, it is a hot high pressure vapor (as pressure goes up – temperature goes up).
- The hot vapor enters the condenser and starts to flow through the tubes.
- Cool air is blown across the out side of the finned tubes of the condenser (usually by a fan or water with a pump).
- Since the air is cooler than the refrigerant, heat jumps from the tubing to the cooler air (energy goes from hot to cold – "latent heat").
- As the heat is removed from the refrigerant, it reaches it's "saturated temperature" and starts to "flash" (change states), into a high pressure liquid.
- The high pressure liquid leaves the condenser through the "liquid line" and travels to the "metering device". Sometimes running through a filter dryer first, to remove any dirt or foreign particles.



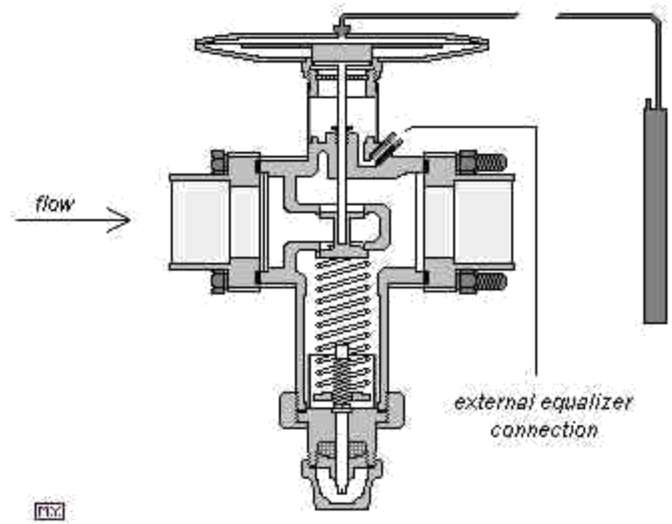
Metering Devices



- Metering devices regulate how much liquid refrigerant enters the evaporator .
- Common used metering devices are, small thin copper tubes referred to as "cap tubes", thermally controller diaphragm valves called "TXV's" (thermal expansion valves) and single opening "orifices".
- The metering device tries to maintain a preset temperature difference or "**super heat**", between the inlet and outlet openings of the evaporator.
- As the metering devices regulates the amount of refrigerant going into the evaporator, the device lets small amounts of refrigerant out into the line and looses the high pressure it has behind it.
- Now we have a low pressure, cooler liquid refrigerant entering the evaporative coil (pressure went down – so temperature goes down).

Thermal Expansion Valves

- A very common type of metering device is called a TX Valve (Thermostatic Expansion Valve). This valve has the capability of controlling the refrigerant flow. If the load on the evaporator changes, the valve can respond to the change and increase or decrease the flow accordingly.
- The TXV has a sensing bulb attached to the outlet of the evaporator. This bulb senses the suction line temperature and sends a signal to the TXV allowing it to adjust the flow rate. This is important because, if not all, the refrigerant in the evaporator changes state into a gas, there could be liquid refrigerant content returning to the compressor. This can be fatal to the compressor. Liquid can not be compressed and when a compressor tries to compress a liquid, mechanical failing can happen. The compressor can suffer mechanical damage in the valves and bearings. This is called" liquid slugging".

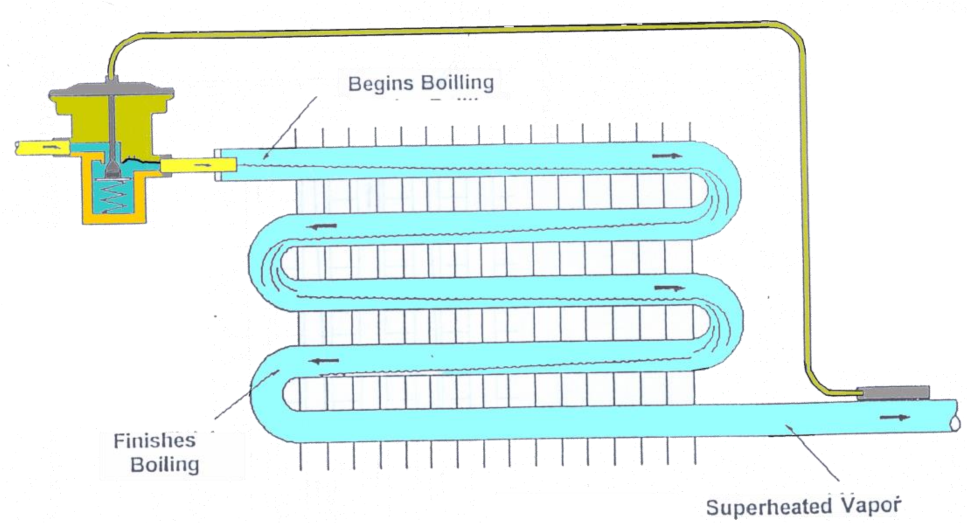


- Normally TXV's are set to maintain 10 degrees of superheat. That means that the gas returning to the compressor is at least 10 degrees away from the risk of having any liquid.

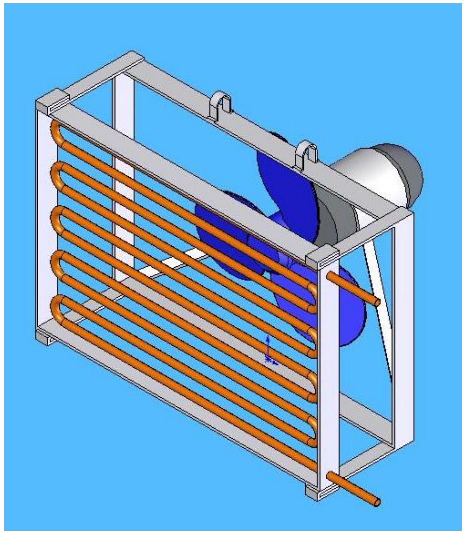
https://youtu.be/HqH1MSWakgo

Evaporator

- The evaporator is where the heat is removed from your house , business or refrigeration box.
- Low pressure liquid leaves the metering device and enters the evaporator.
- Usually, a fan will move warm air from the conditioned space across the evaporator finned coils.
- The cooler refrigerant in the evaporator tubes, absorb the warm room air. The change of temperature causes the refrigerant to “flash” or “boil”, and changes from a low pressure liquid to a low pressure cold vapor.
- The low pressure vapor is pulled into the compressor and the cycle starts over.

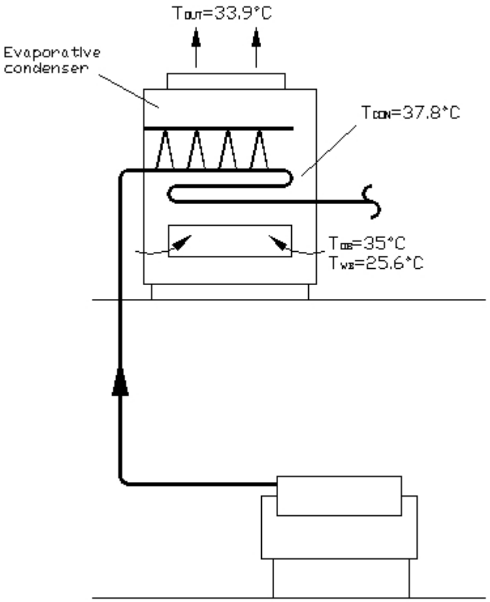


Heat Rejection System
Condenser (1)



- Air cooled condensers
  - small or medium size refrigerant plant
  - water not available

- Evaporative condensers
  - extract condensing heat from the coil directly by means of the evaporative cooling effects

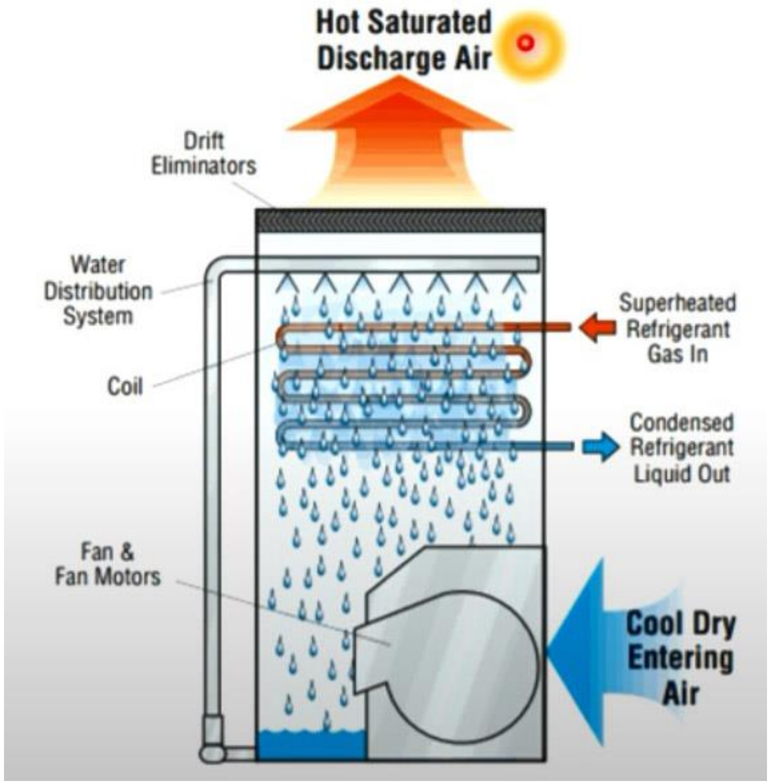


Heat Rejection System

Ex: Air-cooled condenser, 550 tons

Heat Rejection System

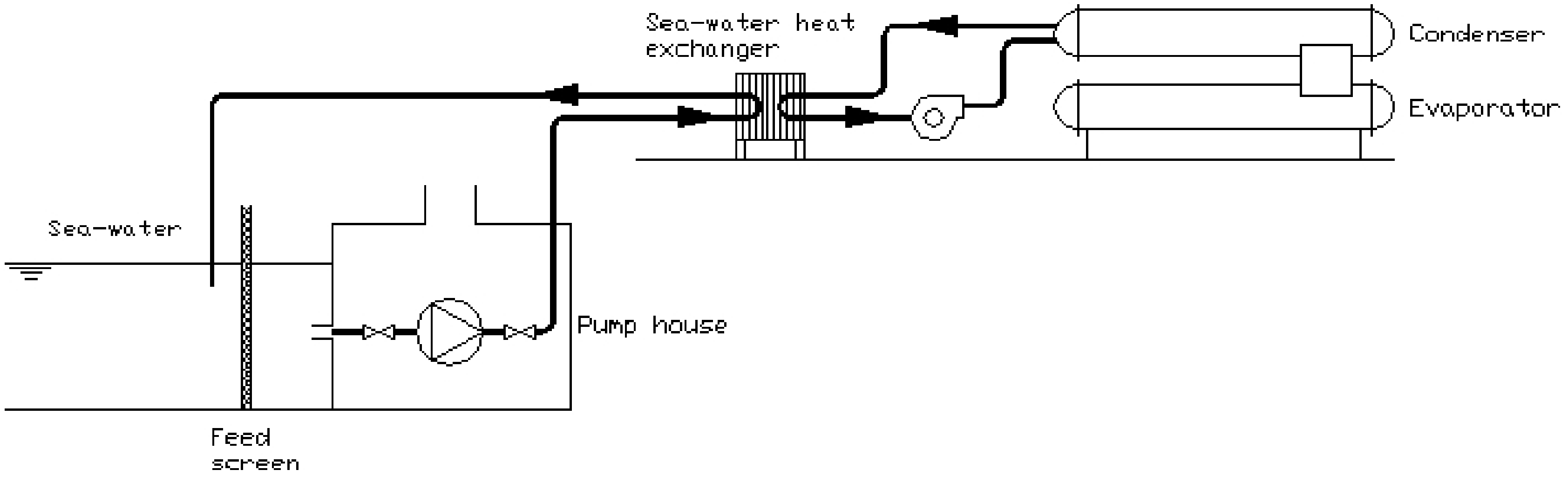
Ex: Evaporative Condenser



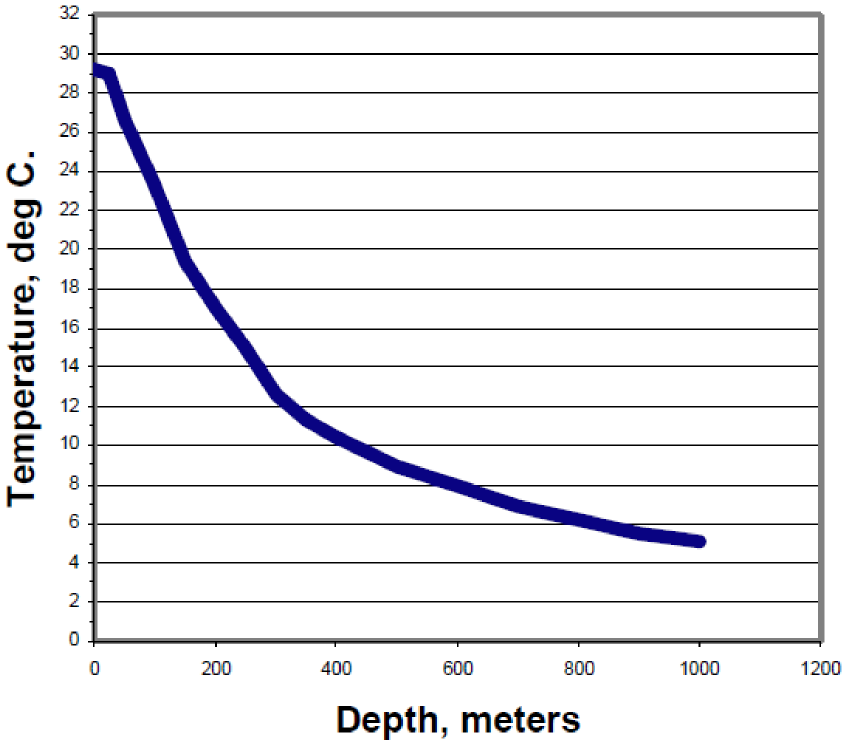
During the cooling, air may collect water droplet. As the air leaves the system, it can carry aerosol (contaminated with bacteria or viruses):
Legionella bacteria, HK youtu.be/UPLukCLREYg, US youtu.be/iiJEAovcRbc

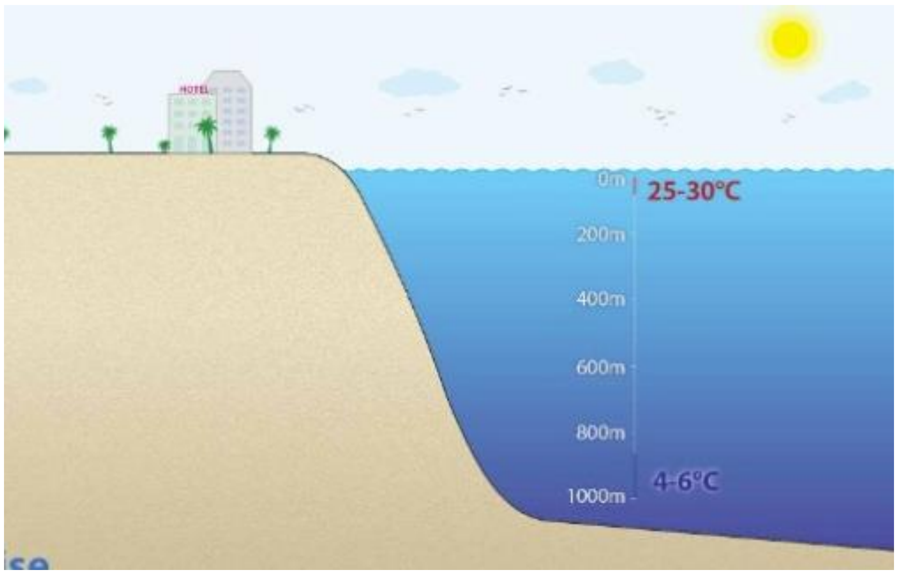
Heat Rejection System Condenser (2)

- Sea Water Air Conditoning (SWAC)
  - filtering device to remove dirt and solid particles from fouling condenser units
  - water treatment needed to prevent growth of microorganism
  - sea water is corrosive to many metals
  - stainless steel or titanium for sea water condenser water tube
  - effective filter system to prevent direct impurities from blocking the passage



Tempearture Profile of Typical Tropical Deep Ocean

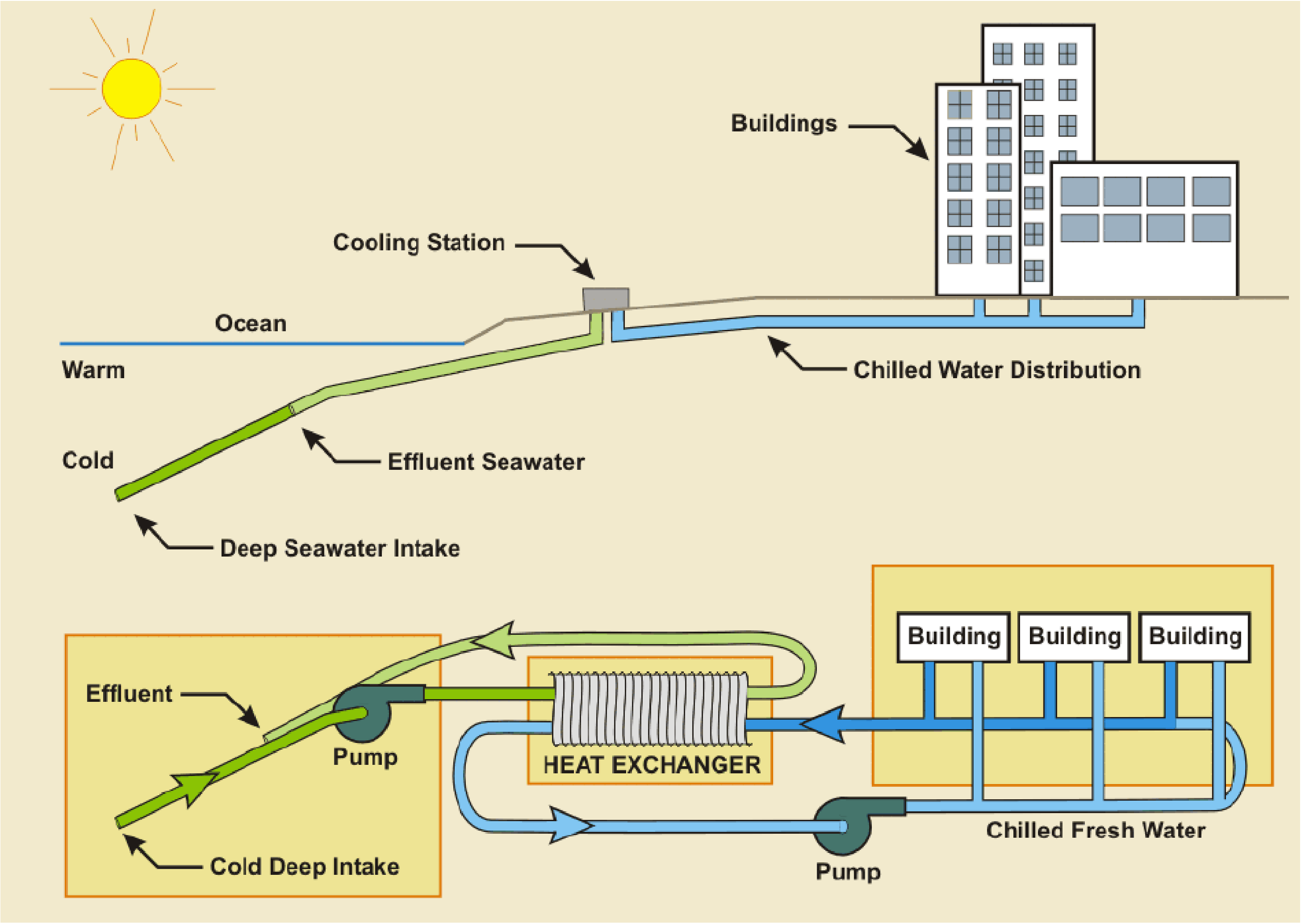




- could save up to 90% energy;   good for Data Center, School, etc

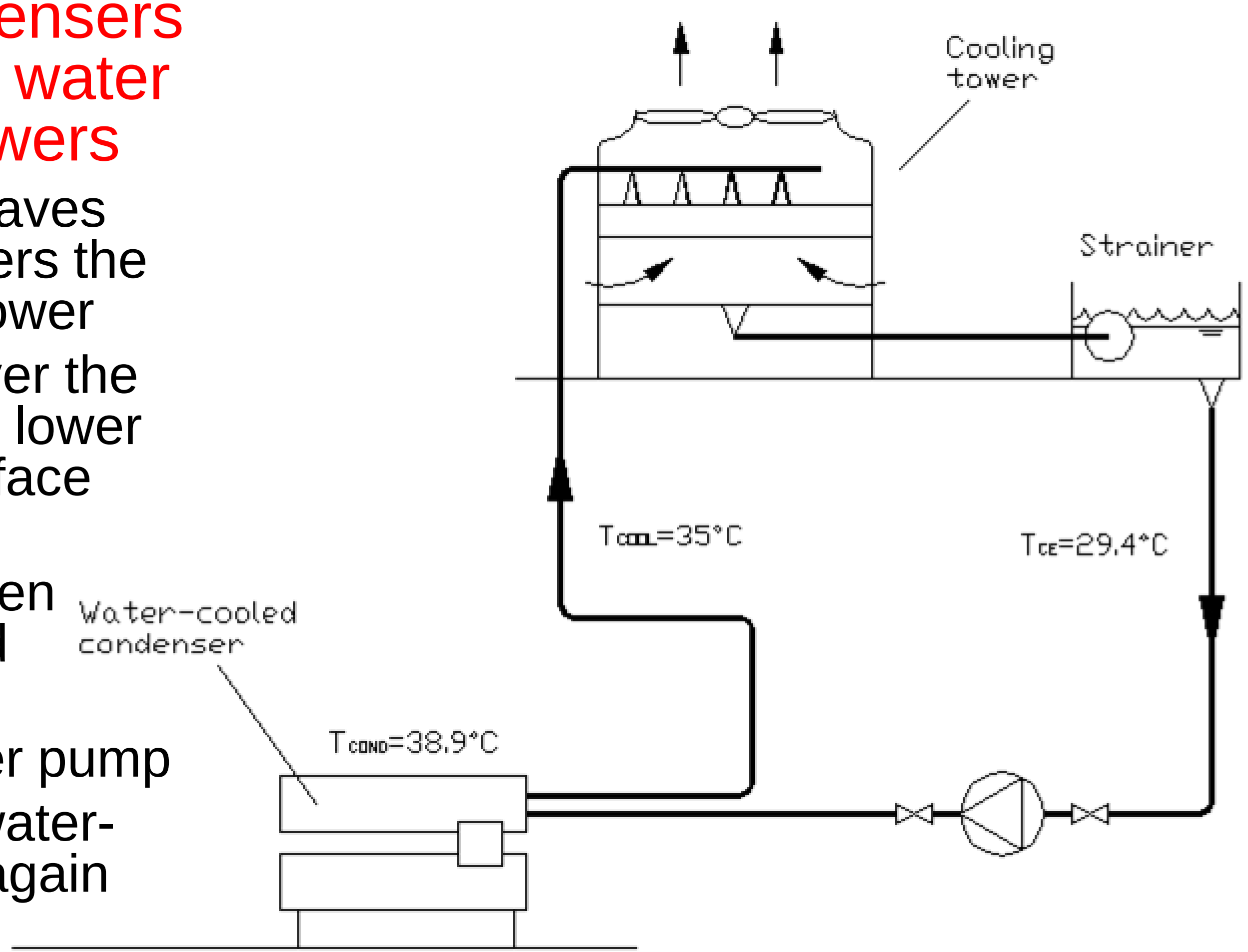
Ref: Makai Ocean Engineering Co.: https://tinyurl.com/yb76qnos

Sea Water Air Conditoning System



Heat Rejection System Condenser (3)

- Water cooled condensers using re-circulation water from the cooling towers
  - condenser water leaves condenser and enters the top of the cooling tower
  - water is sprayed over the fills and cooled to a lower temperature by surface evaporation
  - condenser water then passes strainer and chemically treated
  - extracted by a water pump
  - discharged to the water-cooled condenser again



Refrigerants (1)

- A refrigerant is a compound used in a heat cycle that undergoes a phase change from a gas to a liquid and back.
- The two main uses of refrigerants are refrigerators/freezers and air conditioners. Cf. coolant.
- The ideal refrigerant has good thermodynamic properties, is non-corrosive, stable, and safe.
- The desired thermodynamic properties are a boiling point somewhat below the target temperature, a high heat of vaporization, a moderate density in liquid form, and a relatively high density in gaseous form.
- Since boiling point and gas density are affected by pressure, refrigerants may be made more suitable for a particular application by choice of operating pressure.

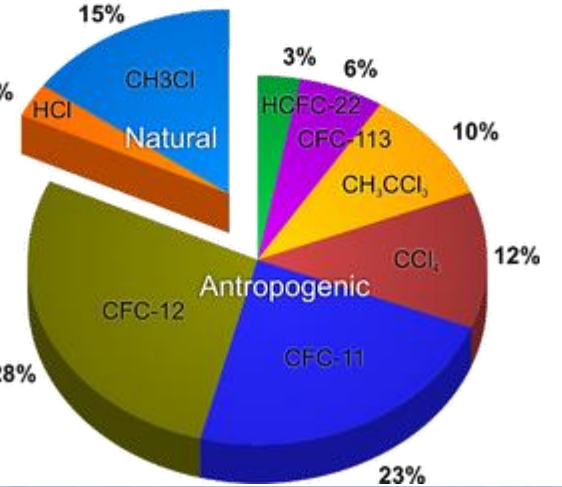
Refrigerants (2)

- Corrosion properties are a matter of materials compatibility with the components used for the compressor, piping, evaporator, and condenser.
- Safety considerations include toxicity and flammability.
- Early mechanical refrigeration systems employed sulfur dioxide gas or anhydrous ammonia, with small home refrigerators primarily using the former. Being toxic, sulfur dioxide rapidly disappeared from the market with the introduction of Freon. Ammonia is still used in some large commercial plants, well away from residential areas, where a leak will not cause widespread injuries.
- Until concerns about depletion of the ozone layer arose in the 1980s, the most widely used refrigerants were the halomethanes R-12 and R-22, with R-12 being more common in automotive air conditioning and small refrigerators, and R-22 being used for residential and light commercial air conditioning, refrigerators, and freezers.

Common Refrigerants

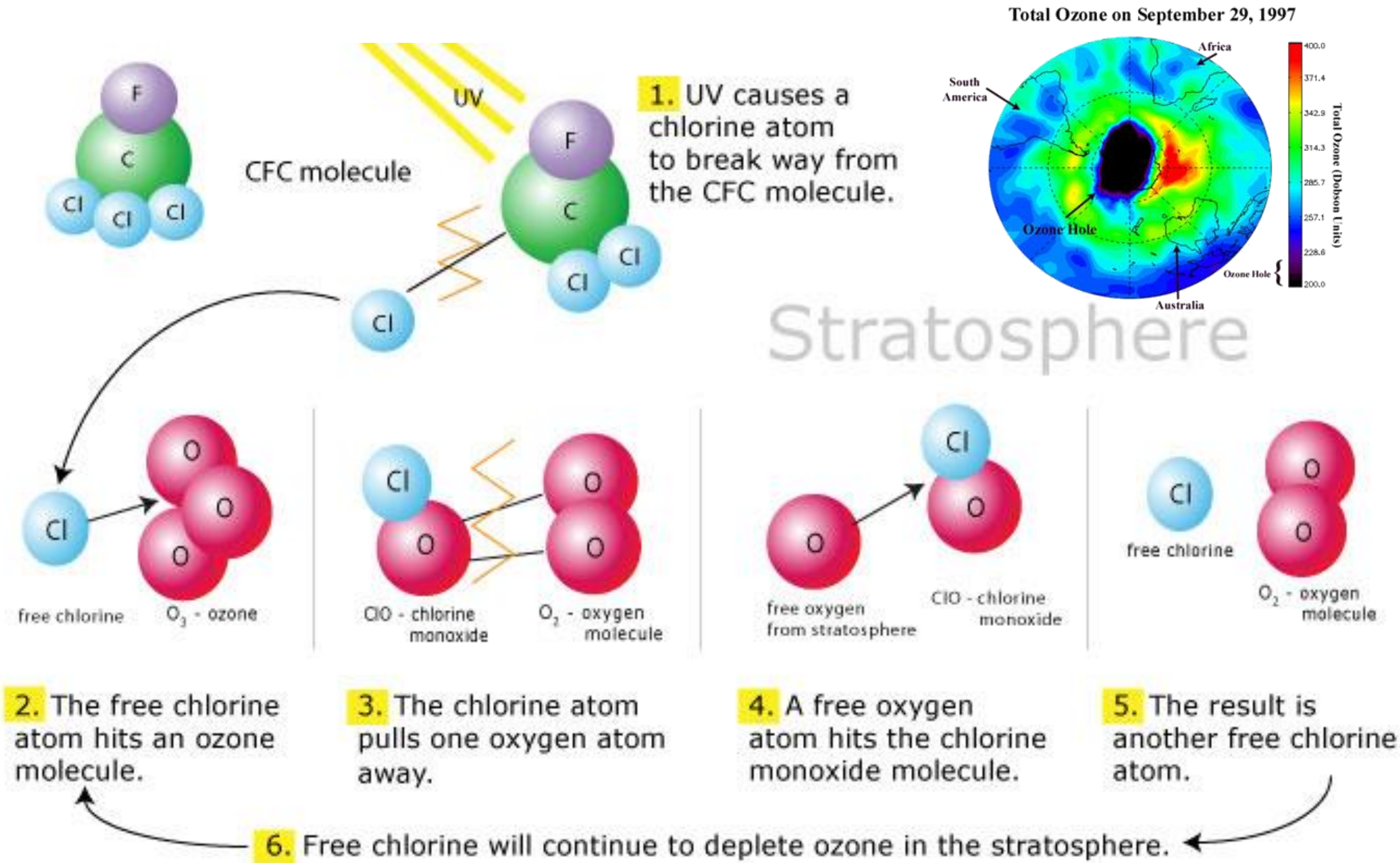
- Halocarbons
  - CFCs (chloroflurocarbons)
    - R-11 (CCl_3F)
    - R-12 (CCl_2F_2)
  - HCFCs (hydrochloroflurocarbons)
    - R-22 ($CHCl_2F$)
    - R-123 ($C_2HCl_2F_3$)
- Hydroflurocarbons (HFCs)
  - R-125 (C_2HF_5O)
  - R-134a ($C_2H_2F_4$)
  - R-143a ($C_2H_3F_3$)
- Hydrocarbons
  - R-50 (CH_4)
  - R-170 (C_2H_6)
- Inorganic compounds
  - R-717 (NH_3)
  - R-718 (H_2O)
  - R-744 (CO_2)

Environmental Concerns for Refrigerants



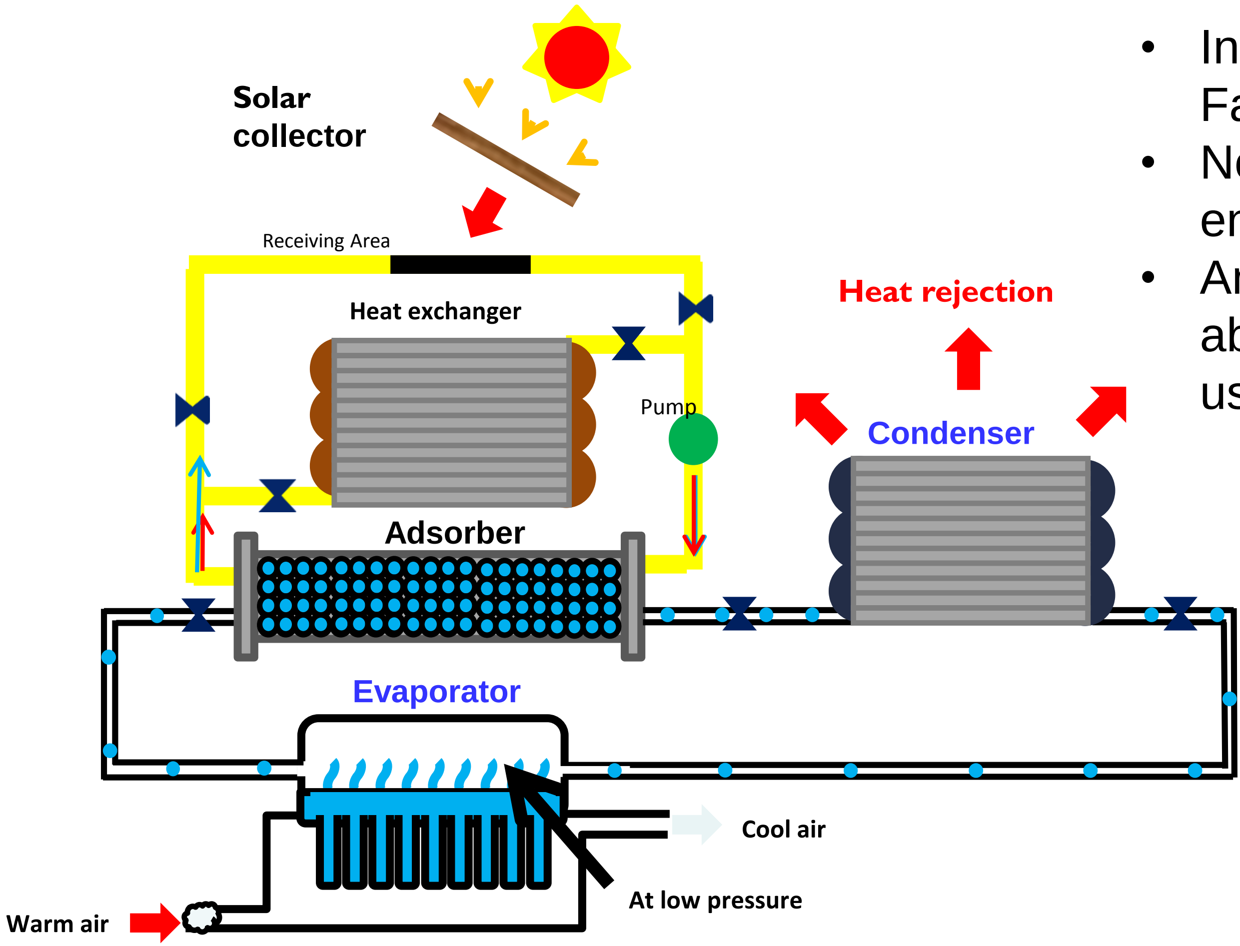
- Both CFCs and HCFCs are:
  - non-toxic
  - free of fire and explosive risk
  - ideal thermodynamic properties
- However
  - ozone depletion
  - global warming
- The end of 1995, CFCs banned (*India and China in 2010*)
- HCFCs will be phased out in 2015 (*India and China in 2040*)

Ozone Depletion by CFC Refrigerants



https://youtu.be/5BM4wXCP3Vc, https://youtu.be/aU6pxSNDPhs

Adsorption Cooling



- Invented by Michael Faraday in 1821
- Noiseless, non-corrosive, environmentally friendly
- Ammonia-water absorption: commonly used

https://youtu.be/mKQly9uGs7Q

Moisture in the Air

- Humid air can lead to mold and mildew
- Humid air is preferred by many insects
    - moths
    - fleas
    - cockroaches, etc
- Humidity control in industrial climatic chambers
- Humidity is one of the reasons we feel uncomfortable, as high moisture content in the air makes it difficult for us to sweat prohibiting cooling our body temperature through the skin

Indication of Excessive Moisture

- Condensation, frost or ice on the inside surface of windows
- Damp spots on ceilings or inner surfaces of exterior walls
- Mold or mildew growth on walls and ceilings
- Peeling or blistering of exterior paints
- Ice or frost on the underside of roof sheathing in the attic space
- Moisture on basement walls and floors
- Sweating water pipes

Controlling Household Humidity (1)

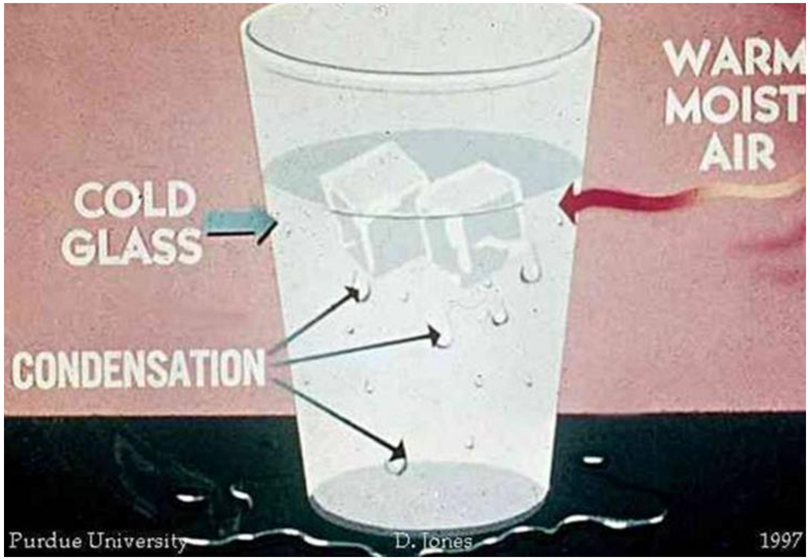
- Normal household activities such as cooking, cleaning, bathing, washing clothes and dishes, drying clothes, breathing and perspiring can raise the humidity level too high.
- To avoid the problems of excess moisture, it is necessary to limit or control the amount of water vapor in the house.
- Exhaust fans in the bathroom and kitchen will help eliminate moisture before it spreads throughout the house.

Controlling Household Humidity (2)

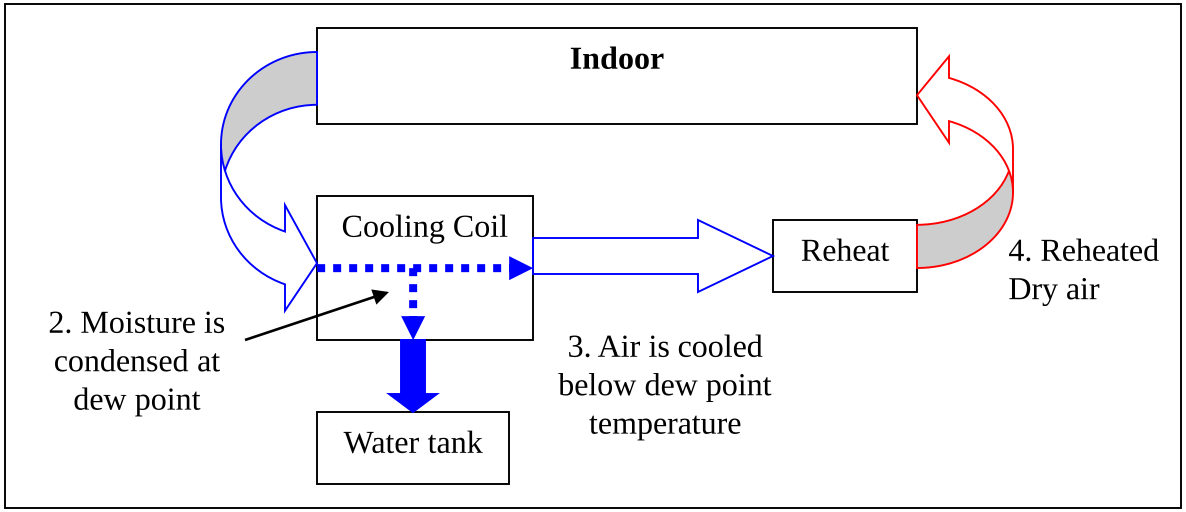
- Insulation by storm windows and insulating windows
  - Insulation is important in controlling moisture problems because it increases the temperature of the inside surfaces of walls, ceilings and floors, preventing condensation on those surfaces
  - In cases where mildew or dampness is appearing on the ceilings at its edges near the outside walls, there is a possibility that the ceiling insulation is not properly installed

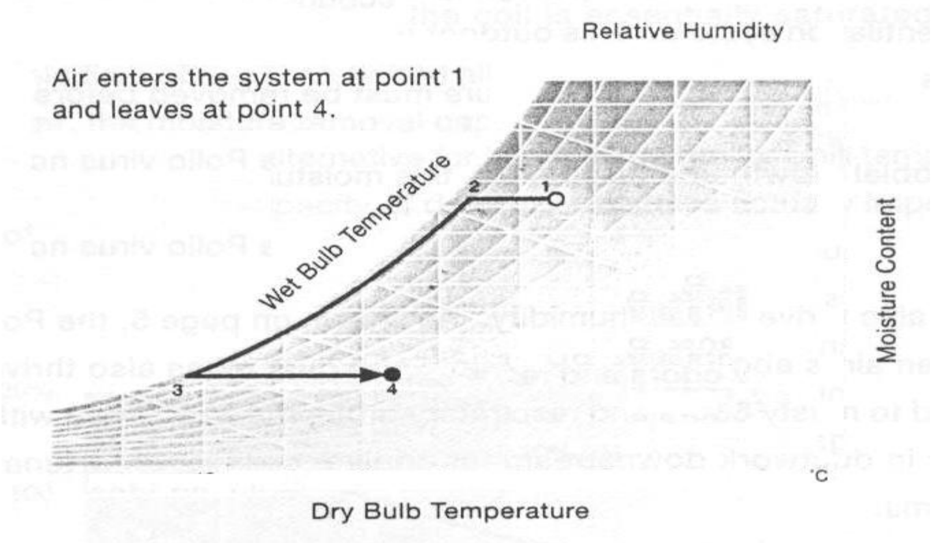
Dehumidification of Air

- Dehumidification of air takes two basic forms — mechanical coil and desiccant.
  1. Compressor-based dehumidifies the air by cooling it, as cooler air holds less humidity, so lowering the temperature causes water to condense out of it.
  2. Desiccant dehumidifier: use desiccant material that soaks up large amounts of moisture
     - dry desiccant
     - liquid desiccant spray

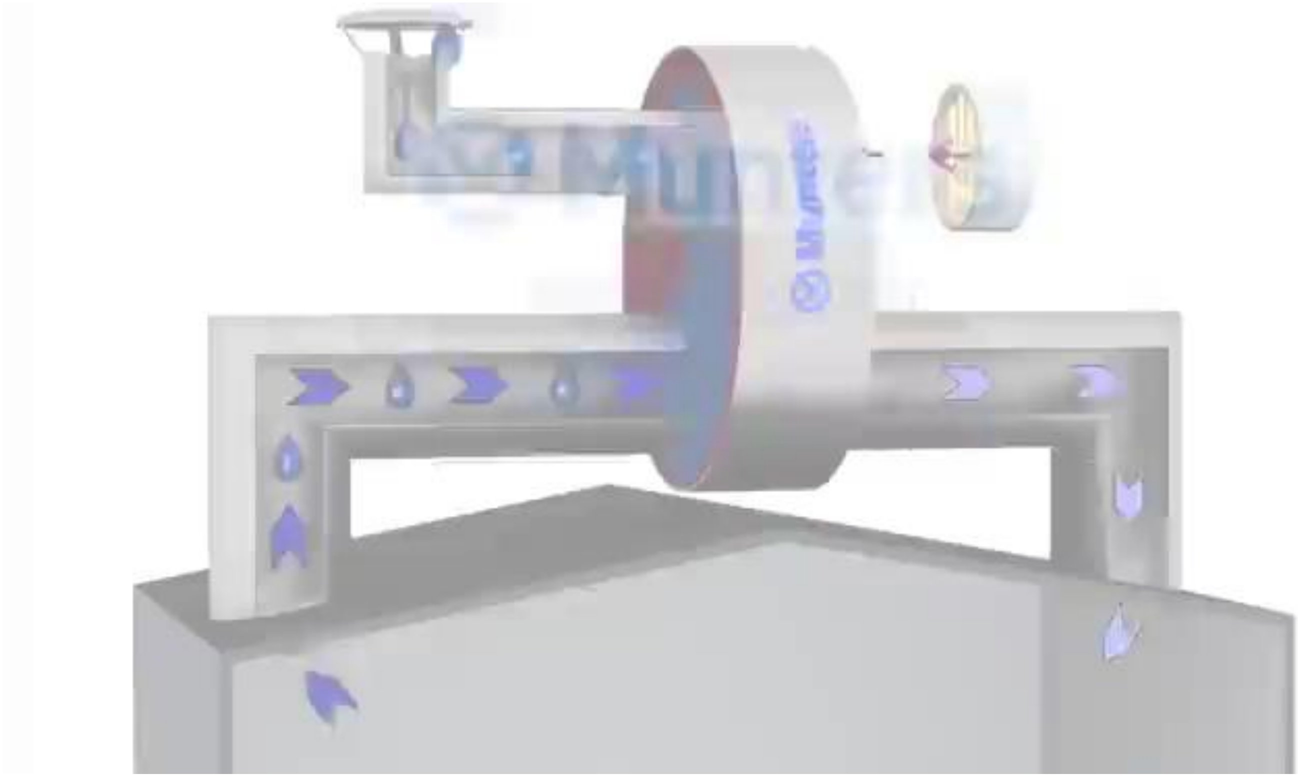


Compressor-Type Dehumidifier





Dessicator-Type Dehumidifier



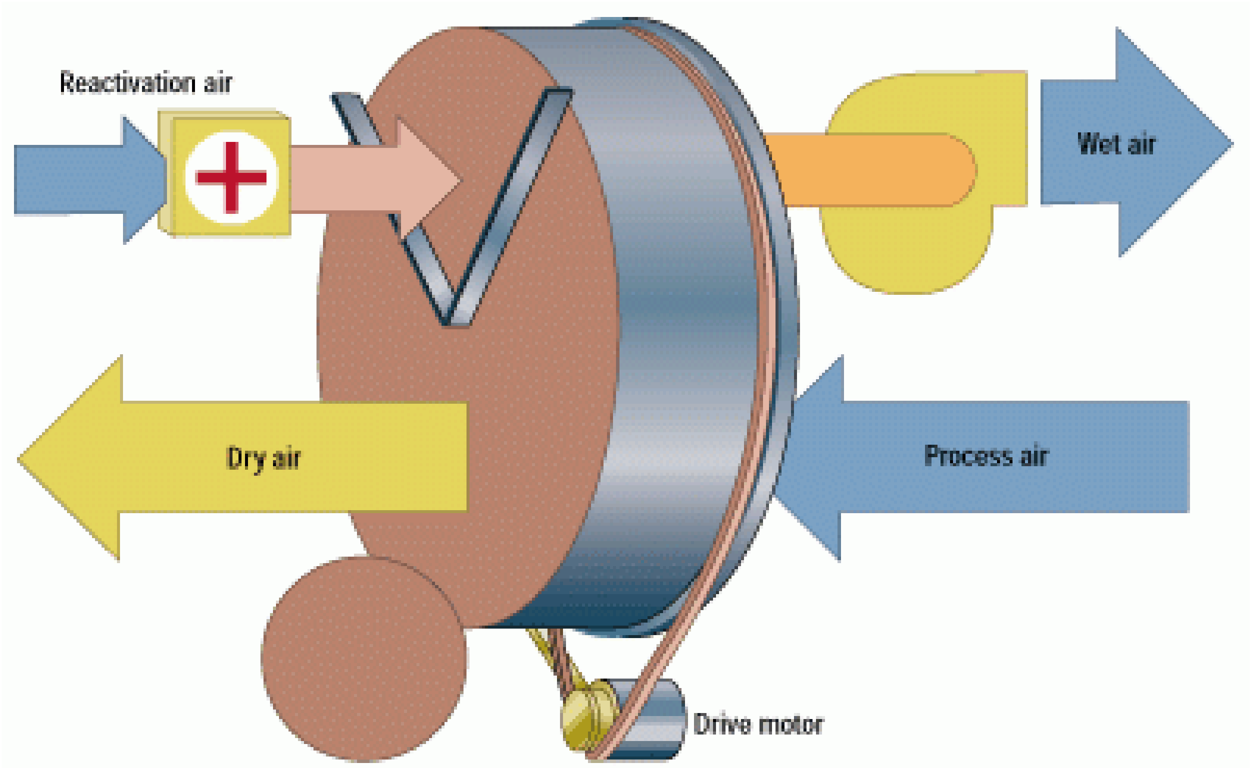
From: Munters company, Sweden
https://youtu.be/fn83bNzi_uE

Drying Agents

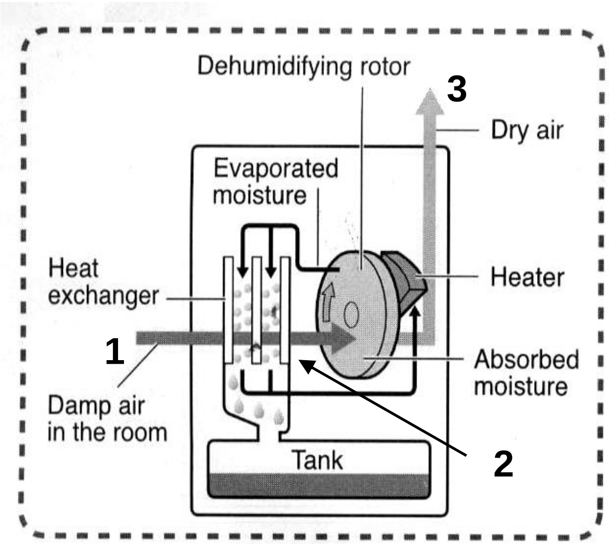
Drying agent	Most used for	Residual water, mg H_2O per liter of dry air (25 ^oC)	Grams water removed per gm of dessicant	Regeneration ^oC
Al_2O_3	Hydrocarbons	0.002 - 0.005	0.2	175 (24 h)
$Ba(ClO_4)_2$	Inert gas streams	0.6 – 0.8	0.17	140
BaO	Basic gases: hydrocarbons, aldehydes, alcohols	0.0007 – 0.003	0.12	1000
CaC_2	Ethers		0.56	Impossible
$CaCl_2$	Inert organics	0.1 – 0.2	0.15 (1 H_2O) 0.30 (2 H_2O)	250
CaH_2	Hydrocarbons, ethers, amines, esters, higher alcohols	0.00005	0.85	Impossible
CaO	Ethers, esters, alcohols, amines	0.01 – 0.003	0.31	Difficult, 1000
$CaSO_4$	Most organic substances	0.005 – 0.07	0.07	225
Dow Desiccant 812	Most materials	(5 – 200 ppm)		No
K_2CO_3	Most materials except acids and phenols		0.16	158
KOH	Amines	0.01 – 0.9		Impossible
$LiAlH_4$	Hydrocarbons		1.9	Impossible
$Mg(ClO_4)_2$	Gas streams	0.0005 – 0.002	0.24	250 (high vacuum)
MgO	All but acidic compounds	0.008	0.45	800
$MgSO_4$	Most organic compounds	1 – 12	0.15 - 0.75	Not feasible
Molecular sieves: 4X 5X	Molecules with effective diameter > 4 Å Molecules with effective diameter > 5 Å	0.001 0.001	0.18 0.18	250 250
9.5% Na-Pb alloy	Hydrocarbons, ethers	(for solvent only)	0.08	Impossible
Na_2SO_4	Ketones, acids, alkyl and aryle halides	12	1.25	150
P_2O_5	Gas streams, not suitable for alcohols, amines, ketones or amines	0.00002	0.5	Not feasible
Silica gel	Most organic amines	0.002 – 0.07	0.2	200 – 350
Sulfuric acid	Air and inert gas streams	0.003 – 0.008	Indefinite	Not feasible

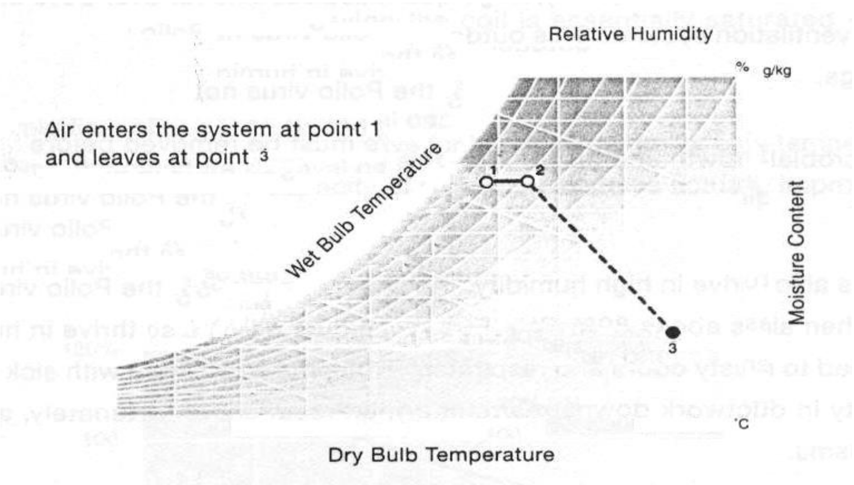
Dry Desiccant Wheel

- A honeycombed wheel filled with a desiccant rotates through the air stream, removing moisture.
- The desiccant is then heated to re-dry it and used again.



Desiccant-Type Dehumidifier





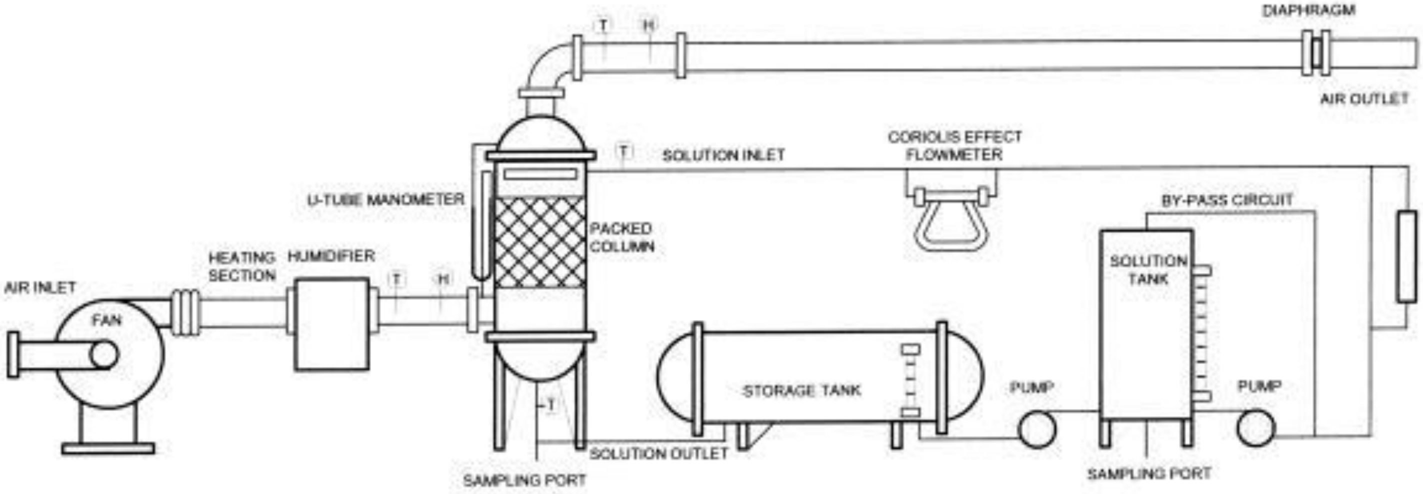
Dehumidification by Liquid Desiccant (1)

- Liquid desiccant systems work on the principal of chemical absorption of water vapor from air, and are fundamentally comprised of a conditioner section, which introduces the liquid desiccant solution into the airstream to be dehumidified, and a regeneration section, where the absorbed water is evaporated out of the desiccant solution into a “scavenger” exhaust airstream.
- The desiccant solution is transferred between the two sections via interconnecting piping.
- Heat exchangers are provided for cooling the solution delivered to the conditioner and heating the solution sprayed into the regenerator, along with pumps for circulating the desiccant solution.
- Fans are also required for drawing air to be dehumidified through the conditioner section, and air through the regeneration section to facilitate removal of moisture from the desiccant solution.
- The air discharge section of the conditioner and regenerator are typically furnished with mist eliminators to prevent carryover of moisture into the airstreams leaving the equipment.

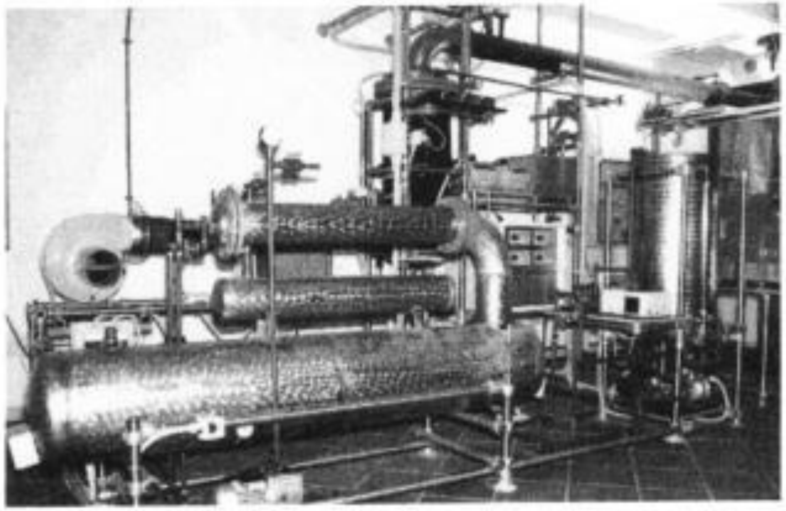
Dehumidification by Liquid Desiccant (2)

- A hygroscopic liquid is used to remove water and water vapor from a gas stream. Some liquid desiccants are glycols (diethylene, triethylene and tetraethylene), solutions of lithium bromide, and lithium chloride, calcium chloride, etc. which are substances that can be regenerated.
- Regeneration means that the water absorbed by these substances can be separated from them.
- Some liquid desiccants, such as methanol or ethylene, cannot be regenerated.

Dehumidification by Liquid Desiccant (3)



(a)



(b)

Case Study:

Air conditioner can also be used to dehumidify indoor air content. Discuss the cost and benefits of the installation of an extra dehumidifier in addition to the air-conditioner already installed.

- COST
  1. installation of an extra dehumidifier
  2. extra maintenance
  3. extra room space
  4. extra storage when not in use
  5. extra management

- BENEFITS
  1. save electricity
  2. precise control of indoor environments
  3. good reputation for energy saving
  4. prevent service stoppage

- RISK
  1. operation skills
  2. change of technology
  3. change of service provider(s)

- SENSITIVITY
  1. electricity cost
  2. service life of the machines
  3. inflation rate
  4. MARR

https://youtu.be/lMqoKLIi0Y4