

***HVAC***

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***Fall 2018***

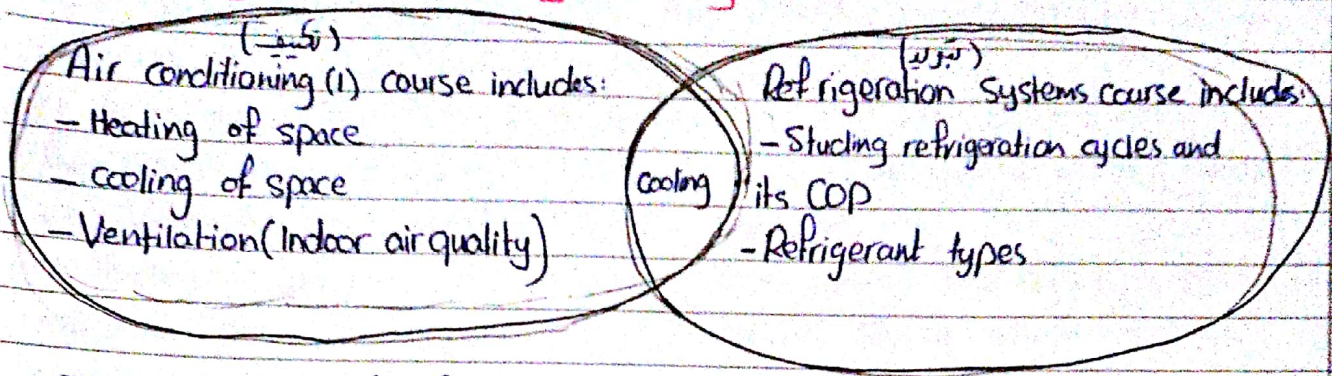


كن أنت التغيير..

**MechFamily**

**Notebooks**

# HVAC: Heating, Ventilation, Air Conditioning



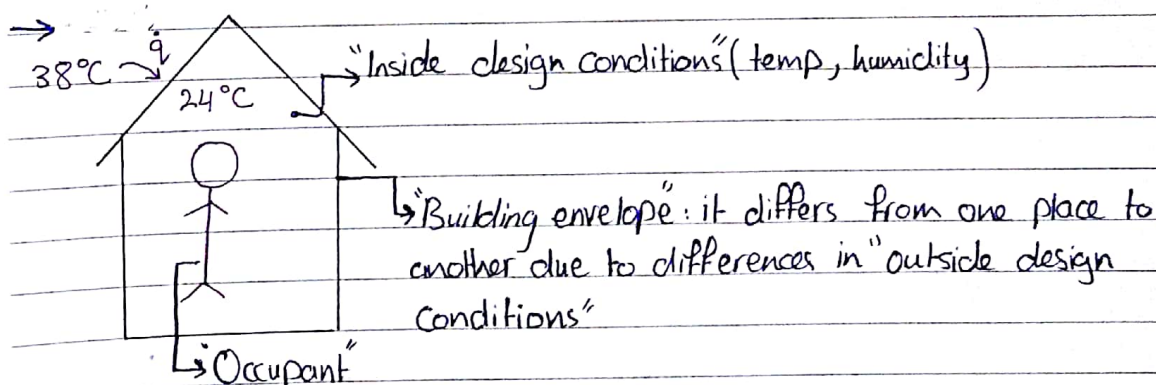
- The main goal of refrigeration systems course is to design refrigerations systems for industrial purposes [household refrigerators, industrial freezers]
- The main goal of air conditioning course is to maintain the environment in enclosed spaces at conditions that induce the feeling of thermal comfort to all occupants of the space. → Thermal comfort means you neither feel hot nor cold - i.e. the weather of the space is kind.
- Thermal comfort is influenced by 5 criteria:
- [1] Temperature (Acceptable range of temperature = comfort zone =  $22^{\circ}\text{C} - 26^{\circ}\text{C}$ )
  - [2] Humidity (Acceptable humidity ranges from 40% - 60%)
  - [3] Indoor air quality (Includes the absence of odors, toxic fumes and suspended particles such as dust and dirt particles. Human bodies produce  $\text{CO}_2$ , indoor air quality includes also reducing  $\text{CO}_2$  levels in space and increasing  $\text{O}_2$  levels)
  - [4] Air distribution (Characterizing how air is introduced to, flows through, and is removed from spaces is called air distribution. Example:  
Assuming that the cooling load for a certain room = 9 tons of refrigeration. It is better to install 3 air conditioners [each one has a cooling load of 3 tons] than installing 1 air conditioner that has a cooling load of 9 tons. This will result in a better air distribution inside the room.)
  - [5] Noise level (Some air conditioning devices produce noise. We have to select these devices with acceptable noise level)
- نحن نقضي 90% من وقتنا في الداخل - قال المهندس الذي يعمل لشركة Velux company. This company manufactures skylight windows.
- Building envelope: is the physical separator between indoor and outdoor.
- Thermal insulation of polystyrene of thickness = 3cm is equivalent to the thermal insulation of concrete of thickness = 1.5m.



→ Before the invention of air conditioning devices, humans built their buildings from local building materials, such that they provide thermal comfort.

Examples:

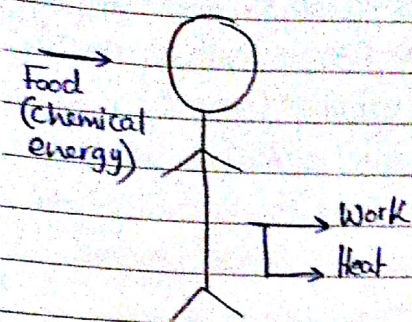
- In Petra, the walls of the buildings were made of local building material. These walls can store large amounts of thermal energy (high thermal inertia), and hence, the space inside the building maintains cool.
- In Yemen, the windows of the buildings were small + The buildings were tall and hence, they were shaded by the shade of the neighboring buildings.
- In the north pole, buildings are made of local building material (ice). There are no windows. The door is built at low height to prevent the warm air inside the building from escaping outside →  $q_{\text{loss}} = U A \Delta T$   
 $q_{\text{loss}} = U A (T_{\text{inside}} - T_{\text{outside}})$
- In deserts, the climate is hot and dry. The temperature inside the tent is less than the temperature of outside the tent (due to the shade made by the tent). Because of this temperature difference, air circulation will occur.
- In UAE, the buildings were made of Palm Fronds (  $\text{جذع النخلة}$  ) + buildings were built with wind scoops (  $\text{مروحة الرياح}$  ), which work as ventilation and cooling system. Wind scoops are structures that catch the winds + redirect them to the interior of the building.



- The above figure illustrates some terminologies
- My duty as a mechanical engineer is to achieve thermal comfort for the occupants.
- Cooling load is defined as the rate at which thermal energy must be removed from the space to maintain constant temperature (will be discussed in Ch.9)
- Heating load: the rate at which thermal energy must be provided to the space to maintain constant temperature (will be discussed in Ch.6)



→ Download HAP software (HAP stands for Hourly Analysis Program)



→ The normal human body temperature is  $37.2^{\circ}\text{C}$

→ To maintain constant temperature, heat must be produced within the body in amounts equal to the heat loss by the body.

→ Metabolism (مِيتَابُولِيزْم): is the biological process by which body cells generate heat from consumed food.

→ The amount of heat produced by the human body depends on the sex, age, type of activity undertaken by the individual and size.

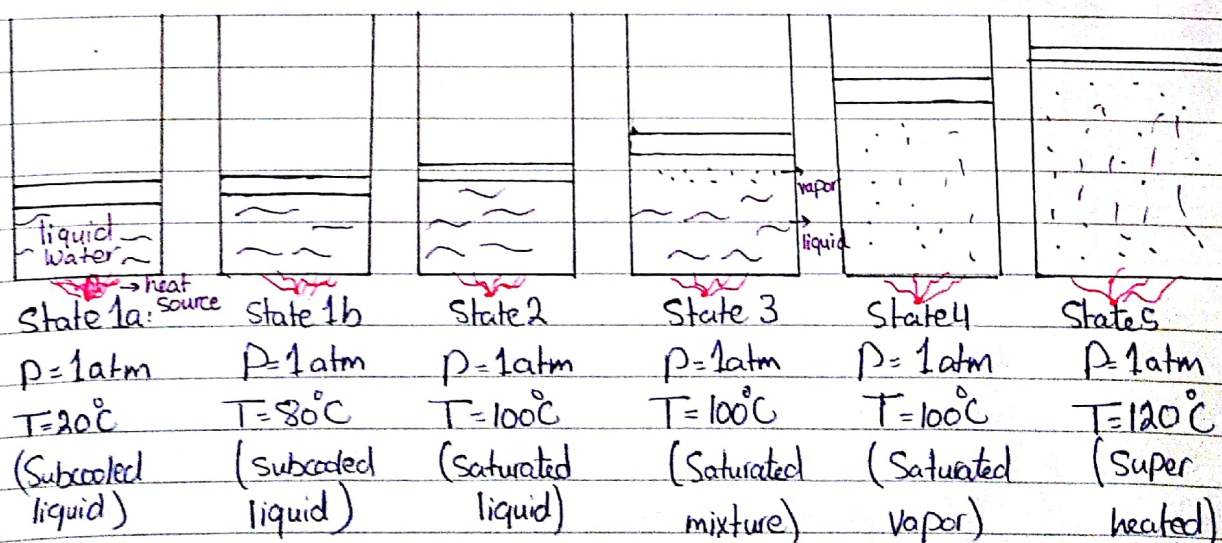
Note: The amount of heat produced by the body depends on the number of cells of the body.

→ Check Table 4-1 + Table 4-2

- Table 4-1 shows the average metabolic rate for a mixture of people representing both sexes and all ages and undertaking various activities. The rate of heat produced by the body through metabolism is called metabolic rate and it is measured in Met

[1 Met =  $58.2 \text{ W/m}^2$  of the surface area of the body skin]

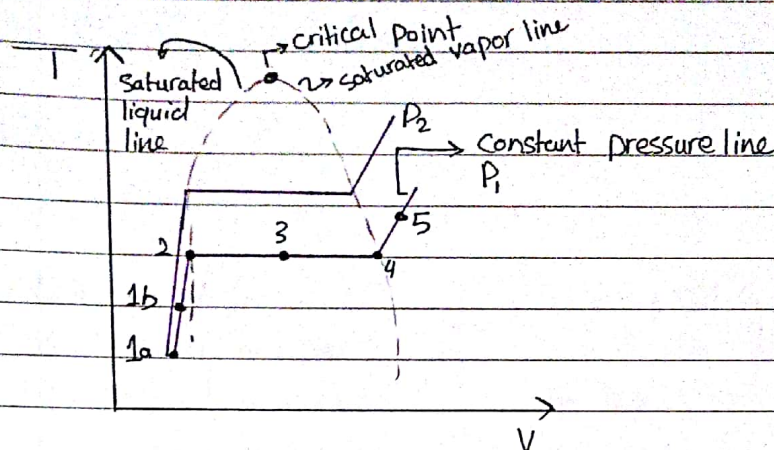
- Before you check Table 4-2, Recall the following experiment from Thermodynamics: The following is a piston cylinder arrangement





→ Notice that the temperature has increased from state 1a to state 1b due to addition of thermal energy. This type of heat is called sensible heat. However, this is not the case in the process from state 2 to state 3. The type of thermal energy added through this process, which has caused a change in phase only, is called latent heat.

→ The T-V diagram of the process [from state 1a to state 5] is shown below.

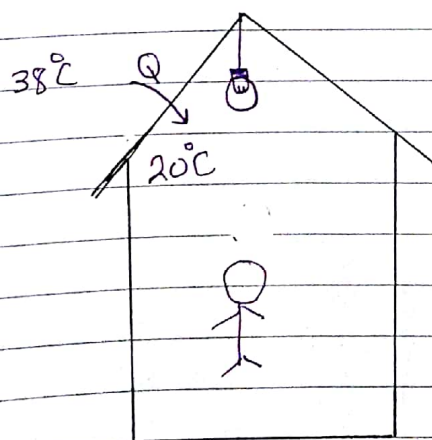


→ Check Table 4.2 which gives "instantaneous" values of both sensible and latent heat rates.

- Sensible heat is the amount of thermal energy transferred from the human body to the air due to the temperature difference between the body and the air. Addition of sensible heat to the air will increase its temperature.

- Latent heat is the amount of thermal energy transferred from the human body to the air due to sweat evaporation + respiration. Addition of latent heat to the air will increase its temperature and humidity.

- Total adjusted heat dissipation = Sensible heat + latent heat



حتى نحصل من الحرارة  
من شخص هو بارد  
ومن شخص من الحرارة  
من شخص هو بارد

- Any designing process is based on worst case scenario. Hence, to calculate

[1] The cooling load, you have to consider the heat produced by occupants + appliances (internal gain) + heat transferred from outside to inside (external gain)

[2] The heating load, you have to consider only the heat loss from inside to outside (i.e. don't consider the heat produced by occupants and appliances)



→ The total cooling load due to "occupants" only is given by

$$\dot{Q}_{occ} = n(\dot{q}_{sen} * (CLF)_{occ.} + \dot{q}_{lat})$$

$n$  = number of occupants

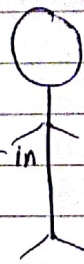
$\dot{q}_{sen}$  = sensible heat per occupant

$\dot{q}_{lat}$  = latent heat per occupant

$CLF$  = cooling load factor

→ Cooling load factor

- Latent heat rates go directly into the air in the space without delay and thus becomes part of the space cooling load



→ Sensible heat rates are delayed due to the storage of the energy in the space and its furniture. Thus, the values of  $\dot{q}_{sen}$  must be multiplied by a factor  $CLF$

it is called  $CLF$  because we only consider it when we calculate the cooling load.

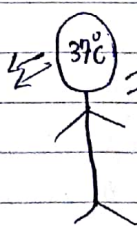
- In other words, part of sensible heat generated is first absorbed by the surroundings and then gradually released into the air (delay)

Review:

→ The human body tries to attain thermal comfort by dissipating the excess heat. If the body doesn't dissipate the excess heat, you will feel hot. and if it dissipates more than the excess heat you will feel cold.

→

• The body dissipates latent heat by respiration and sweat evaporation



23°C

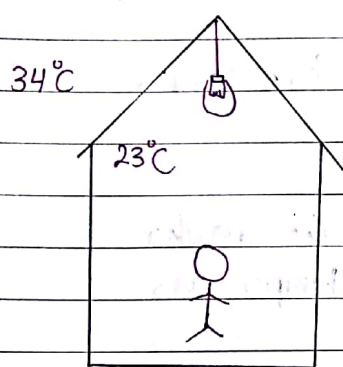
• The body dissipates sensible heat, due to the temperature difference between the body and the air, by 3 methods: radiation / convection / conduction

• Convection depends on many factors such as: speed of the air, skin area, clothing type, temp. difference between the air and the body



- We classify the heat produced by the body into sensible and latent heat (2 different categories), because we get rid of them using 2 different methods.
  - Sensible heat: causes heating → solution: cooling
  - latent heat: causes humidification → solution: dehumidification
- Table 4-3 gives the values of cooling load factor. These values are based on statistics and studies.

→ It is important to know the CLF at every hour, because I have to calculate the cooling load hourly, in order to determine the peak cooling load. Thus I can choose a cooling device that can cover this peak load.



→ More accurately, to find the peak load, we have to calculate the total cooling load hourly:

$$\text{Total cooling load} = \text{Internal load} + \text{external load}$$

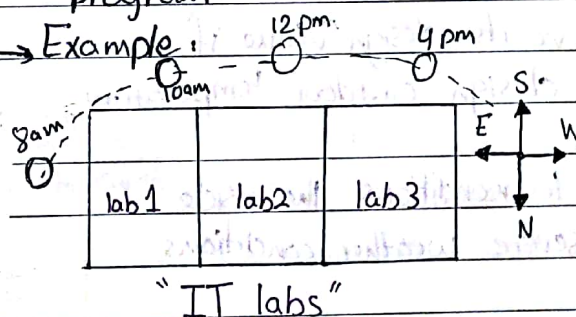
occupants  
appliances  
lightings

Solar radiation  
+ temperature  
difference between  
inside and outside

→ This process of finding the peak load is difficult, because both the external and internal loads vary continuously with time

→ For this purpose, we can use HAP software: Hourly Analysis Program.

→ Example:



- Assume that we want to install a chiller as a cooling system for the 3 labs (we will install a single cooling system for the 3 labs, we will not install 3 split units. [1 unit for each lab])

- For lab1, the peak load occurs between 8am - 10am

- For lab2, the peak load occurs between 11am - 2pm

- For lab3, the peak load occurs between 3pm - 6pm

- Assume that the peak load for lab1 = for lab2 = for lab3 = 10 TR

- The chiller must have a cooling capacity less than

30 TR, because the peak load for the 3 labs

don't occur simultaneously.

TR means  
Tons of refrigeration



→ We have to look for the instant at which the "total" cooling load of the 3 labs is maximum

$$\text{(Total cooling load} = \text{cooling load of lab 1} + \text{cooling load of lab 2} + \text{cooling load of lab 3)}$$

Hence, the cooling capacity of the chiller must be equal to the maximum (peak) total cooling load.

→ Note:

am = ante meridiem

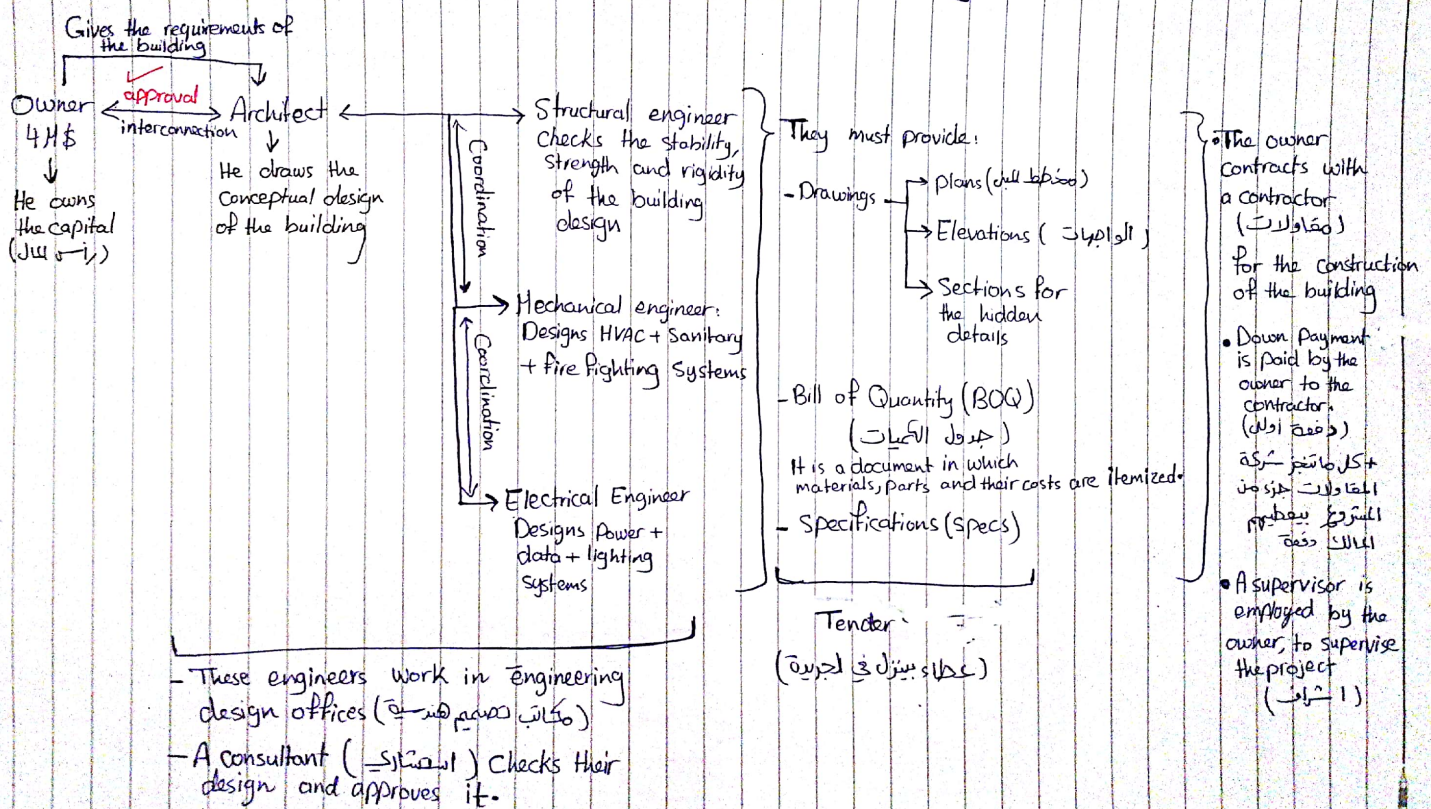
pm = post meridiem

→ ASHRAE stands for American Society for Heating Refrigeration Airconditioning Engineers. It develops and publishes technical standards in the HVAC field.

→ CIBSE stands for Chartered Institution of Building Services Engineers. It develops and publishes the british technical standards in the HVAC field.



The following figure shows the stages of constructing a certain building





→ Notes related to the previous figure:

- A variation order (تغييرات في المشروع) is issued by the contractor whenever there is a variation in the project.
- The contractor contacts with sales engineers to supply the contractor with the required goods.

Example: Assume an office is occupied by 10 persons. The office working hours are from 9:00 am to 5:00 pm. Find  $\dot{Q}_{\text{occupants}}$  @ ... (Assume that the type of the activity is "seated at rest")

Solution:

$$\dot{Q}_{\text{occ}} = n(\dot{q}_{\text{sen}} \times \text{CLF}) + \dot{q}_{\text{lat}}$$

- $n = 10$  persons
- From table 4-2  $\dot{q}_{\text{sen}} = 65 \text{ W/person}$ ,  $\dot{q}_{\text{lat}} = 30 \text{ W/person}$
- From table 4-3  $\text{CLF} = 0.8$

$$\dot{Q}_{\text{occ}} = 10(65 \times 0.8 + 30) = 820 \text{ Watt}$$

Note: - To calculate the internal load, we have to find  $\dot{Q}_{\text{occupants}} + \dot{Q}_{\text{appliances}}$

- Most appliances reject sensible heat to the air. However, some of them (such as electric water kettle + steam iron) reject both latent and sensible heat.



## \* Central heating and air conditioning system (نظام تدفئة + تكييف مركزي)

→ Comparison between liquids and gases (or air)

|                                                   | Liquid       | Air                                                                 |
|---------------------------------------------------|--------------|---------------------------------------------------------------------|
| How do we convey it?                              | using a pipe | using a duct (which may have circular or rectangular cross section) |
| How do we control or regulate its mass flow rate? | using valves | using clampers                                                      |
| How do we increase its pressure?                  | using pumps  | using: Compressors<br>blowers<br>fans<br>!                          |

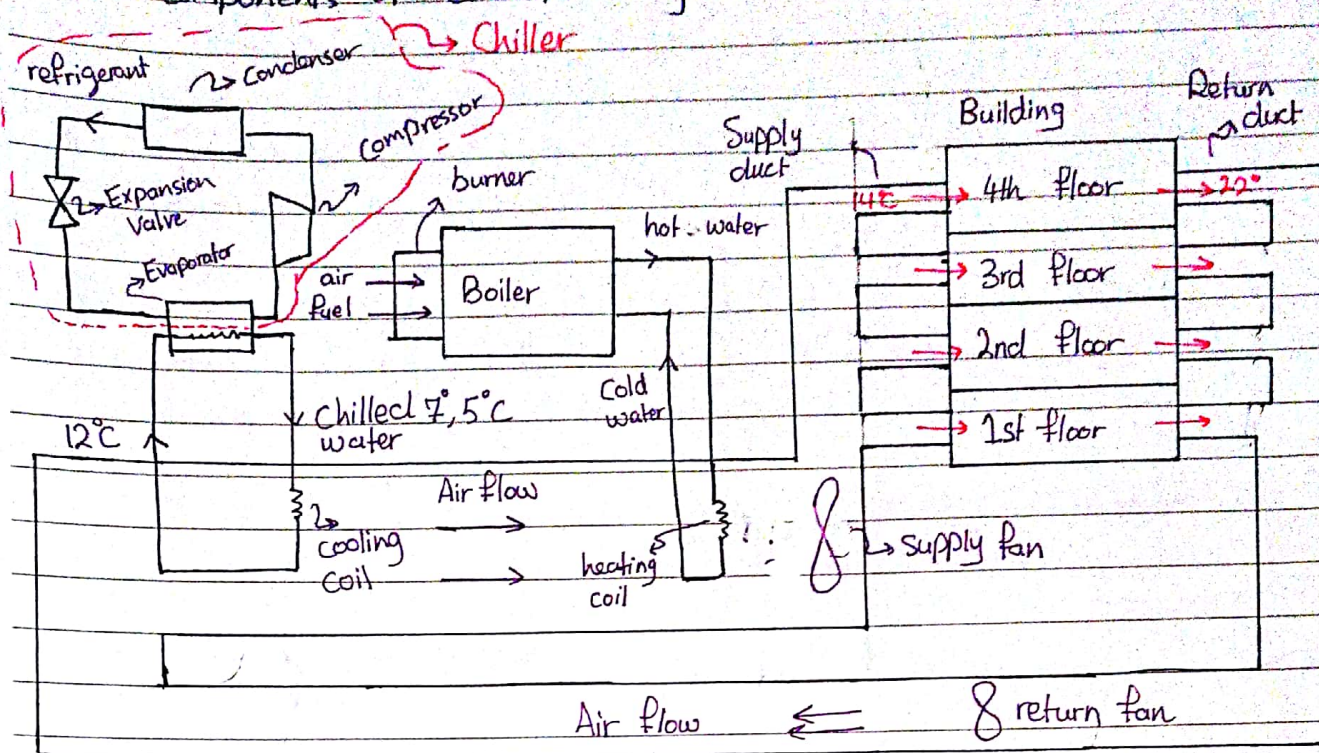
↳ A fan moves large amounts of gas (high flow rate) with a low increase in pressure

→ A blower moves moderate amounts of gas (moderate flow rate) with a relatively high increase in pressure

→ A compressor moves small amounts of gas (low flow rate) with a high increase in pressure



## → The components of central heating and air conditioning system:



### - Heating system (Boiler)

- A boiler is a closed vessel in which fluid (generally water) is heated by the thermal energy released from burning a fuel in a burner. The hot water flows through a heating coil. When air flows across the heating coil, it gets hot. This air is provided to the building using supply duct. A supply fan is used to move the air towards the building.

### - Air conditioning system (Chiller)

- A Chiller is a machine that removes heat from a liquid (generally water) via a refrigeration cycle. The cooled water, which is called chilled water, flows through a cooling coil. When air flows the cooling coil, it gets cold. This air is provided to the building using supply duct. [Air will be cooled from  $22^{\circ}\text{C}$  to  $14^{\circ}\text{C}$ ]

- The condenser in the chiller has 2 types

[1] Air cooled condenser (used widely in Jordan): in this type, the refrigerant releases its thermal energy to the air

[2] Cooling tower (used widely in Gulf countries): in this type, the refrigerant releases its thermal energy to water.

← لا يبرد بالتبريد المائي ← لا يبرد بالتبريد المائي ← لا يبرد بالتبريد المائي

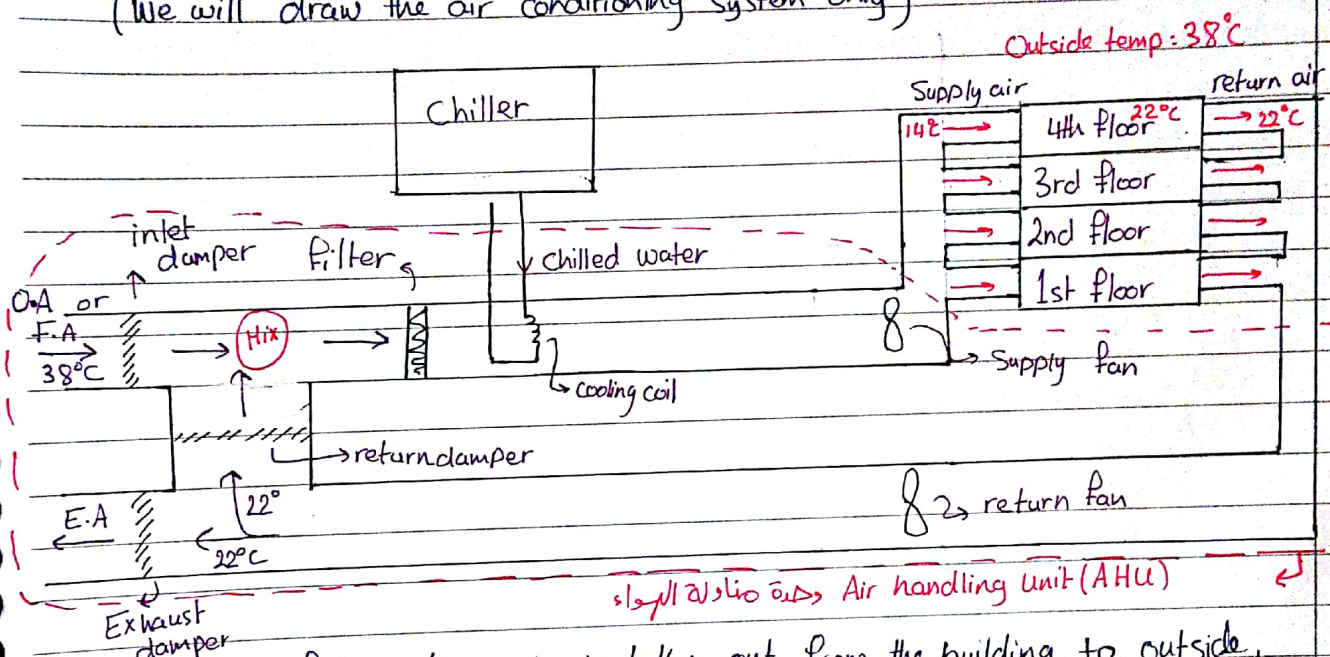
- In winter, the valves of the cooling coil are closed, while in summer, the valves of the heating coil are closed



• If we continue providing the building with (cold or hot) air, the building gets pressurized. Hence, return ducts are installed to remove air from the building (When air of certain amount is supplied into a room, the same amount of air must be removed in order to maintain the pressure inside the room)

• Notice that the same air is circulated in the system. There is no fresh air introduced to the system (There is no ventilation, and hence, the indoor air quality will be reduced)

→ We will modify the previous system for ventilation purposes (We will draw the air conditioning system only)



- If 100% of the return air is taken out from the building to outside, and replaced with 100% of fresh air, the chiller must cool the air from  $38^{\circ}\text{C}$  to  $14^{\circ}\text{C}$  instead of  $22^{\circ}\text{C}$  to  $14^{\circ}\text{C}$  (i.e. the cooling capacity of the chiller must be increased, which is very expensive)

- To save money, a part of the return air is taken to outside, (E.A = Exhaust Air); while the other part is kept in the system and mixed with fresh air F.A (or outside air O.A). F.A must be cooled from  $38^{\circ}\text{C}$  to  $22^{\circ}\text{C}$  before it is mixed with the return air. Hence, another cooling coil must be added.

OR  
We can keep the F.A at  $38^{\circ}\text{C}$ , mix it with return air, and use one cooling coil with higher cooling capacity

بداخل F.A  
أقل ما يمكن  
وبلتر فقط  
بالماء العادية  
لكمية F.A  
لأنه لا يمكن خسارة  
بالنسبة إلى



- Dampers are used to control the amount of the air taken out, introduced, kept in the system. [Note: the amount of the air taken out must be equal to the amount of the air introduced to the system to maintain the pressure in the building i.e.  $E \cdot A = F \cdot A$ ]
- Filter is used to remove solid particles, such as dust, from the air.
- In some critical applications (like in hospitals), we have to introduce 100% of fresh air to the system.
- Conclusions:

- The main components of Central heating and air conditioning system:
  - [1] Cooling system: is used to reduce the temp. of the environment. It consists of the following components: Chiller/cooling tower (or air cooled condenser)/pumps
  - [2] Heating system: is used to increase the temp. of the environment. It consists of: boiler/pumps
  - [3] Air handling unit: Controls the ventilation and temp in a building by controlling the air flow capacity. It consists of: cooling coil/heating coil/filter/ducts/supply fan/return fan/inlet damper/exhaust damper/return damper

→ How can we determine the amount of the fresh air that must be introduced to the system

- Table 4-6 gives the "minimum" recommended rates of fresh air requirements ventilation for different activities in residential places.

Check the table and notice that there are 3 main columns:

The first one shows the type of application

- The 2nd one shows the maximum occupancy per  $100\text{m}^2$  (Sometimes, the building plan doesn't show the number of occupants in the space. If this is the case, use this column to estimate the number of occupants in the space.

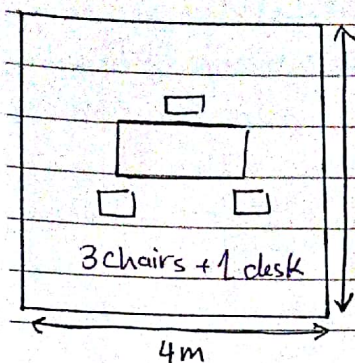
The 3rd one has 2 subcolumns: it shows the ventilation air rate requirements in  $\text{L/s/person}$  and  $\text{L/s/m}^2$

↓

Sometimes, you are unable to determine the number of persons in a certain space, because the number is continuously varying (like in malls). Hence, the ventilation requirement is determined based on the area of the space.



Example: The following figure shows a plan of a public office. Calculate  $\dot{V}_{\text{ventilation}}$



From table 4-6:

Ventilation air rate requirements:

$$10 \text{ L/s/person} \text{ or } 10 \text{ L/s/m}^2$$

because there are 3 chairs

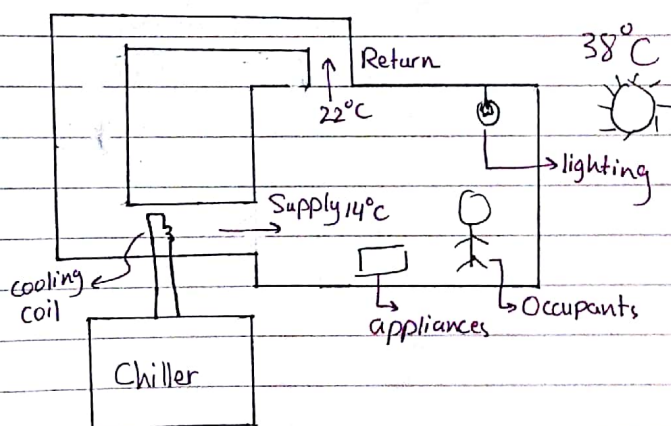
$$\therefore \dot{V}_{\text{vent}} = 3 \text{ persons} \times \frac{10 \text{ L}}{\text{s}} + 4 \times 4 \text{ m}^2 \times 10 \frac{\text{L}}{\text{s}} \\ = 30 + 160 = 190 \text{ L/s}$$

Example: A classroom seats 60 students. Find  $\dot{V}_{\text{ventilation}}$

From table 4-6:

Ventilation air rate requirements: 8 L/s/person

$$\therefore \dot{V}_{\text{vent}} = 60 \times 8 = 480 \text{ L/s}$$



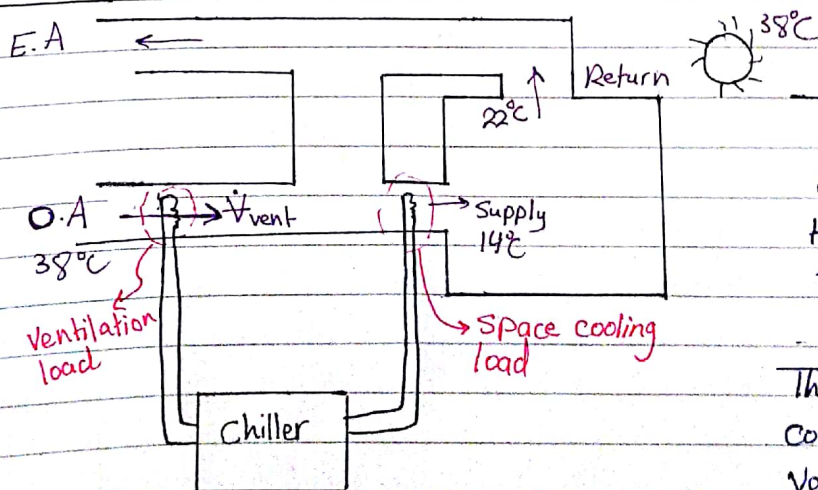
→ The adjacent figure shows a cooling system (without ventilation) =

The Space cooling load

$$= \text{Internal load} + \text{external load}$$

occupants  
lighting  
appliances

→ The cooling capacity of the cooling coil must be equal to the space cooling load.



→ When a ventilation system is added, additional cooling coil must be added to cool the fresh air from

$38^\circ\text{C} \rightarrow 22^\circ\text{C}$  من 22 إلى 38

The capacity of this cooling coil must be equal to the ventilation load



→ Recall the previous example:  $\dot{V}_{vent} = 480 \text{ L/s}$  for a classroom.  
 Assume that the fresh air will be cooled from  $38^\circ\text{C}$  to  $22^\circ\text{C}$ . Find the ventilation load (assume sensible cooling process i.e. dehumidification).  
 [The outside design conditions  $T = 38^\circ\text{C}$ , 50% relative humidity]

Ventilation load =  $\dot{m}_{vent} * C_{p,air} * \Delta T$

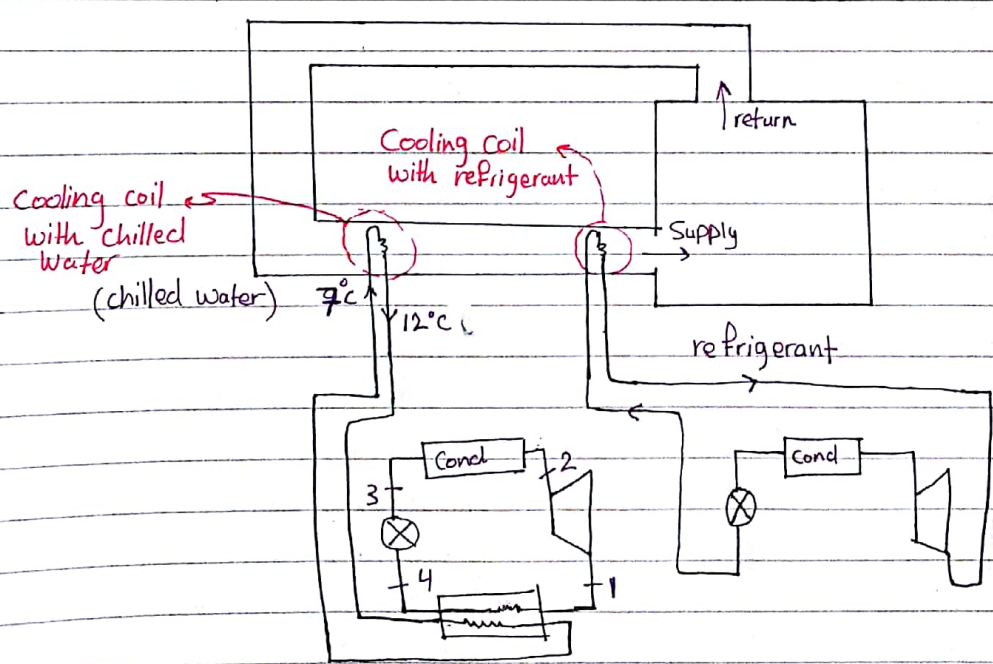
$$= \underbrace{\frac{\dot{V}_{vent}}{\text{specific volume}}}_{\substack{\text{specific} \\ \text{volume}}} * C_{p,air} * \Delta T = \frac{480}{1000} \frac{\text{m}^3}{\text{s}} * \frac{1 \text{ kJ}}{0.8 \frac{\text{m}^3}{\text{kg}} \cdot \text{kg}} * (38 - 22)$$

obtained from the Psychrometric chart  
 (use  $T = 38^\circ\text{C}$ , 50% relative humidity to find  $\nu$ )  
 assume  $\nu = 0.8 \text{ m}^3/\text{kg}$

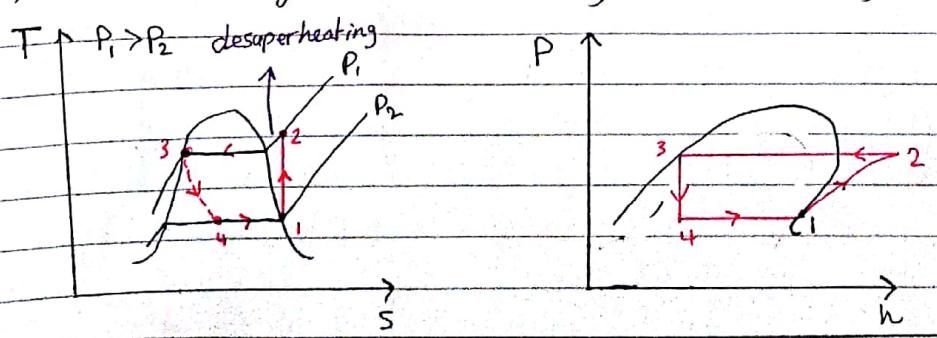
$$= 9.6 \text{ kW} = \frac{9.6}{3.5} \text{ TR} = 2.74 \text{ TR}$$

tons of refrigeration

→ The 2 cooling coils might be replaced by 1 cooling coil, with a cooling capacity = space cooling load + ventilation load.



→ The P-h diagram and T-s diagram of the refrigeration cycle:





→ In chillers, water is used to cool the space air. Using water for ~~ext~~ cooling is better than using refrigerants, for the following reasons:

- 1] Water is cheaper than refrigerants
- 2] If leakage occurs, water is more safe than refrigerant
- 3] Refrigerants have bad environmental impact, while water doesn't have any bad environmental effect

→ In chillers, the refrigerant cools the water, which cools the flowing air. Chilled water flows through the cooling coil, hence it is called: Cooling coil with chilled water.

→ Sometimes, if electricity is cut off, additional backup cooling coil is installed (this coil is used for emergency cases such as operating rooms in hospitals). It is called: cooling coil with refrigerant (or Direct expansion cooling coil [DX coil]), because a refrigerant flows through the cooling coils. Notice that the refrigerant is used to cool the flowing air

- Note: the compressor of the refrigeration cycle of the back up cooling coil is driven by a back up generator.
- Split units use DX coils

## \* Types of air conditioners

### 1] Window AC:

- Window AC is a single piece compact box housing all the components: Condenser + compressor + expansion valve + evaporator.
- It is installed in a window (i.e. it can be installed on an exterior wall, but it can't be installed on an interior wall).
  - ↳ in order to reject the heat to outside.
- It is cheap
- It is noisy as compared to split AC, as the compressor is built into the cooling unit

### 2] Split AC:

- Split AC is called "split" because it consists of 2 parts:

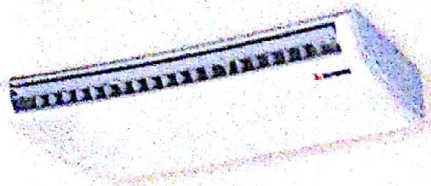
1] Indoor unit: consists of evaporator + cooling fan which circulates the air  
↳ it causes low level noise

2] Outdoor unit: consists of compressor + condenser + expansion valve + fan which helps in heat rejection



- The indoor unit has many types
- [1] Ceiling type [2] Wall type [3] Stand type [4] Cassette type
- Split units provide cooling without ventilation

[1] Ceiling type



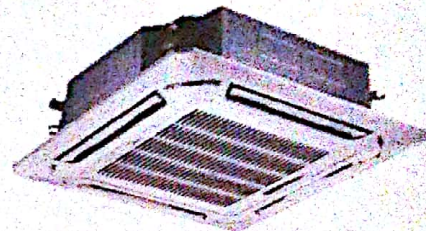
[2] Wall type



[3] Stand type



[4] Cassette type



### → Notes:

- BIPV stands for Building Integrated photovoltaic, which means: using PV materials to replace conventional building materials in parts of the building envelope such as roof or facades
- NZEB stands for Net Zero Energy Buildings: are highly efficient buildings with extremely low energy demand, which is met by renewable energy sources. Such buildings produce as much energy as they consume (nearly zero losses)



## \* Psychrometric Chart:

- Suppose that you are going to design a central cooling system for a classroom, which seats 50 persons. Find the cooling capacity of the cooling coil  $\dot{Q}_{cc}$  required for ventilation. Assume:
- Inside design conditions:  $22^\circ\text{C}$ , relative humidity = 50%
  - Outside design conditions:  $38^\circ\text{C}$ , relative humidity = 50%.

$$\dot{Q}_{cc} = \dot{m} C_p \Delta T = \dot{m} (h_2 - h_1)$$

- First, Calculate  $\dot{V}_{\text{ventilation}}$ . From table 4-6, Ventilation air rate requirements: 8 L/s/person

$$\therefore \dot{V}_{\text{vent}} = 50 \text{ persons} \times \frac{8 \text{ L}}{\text{s person}} = 400 \text{ L/s}$$

- Second, Calculate  $\dot{m}_{\text{ventilation}}$

$$\dot{m}_{\text{vent}} = \frac{\dot{V}_{\text{vent}}}{v_{\text{outside}}} = \text{specific volume of the outside air}$$

(because the fresh air is introduced from outside)

This value is obtained from the psychrometric chart

- psychrometry is the science that studies the properties of moist air.

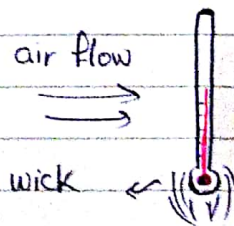
- Moist air = dry air (78%  $\text{N}_2$ , 21%  $\text{O}_2$ , 1% other) + water vapor

- Examples of moist air properties:

### [I] Temperature: dry bulb temperature / Wet bulb temperature

- Dry bulb temperature is the temperature indicated by a thermometer.

- Wet bulb temperature: is the temperature indicated by a thermometer with the bulb wrapped in wet wick. The thermometer must be exposed to air flow when we measure the wet bulb temperature.
- When: dry air passes over the wet wick, some of the water in the wick evaporates. The latent heat of vaporisation is taken from the thermometer and the air surrounding the thermometer.

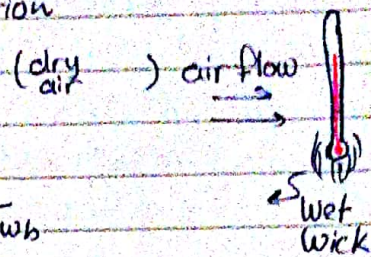


Hence the temperature reading will drop

$$\text{Temperature reading} = \text{Wet bulb temp.} < \text{ambient temp} = \text{dry bulb temp}$$



- In a region with dry air, the rate of evaporation is high, large thermal energy will be absorbed by the water in the wet wick. The thermometer reading will drop significantly, and hence the temperature difference between the wet bulb temp.  $T_{wb}$  and the dry bulb temp.  $T_{db}$  will be high



- In a region with humid air, the rate of evaporation is low, small amount of thermal energy will be absorbed by the water in the wet wick. The thermometer reading will drop slightly, and hence the temp difference between  $T_{wb}$  and  $T_{db}$  will be low.



[2] Relative humidity is:

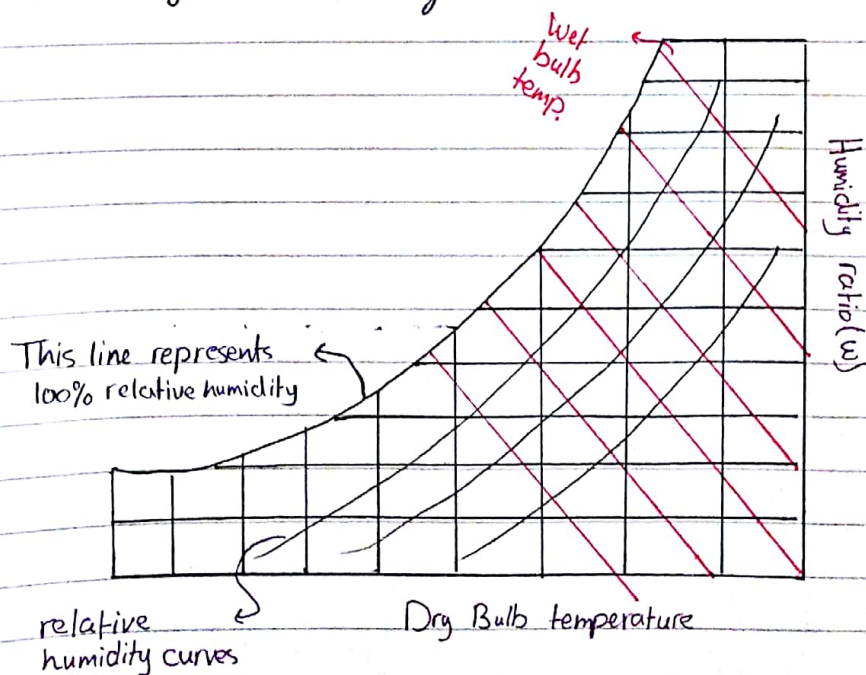
- The ratio of the amount of the water vapor present in air to the amount of the water vapor that the air can hold at that temperature

- If the air temperature increases, it can hold more water vapor

[3] Specific humidity (Humidity ratio / moisture content)

- Specific humidity is the total mass of water vapor present in a 1kg of dry air. It has units of  $\text{kg H}_2\text{O} / \text{kg dry air}$

→ Check your book page 66, which contains the psychrometric chart.

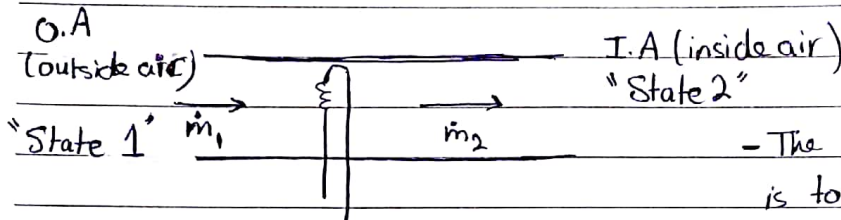


\* When the relative humidity = 100%,  
 $T_{wb} = T_{db}$



Example: Suppose that you are going to design a central cooling system for a classroom, which seats 50 persons. Find the cooling capacity of the cooling coil  $\dot{Q}_{cc}$  required for ventilation. Assume:

- Inside design conditions:  $24^{\circ}\text{C}$ , 50%
- Outside design conditions:  $37^{\circ}\text{C}$ , 45%



- The purpose of ventilation is to supply the inside space with fresh air (i.e. cooling the inside space is not the purpose of ventilation). Thus, the outside air must be cooled from  $37^{\circ}\text{C} \rightarrow 24^{\circ}\text{C}$

لأن الغرض من التهوية هو توفير الهواء الطازج (أي تبريد المساحة الداخلية ليس الغرض من التهوية). لذلك يجب تبريد الهواء الخارجي من  $37^{\circ}\text{C} \rightarrow 24^{\circ}\text{C}$

From table 4-6:

Ventilation air rate requirements for a class room =  $8 \text{ L/s/person}$

$$\dot{V}_{\text{vent}} = 50 \text{ persons} \times \frac{8 \text{ L}}{\text{s person}} = 400 \frac{\text{L}}{\text{s}} = 0.4 \text{ m}^3/\text{s}$$

$$\dot{m}_{\text{vent}} = \frac{\dot{V}_{\text{vent}}}{v_f}$$

$v_f \rightarrow$  The specific volume of the outside air.

From the psychrometric chart

State 1:  $37^{\circ}\text{C}$ , relative humidity = 45%

$$v_f = 0.903 \text{ m}^3/\text{kg dry air}$$

$$\dot{m}_{\text{vent}} = \frac{0.4}{0.903} = 0.443 \text{ kg/s}$$

$$\dot{Q}_{cc} = \dot{m}_{\text{vent}} (h_1 - h_2) \Rightarrow \text{From the psychrometric chart}$$

$$= 0.443 (83 - 84.5) = 15.28 \text{ kW}$$

State 1:  $37^{\circ}\text{C}$ , relative humidity = 45%

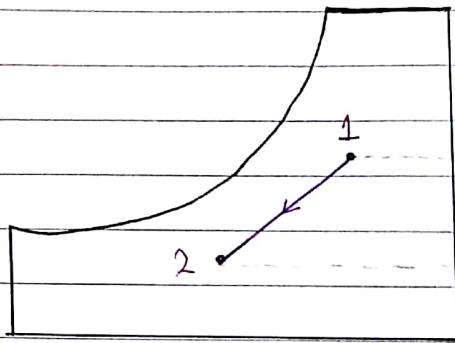
$$h_1 = 83 \text{ kJ/kg dry air}$$

$\therefore 24^{\circ}\text{C}$ , relative humidity

$$h_2 = 84.5 \text{ kJ/kg dry air}$$



Plotting the process on the psychrometric Chart



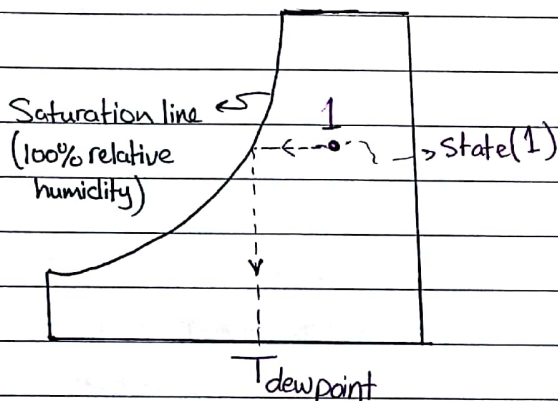
⇒ Notice that  $w_2 < w_1$

Recall:  $w$  = humidity ratio = the total amount of water vapor present in 1 kg of dry air

This indicates that some of the water vapor has been condensed (dehumidification)

→ Condensation occurs when the temperature of the air is reduced to the dewpoint temperature.

→ To find the dewpoint of the outside air (State 1):



- Draw a horizontal line, starting from State 1, until you reach the saturation line. From that point, draw a vertical line and read the temperature.

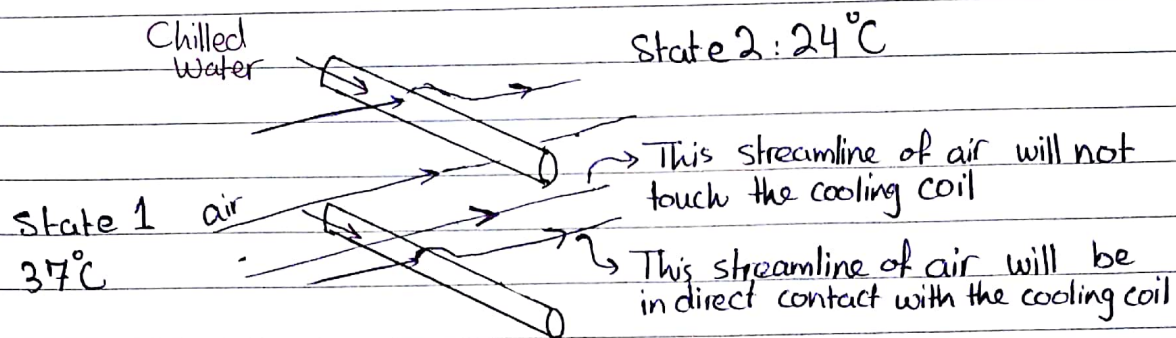
→ From the psychrometric chart @ State 1 ( $37^\circ\text{C}$ , relative humidity = 45%)

$T_{\text{dewpoint}} = 22.8^\circ\text{C}$  i.e if the temperature of the outside air is reduced to  $22.8^\circ\text{C}$ , condensation will occur. However, the temp.

of the outside air is reduced to  $24^\circ\text{C}$ ! (State 2:  $24^\circ\text{C}$ , relative humidity = 50%)

Condensation occurred, although the air temp. didn't reach the dewpoint temperature, how can we justify that?





depends on the temp. difference between the water and the air

- For effective heat transfer, the temperature of the chilled water must be less than  $24^{\circ}\text{C}$  by  $5-6^{\circ}\text{C}$  (i.e. the temp of the chilled water =  $18-20^{\circ}\text{C}$ )
- When the outside air flows across the cooling coil, Part of it will be in direct contact with the coils, while the other part will not be in direct contact with the coil.

- 
- The temperatures of these 2 Streamlines are not identical
- The temp of this streamline of air will decrease significantly, because it is in direct contact with the coil.
  - Its temp. becomes less than  $T_{\text{dewpoint}}$   $\therefore$  condensation occurs
  - The temp of this streamline of air will decrease slightly, because it is not in direct contact with the coil.
  - Its temp will decrease, but it will not decrease below the dewpoint temp.

- The "average" temp of the air after it passes through the coil =  $24^{\circ}\text{C}$
- Condensation occurs although the average temp of the air is above  $T_{\text{dewpoint}}$ .
- Any air conditioning device must be provided with a drain line in order to collect the condensed water vapor.
- We have to modify this equation:  $\dot{Q}_{\text{cc}} = \dot{m}(h_1 - h_2)$  because it doesn't take into consideration the condensed water vapor

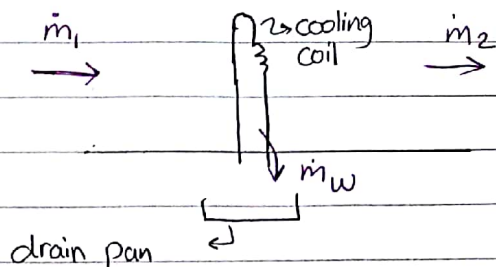


→ Mass balance equation of dry air

$$\dot{m}_1 = \dot{m}_2$$

→ Mass balance equation of the moisture

$$\dot{m}_1 w_1 = \dot{m}_2 w_2 + \dot{m}_w$$



-  $w_1$  = the amount of water vapor present in 1 kg of dry air

-  $\dot{m}_1$  = mass flow rate of dry air

$$\dot{m}_1 w_1 = \frac{\text{kg of dry air}}{\text{second}} * \frac{\text{kg of water vapor}}{\text{kg of dry air}} = \frac{\text{kg of water vapor}}{\text{second}}$$

∴  $\dot{m}_1 w_1$  represents the mass flow rate of water vapor @ state 1

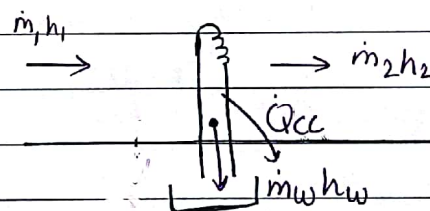
$\dot{m}_2 w_2$  represents the mass flow rate of water vapor @ state 2

$\dot{m}_1 w_1 - \dot{m}_2 w_2$  : the difference between them represents the mass rate of condensing water vapor =  $\dot{m}_w$

→ Energy balance equation

$$\dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_w h_w + \dot{Q}_{cc}$$

$$\dot{m}_1 = \dot{m}_2 = \dot{m}$$



$$\dot{Q}_{cc} = \dot{m}(h_1 - h_2) - \dot{m}_w h_w$$

→  $h_w$  @  $T_{\text{dew point}}$

\* الطاقة التي حامتها الهواء  
الى داخل جزء منها بياضه الـ  
cooling coil  
وجزء بيطالع مع اعلى الـ ناتجة  
من التكلفة و جزء يدخل في الهواء الـ  
طالع

→ We have to re-calculate  $\dot{Q}_{cc}$

$$\dot{Q}_{cc} = \dot{m}(h_1 - h_2) - \dot{m}_w h_w$$

كلنا قبل

$$\dot{m}_w = \dot{m}_1 w_1 - \dot{m}_2 w_2 \rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m} = \dot{m}_{\text{vent}} = 0.443 \text{ Kg/s}$$

$$\therefore \dot{m}_w = \dot{m}(w_1 - w_2)$$

From the psychrometric chart

State 1 (37°C, 45%) ⇒  $w_1 = 0.018 \text{ Kg H}_2\text{O/Kg dry air}$

State 2 (24°C, 50%) ⇒  $w_2 = 0.009 \text{ Kg H}_2\text{O/Kg dry air}$



$$- \dot{m}_w = \dot{m}(w_1 - w_2) = 0.443(0.018 - 0.009) = 3.987 \times 10^{-3} \text{ kg/s}$$

$$- h_w = h_{f@T_{\text{dew point}}} \approx 83.9 \text{ kJ/kg (obtained from water tables)}$$

$$\dot{Q}_{cc} = \dot{m}(h_1 - h_2) - \dot{m}_w h_w = 15.28 - 3.987 \times 10^{-3} \times 83.9 = 14.95 \text{ kW}$$

← هذا هو القيمة  
التي نأخذها  
لنقارن بها  
القيمة التي  
حسبناها

This value is more accurate  
than the previous calculated value

$$\dot{Q}_{cc} = \dot{m}(h_2 - h_1) = 15.28 \text{ kW}$$

∴ The cooling capacity of the cooling coil = 14.95 kW

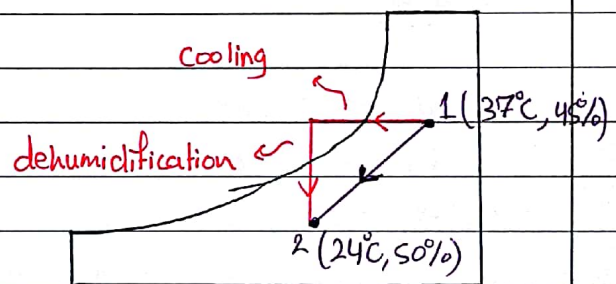
$$\text{Error \%} = \frac{|\text{Accurate value} - \text{less accurate value}|}{\text{accurate value}} = \frac{|14.95 - 15.28|}{14.95} = 1.8\%$$

Small error %

∴ We can neglect this  
term:  $\dot{m}_w h_w$

- The process is shown in the adjacent  
psychrometric chart. This process is called  
cooling and dehumidification

- Check example 3-9



Notes:

- One of the problems that we may face in winter is damp walls (الرطوبة على الجدران)

- Suppose that the temperature of the air inside a room  $T = 15^\circ\text{C}$

relative humidity = 80%

From the psychrometric chart,  $T_{\text{dew point}} = 11.5^\circ\text{C}$

If the temperature of the walls of the room  $\leq 11.5^\circ\text{C}$ , the water  
vapor inside the room will condensate on the walls → يتكثف بخار الماء

على الجدران ← الرطوبة على الجدران

(The temp. of the walls is always less than the temp of the air inside the room)

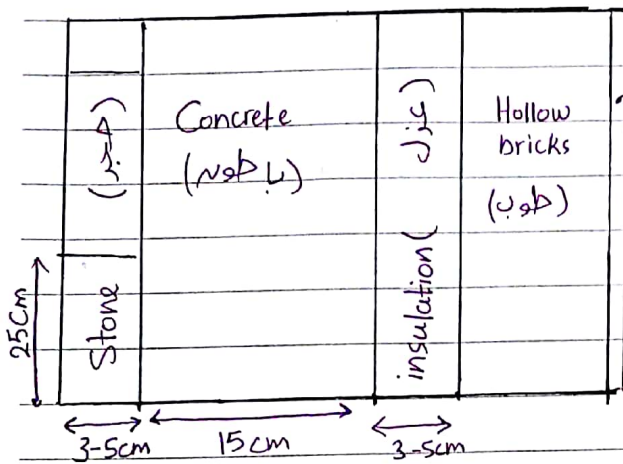
- How to avoid this problem?

[1] turning on the heating system, in order to keep the temperature of the  
walls above  $T_{\text{dew point}}$ , hence, no condensation will occur

[2] Using insulation (العزل): Using an insulation will keep the  
wall temp  $> T_{\text{dew point}}$  even if the heating system is turned off.



- The insulation is inserted between the layers of the wall as shown below:



- This is the conventional arrangement of layers in Jordan

- The location of insulation in the is? layers depends on several factors:

[1] If the building is new or retrofit

[2] Cooling load and heating load (which one is greater)

will be discussed in chapter 5

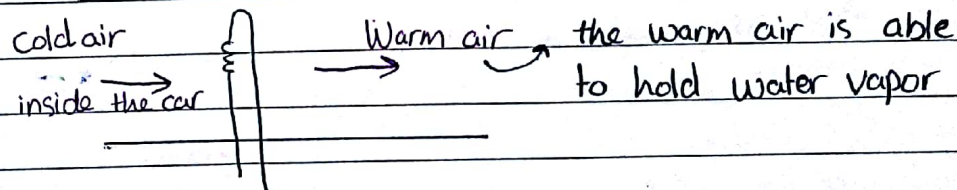
- Another problem that we may face in winter is the condensation of water vapor on the inside of the car windows (الرطوبة على الزجاج الداخلي للسيارة)

- The car is a closed environment, which traps moist air inside it. [moist air = dry air + water vapor]

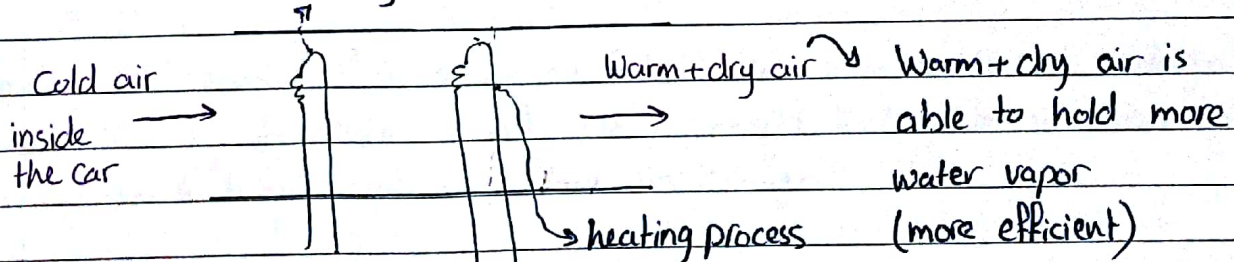
- When this moist air meets the cold windows of the car, the temperature of the air will decrease, and it becomes below Tdewpoint. The cold air will be unable to hold the water vapor, hence, condensation will occur on the inside of the car windows

- How is this problem solved?

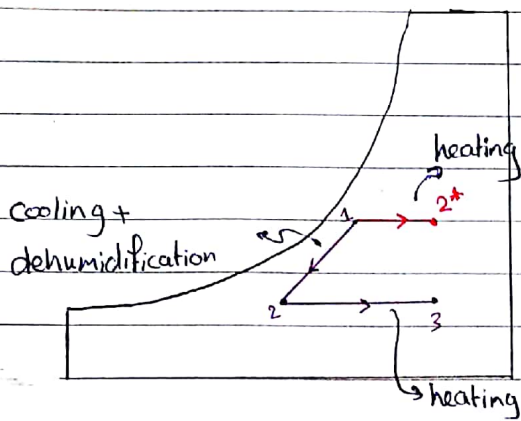
• In old cars "Sensible heating process"



• In modern cars "cooling + dehumidification process"







- In modern cars, 2 processes occur  
 $1 \rightarrow 2 + 2 \rightarrow 3 \rightarrow$  The result: Warm + dry air ✓ better
- In old cars, 1 process occurs  
 $1 \rightarrow 2^* \rightarrow$  The result: Warm + wet air

### \* Adiabatic mixing

- Note:

Air conditioning processes

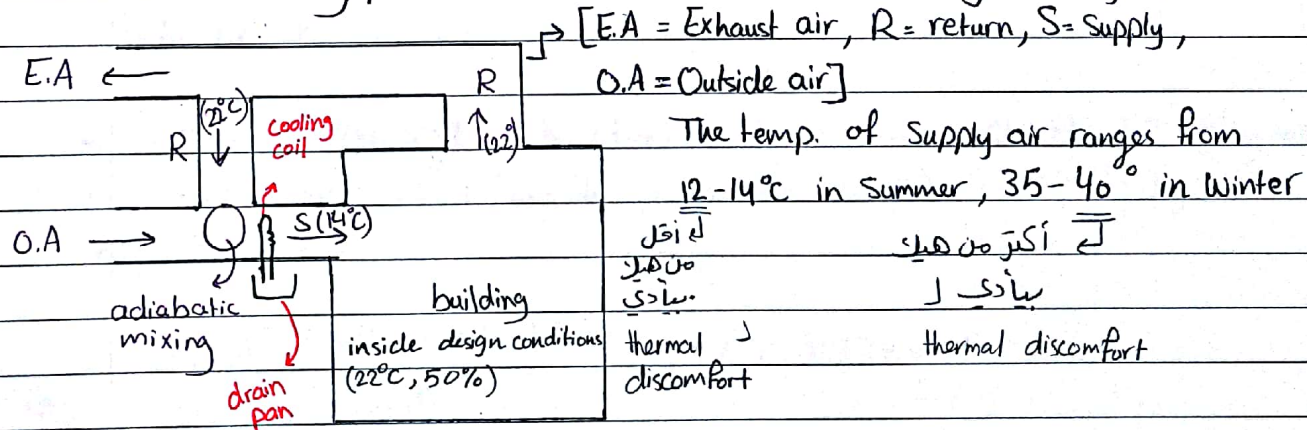
- Sensible heating (or cooling)
- cooling and dehumidification
- Heating and humidification
- Adiabatic mixing → We will talk about this process

The 2 streams have different properties

- Adiabatic mixing involves mixing of two different streams of moist air in an insulated duct. (Since this process is fast + it occurs in an insulated duct  $\Rightarrow$  the process is adiabatic)

→ There is no heat transfer

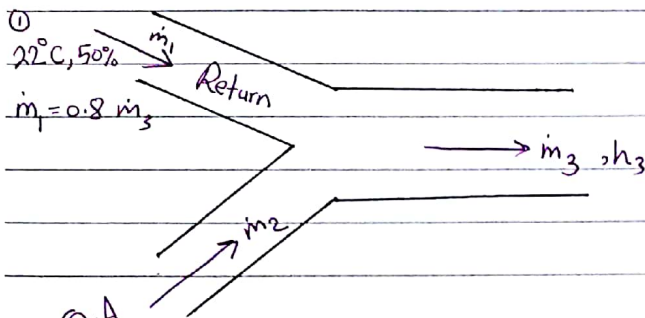
- Adiabatic mixing process is found in central cooling + heating system



- Ideally, the properties of the return air (R) is the same as the inside design conditions. Actually, the return air may lose or absorb heat while it is flowing through the duct, hence, its temperature will change.



Example: In the following adiabatic mixing process, find  $\dot{m}_3 + h_3$



\* Check examples  
(3-10) + (3-11)

② ①.A  
400 L/s, 38°C, 50%

- Mass balance equation (not volume balance equation)  
 $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$ ,  $\dot{m}_1 = 0.8 \dot{m}_3$

$\dot{V}_2 = 400 \text{ L/s} = 0.4 \text{ m}^3/\text{s}$  From the psychrometric chart (38°C, 50%)  
 $\omega_2 = 0.011 \text{ kg/kg}$

$$\dot{m}_2 = \frac{\dot{V}_2}{\omega_2} = \frac{0.4}{0.011} = 0.439 \text{ kg/s}$$

$$0.8 \dot{m}_3 + 0.439 = \dot{m}_3 \Rightarrow \dot{m}_3 = \frac{0.439}{0.2} = 2.195 \text{ kg/s}$$

- Energy balance equation

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$$

$\dot{m}_1 = 0.8 \times \dot{m}_3 = 1.756 \text{ kg/s}$ ,  $h_1$  (From the psychrometric chart) = 43 kJ/kg dry air

$\dot{m}_2 = 0.439 \text{ kg/s}$ ,  $h_2$  (from the psychrometric chart) = 92 kJ/kg dry air

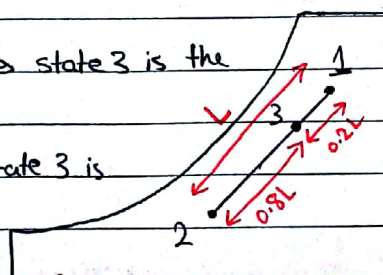
$\dot{m}_3 = 2.195 \text{ kg/s}$

$$\therefore h_3 = \frac{1.756 \times 43 + 0.439 \times 92}{2.195} = 52.8 \text{ kJ/kg}$$

→ You can find the properties of state 3 graphically as shown below

• If  $\dot{m}_1 = \dot{m}_3$ ,  $\dot{m}_2 = 0 \Rightarrow$  state 3 is the same as state 1

• If  $\dot{m}_2 = \dot{m}_3$ ,  $\dot{m}_1 = 0 \Rightarrow$  state 3 is the same as state 2



• Since  $\dot{m}_1 = 0.8 \dot{m}_3$ ,  $\dot{m}_2 = 0.2 \dot{m}_3$   
State 3 will be located on the line connecting state 1 + state 2 and it will be closer to state 1



\* Inside and outside design conditions of the space:

- The goal of the HVAC course is to achieve the thermal comfort for the occupants in an enclosed space.

- In order to achieve this thermal comfort, it is required to

[1] Determine the inside design conditions, and control them using (heating/cooling) devices, taking into consideration the outside design conditions (The first step in the project is to determine both inside + outside design conditions)

[2] Investigate the heat transfer through the building envelope in order to determine the overall heat transfer coefficient "U" of the walls, doors and windows (heat transfer in residential buildings will be discussed in Chapter 5)

- Once you find out the previous requirements, you will be able to calculate the heating load + cooling load. Then, you can select the cooling and heating devices.

~~~~~  
• Inside design conditions:

- The inside design conditions have a certain range, which is called "Comfort Zone".

- The selection of the inside design conditions depends on several factors:

[1] Clothing Factor

[2] The outside design conditions

[3] The level of activity of the occupants

[4] The period of occupancy of the conditioned space

[5] The type of building construction

- Check Figure 4-1 (Page 152), which shows the ASHRAE comfort zones for summer and winter air conditioning.

- Notice:

\* The suitable inside temp range (in Summer) =  $23 - 27^{\circ}\text{C}$  → This value is acceptable, since you wear light clothes in Summer

The suitable inside relative humidity range (in Summer) = 30-60% (يعني لا تقيتر حر)

\* The suitable inside temp range (in winter) =  $19 - 24^{\circ}\text{C}$

\* There is an overlap between summer and winter comfort zones. If this range of temp is achieved, thermal comfort will be achieved in both summer and winter.

→ This value is acceptable, since you wear heavy clothes in winter (يعني لا تقيتر برد)



- Check table 4-4, which shows the recommended inside design conditions for 'Summer and winter operations'. The table is divided into 3 main columns:

[1] Type of application:

[2] Summer Operation. It is divided into 2 subcolumns:  
Deluxe (luxurious) applications + Commercial applications

[3] Winter operation. It is divided into 2 subcolumns:  
heating with humidification + heating without humidification

- Check table 4-5, which shows the design inside dry bulb temperature range usually used for sensible heating only (Example: radiators can only raise the temp of the air inside the space "Sensible heating" without affecting the amount of water vapor in the air)

- Check table 6-9 (Page 227), which shows the heating load summary sheet for a room in a building

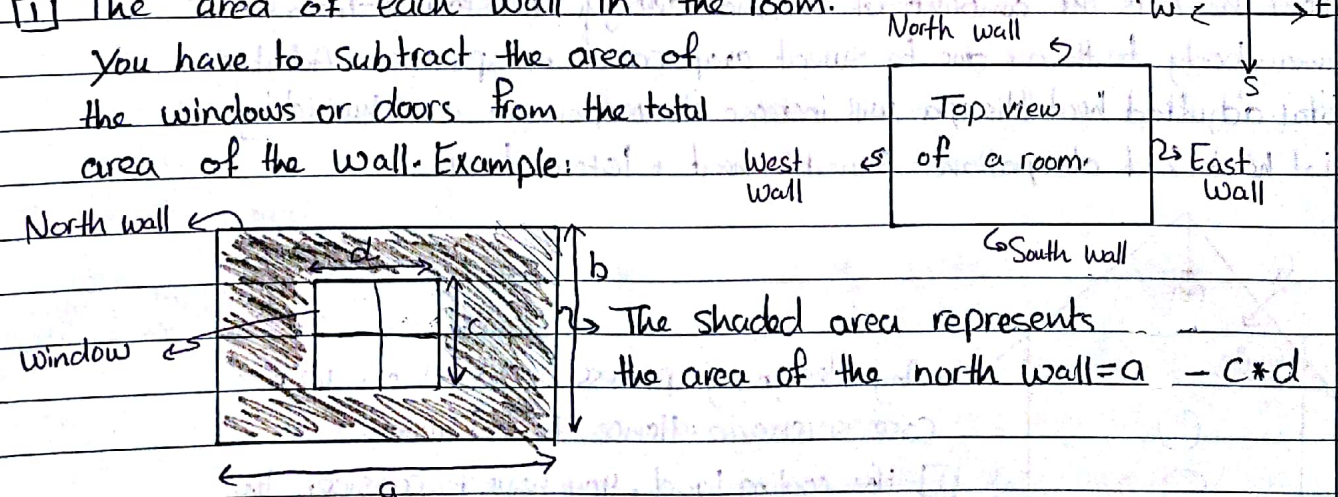
- The calculation of the total heating load of a building must be carried on a room by room analysis. In other words, the heating load for each room is calculated, then, we can find the total heating load:  
Total heating load of the building =  $\Sigma$  heating load for each room in the building.

- The heating load for each room is tabulated as shown in Table 6-9.

- In this table you have to fill the following data:

[1] The area of each wall in the room.

You have to subtract the area of the windows or doors from the total area of the wall. Example:



[2] Ceiling + floor areas: Ceiling area = floor area

[3] Windows + doors areas

[4] Infiltration (will be discussed later)

[5] Overall coefficient of heat transfer  $U$ . The  $U$  value represents the rate of heat transfer through  $1 \text{ m}^2$  of a surface, when the temperature difference between the sides of the surface =  $1 \text{ K}$



[16]  $T_{\text{inside}} - T_{\text{outside}}$

[17] Finally you can calculate the heat loss from each component. Example:

- For the north wall  $Q_{\text{loss}} = U A \Delta T$   $\rightarrow$  temp. difference between the sides of the wall

$U$  value of the wall  
(we will find it in the next lecture)

area of the wall  
(obtained from plans + elevations)

- For the east window  $Q_{\text{loss}} = U A \Delta T$   $\rightarrow$  temp. difference between the sides of the window

$U$  value of the window

area of the window

$\therefore \dot{Q}_{\text{room}} = \sum \dot{Q}_{\text{loss}}$  of the components of the room

(windows + walls + doors + floor + ceiling)

### • Outside design conditions

- The outside design conditions is determined according to the season of the years (summer or winter) + weather and climate of the location.
- The outside design conditions must be evaluated correctly, since it will determine whether the air conditioning system will provide comfort condition or not, whether the system will be undersized or oversized or correctly designed.

- Undersized system will not provide the desired indoor conditions for comfort.

- Oversized system will cost more than it should be for a proper economical engineering system. [If a heating system is designed for severe weather conditions, excess heating capacity will exist during most of the system operation life. This choice is not economical]

← هنا أهم نظام تدفئة ما يحتاج درجة حرارة خارجية منخفضة كثير (مثل التي بتحدث خلال العواصف الثلجية زي عاصفة هيو، واليكنسا) لأنه هاي العواصف ما بتستمر كل سنة. لو صممت على درجة حرارة منخفضة كثير، نظام التدفئة رح يكون فعال على part load طول فترة الشتاء ← دهاد رح يخلي نظام التدفئة مكلف. (oversized system)



- Check table 4-8 (Page 165), which gives the recommended outside design condition for both summer and winter seasons for some selected locations throughout the world:

- Notice, in the 2nd column, which shows the winter design dry bulb temp., there is a percentage: 97.5%  
↓

This percentage means that 97.5% of the winter days, the weather temperature will be greater than (or equal to) the outside design temp listed in the table. (أيام الشتاء 97.5% من أيام الشتاء تكون درجة حرارة الجو أقل من درجة الحرارة الخارجية التي أنا صممت بناءً عليها)

(أيام الصيف 2.5% من أيام الصيف تكون درجة حرارة الجو أكبر من درجة الحرارة الخارجية التي أنا صممت بناءً عليها)

- Modern ASHRAE standards increased this value to 99.6%

- In the 3rd column, which shows the summer design dry bulb temp., there is a percentage: 2.5%  
↓

This percentage indicates that 2.5% of the summer days, the weather temp will be greater than (or equal to) the outside design temperatures listed in the table. (أيام الصيف 2.5% من أيام الصيف تكون درجة حرارة الجو أكبر من درجة الحرارة الخارجية التي أنا صممت بناءً عليها)

(أيام الشتاء 97.5% من أيام الشتاء تكون درجة حرارة الجو أقل من درجة الحرارة الخارجية التي أنا صممت بناءً عليها)

- In winter, the inside temperature will drop below its design value if the outside air temperature value falls below its design outdoor temperature during winter severe cold weather conditions

- In Summer, the inside temperature will rise above its design value if the outside air temperature rises above its design outdoor temperature during summer severe hot weather conditions.

- The failure of the air conditioning system to maintain the inside design conditions during short periods of severe weather conditions in summer and winter is not a critical case

- Table A-7 in Appendix A lists winter and summer outdoor air design conditions for selected locations in Jordan. Use this table to determine the outside design conditions (Don't use table 4-8)



## [\*] Heat transfer in residential buildings

- The heating and cooling loads of an insulated building will not be the same as for a non-insulated system.
- Insulating a certain building represents an additional cost, but it may reduce the thermal losses in the building significantly. Calculations must be made in order to determine whether this additional cost is justified or not.
- In buildings, heat is lost through walls, floors, windows, doors, ceilings, etc.

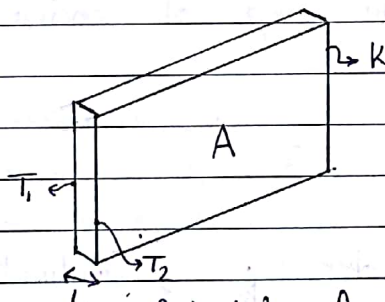
### • Modes of heat transfer

#### [1] Conduction (Fourier's law)

- The amount of conduction heat transfer rate depends on:

- [1] Thermal conductivity of the material through which conduction takes place. It is the property of the material to conduct heat (designated by  $k$ )
- [2] Thickness and surface area of the material through which conduction takes place
- [3] Temperature difference between the side of the material

$$\therefore \dot{Q}_c = \frac{KA\Delta T}{L}$$



- In some applications, the rate of heat transfer must be high (example: radiators in cars), hence we use materials with high thermal conductivity
- Other applications don't require high heat transfer rates, hence we use materials with low thermal conductivity

#### [2] Convection (Newton's law of cooling)

- Convection occurs between a surface and a moving fluid

$$\dot{Q}_{conv} = hA\Delta T;$$

- $h$  is the convection coefficient of heat transfer. It depends on fluid dynamics, not just fluid properties. The value of  $h$  in turbulent flow is greater than the value of  $h$  in laminar flow. The value of  $h$  in forced convection is greater than the value of  $h$  in natural convection

- $A$ : surface area exposed to convection

- $\Delta T$ : the temp. difference between the surface and the moving fluid.



### 13] Radiation (Stephan Boltzman equation)

- The amount of heat emitted by a surface

$$\dot{Q} = \sigma \cdot \epsilon \cdot A \cdot T_s^4$$

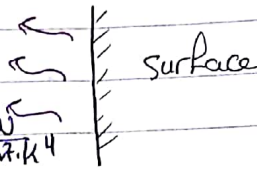
where

$\sigma$  = Stephan boltzman constant  $= 5.669 \times 10^{-8} \frac{W}{m^2 \cdot K^4}$

$\epsilon$  = Emissivity (  $\epsilon_{\text{إشعاعية}}$  )  $0 < \epsilon < 1$

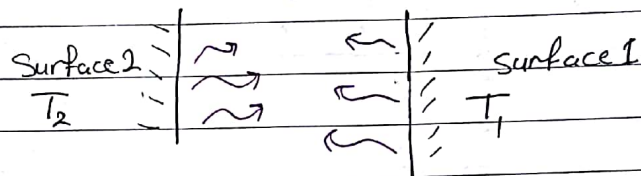
$A$  = surface area

$T_s$  = surface temperature



- The net heat exchange by radiation between 2 bodies is given by

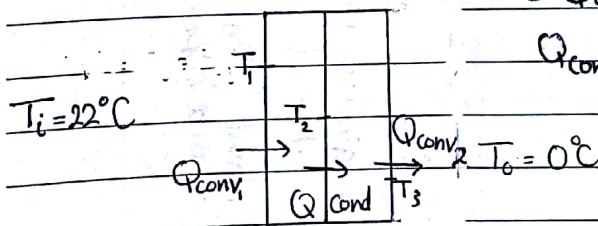
$$\dot{Q} = \sigma \epsilon A (T_{s_1}^4 - T_{s_2}^4)$$



\*Note: Emissivity of the surface of a material is its effectiveness in emitting energy as thermal radiation

$\epsilon = \frac{\text{radiation of the surface}}{\text{radiation of a black body at the same temp. as that surface}}$   
 ↓  
 hypothetical perfect absorber and emitter of energy

- The walls of a building are often made of several layers (not single layer) as shown below

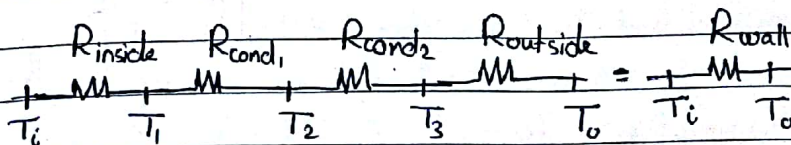


-  $Q_{conv1} = Q_{cond} = Q_{conv2}$ , In order to find  $Q_{conv1}$

$$Q_{conv1} = h A (T_i - T_{s1})$$

Easy to measure requires a sensor embedded within the wall (not practical, thus we use the following method):

The above wall can be represented as a series of thermal resistances



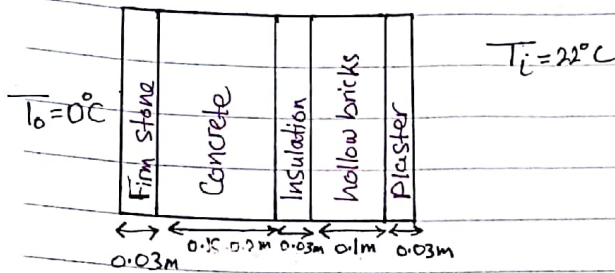
$$U_{wall} = \frac{1}{R_{tot}} = \frac{1}{\sum R_i} \Rightarrow Q_{conv1} = Q_{cond} = Q_{conv2} = U_{wall} A (T_i - T_o)$$

both temp are easy

to measure



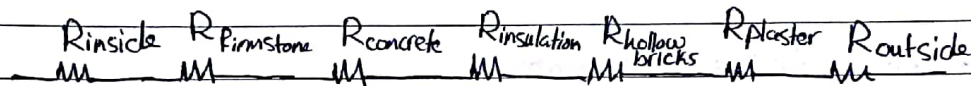
- Typical wall layers in Jordan are shown below:



- If the  $U$  value =  $1 \text{ W/m}^2\cdot\text{K}$ , it means  $1 \text{ kW}$  of heat will pass through  $1 \text{ m}^2$  of the wall if the temperature difference =  $1^\circ\text{C}$  (or  $1 \text{ K}$ )
- From the above definition we can conclude that the  $U$  value of the walls must be minimized, to minimize the heat losses in the building.
- According to the Jordanian code,  $U$  value of the walls must not exceed  $0.56 \text{ W/m}^2\cdot\text{K}$

↳ Obtained from the British standards

- The above wall can be represented as a series of thermal resistances:



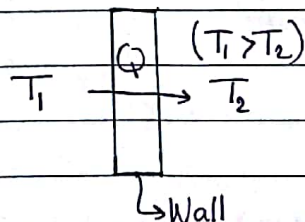
$$U_{\text{wall}} = \frac{1}{R_{\text{tot}}}$$

$$R_{\text{tot}} = R_{\text{inside}} + \sum \frac{x}{k} + R_{\text{outside}}$$

-  $R_{\text{inside}} = \frac{1}{h_i}$ , the values of  $R_{\text{inside}}$  are found in Table 5-2. The

First row gives  $R_i$  for the walls,

| Element | Heat direction | Material type                                    | $R_i (\text{m}^2\cdot\text{K/W})$ |
|---------|----------------|--------------------------------------------------|-----------------------------------|
| Wall    | Horizontal     | Construction material (ماتر البناء)<br>التي فوقه | 0.12                              |
|         |                | Metals (ماتر الكرفان)                            | 0.31                              |



- The conductive resistances are given by  $\frac{x}{k}$ ,  $x$  is the thickness of the layer while  $k$  is the thermal conductivity

Table 5-1 gives the values of  $k$  for several materials

-  $R_{\text{outside}} = \frac{1}{h_o}$ , the values of  $R_{\text{outside}}$  are found in Table 5-3



- Routside depends on the windspeed, As the windspeed  $\uparrow$ , the value of  $h_o \uparrow \therefore R_{outside} \downarrow$  (In Amman, the windspeed  $\approx 3 \text{ m/s}$ )

Example: Find the rate of heat transfer through "normal weight concrete" wall of thickness  $0.35 \text{ m}$  and area  $= 24 \text{ m}^2$

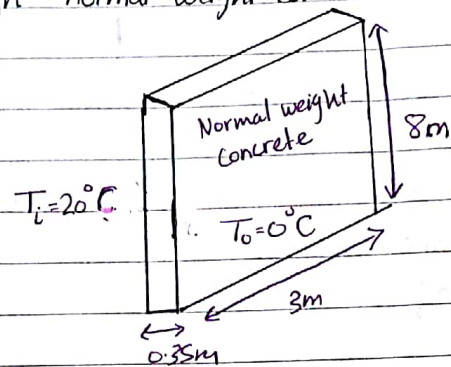
$$R_{tot} = R_i + \frac{x_{concrete}}{k_{concrete}} + R_o$$

From Table 5-2  $\Rightarrow R_i = 0.12 \text{ m}^2 \cdot \text{K/W}$

From Table 5-3  $\Rightarrow R_o = 0.06 \text{ m}^2 \cdot \text{K/W}$

From Table 5-1

$k(\text{normal weight concrete}) = 1.7 \text{ m}^2 \cdot \text{K/W}$



$$\therefore R_{tot} = 0.12 + \frac{0.35}{1.7} + 0.06 = 0.38 \text{ m}^2 \cdot \text{K/W} \Rightarrow U = 2.59 \text{ W/m}^2 \cdot \text{K}$$

$$Q = U * A * \Delta T = 2.59 * 24 * (20 - 0) = 1243.9 \text{ W (without insulation)}$$

Example: If you add 3cm of polystyrene (insulation) to the previous wall Find the rate of heat transfer

$$R_{tot} = R_i + \frac{x_{concrete}}{k_{concrete}} + \frac{x_{polystyrene}}{k_{polystyrene}} + R_o$$

$$= 0.12 + \frac{0.35}{1.7} + \frac{0.03}{0.03} + 0.06 = 1.38 \text{ m}^2 \cdot \text{K/W} \Rightarrow U = 0.72 \text{ W/m}^2 \cdot \text{K}$$

$$Q = U * A * \Delta T = 0.72 * 24 * (20 - 0) = 347.8 \text{ W (with insulation)}$$

Example: How many centimeters of concrete is equivalent to 5cm of polystyrene?

$$R_{concrete} = R_{polystyrene}$$

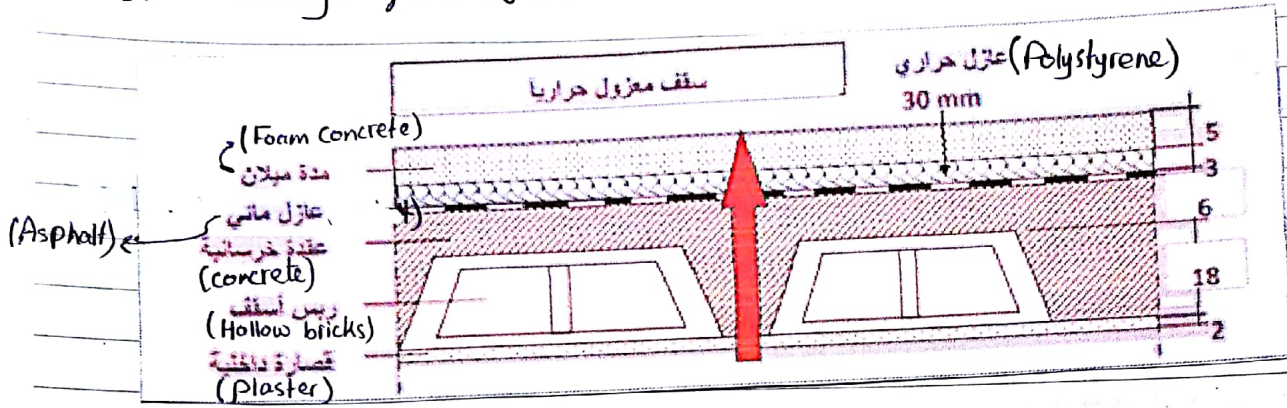
$$\frac{x_{concrete}}{k_{concrete}} = \frac{x_{polystyrene}}{k_{polystyrene}}$$

$$\frac{x_{concrete}}{1.7} = \frac{0.05}{0.03} \Rightarrow x_{concrete} = 2.83 \text{ m}$$

$\therefore$  Thermal insulation of polystyrene of thickness = 5cm is equivalent to thermal insulation of concrete of thickness = 2.83 m!



- Typical ceiling layers in Jordan are shown below



- Ceiling layers

[1] Plaster

[2] Hollow bricks: since they are hollow, they are good thermal + sound insulators.

The sides of the brick are inclined to allow the concrete to flow easily when the concrete is poured

[3] Concrete

[4] Water insulation (عزل مائي): it protects the building from the damage that may result from water leakage. This layer is made of asphalt (الأسفلت/الزفت).

\* من الأنواع المعروفة للعزل المائي:  
- أسفلت بارد على شكل بولات صفرها عازل ومثبتها من خلال استخدام غار ساخن.  
- أسفلت ساخن مغلي ليوصل درجة حرارة التشكيب ومنبعه عازل. مشكلة الأسفلت انه يمتص حرارة كثير عتباته هيك يرسوا على مظهره بل يعد على عكس الاسفة الاقطة

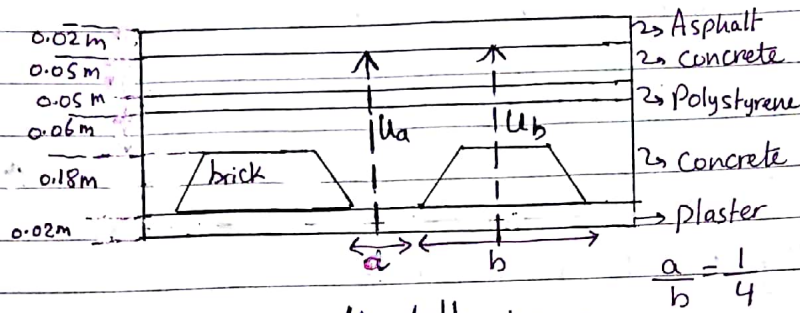
[5] Thermal insulation: made of polystyrene

[6] Slope screed (مادة الميلان): it is made of foam concrete

من اكبر الأذى من السقف يكون سببها 7cm صلا ومن اكبر التاليف سببها ضعف  
بتميل صلابه عتباته صبة المطر تدفع باتجاه الخراب  
\* الأسقف بين الطوابق صابن زمين عزل مائي / مادة صلابه / عزل حراري. بعد العتقة  
الخرسانية ييجي طعم ويعتدها بلاط



Example: Check the ceiling construction found in page 185 in the book.  
Calculate the overall coefficient of heat transfer  $U_{\text{ceiling}}$ . The inside and outside design temperatures are  $24^{\circ}\text{C}$  and  $2^{\circ}\text{C}$  respectively. Windspeed  $< 0.5 \text{ m/s}$



$U_a \neq U_b$ , because  
the layers are not identical

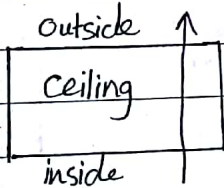
$$\therefore A_{\text{tot}} U_{\text{ceiling}} = A_a U_a + A_b U_b$$

$$R_{\text{ta}} = R_{\text{inside}} + \sum \frac{x}{k} + R_{\text{outside}}$$

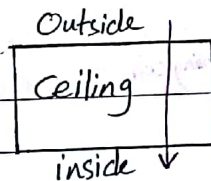
$$- R_{\text{inside}} = 0.1 \text{ m}^2 \cdot \text{K/W} \quad (\text{Heat direction: upward})$$

\* Note:

In winter



In Summer



Heat direction: upward ( $T_o < T_i$ )

$$\therefore R_{\text{inside}} = 0.1 \text{ m}^2 \cdot \text{K/W}$$

Heat direction: downward ( $T_b < T_o$ )

$$R_{\text{inside}} = 0.15 \text{ m}^2 \cdot \text{K/W}$$

$$- R_{\text{outside}} = 0.07 \text{ m}^2 \cdot \text{K/W} \quad (\text{wind speed} < 0.5 \text{ m/s})$$

- From the table shown in page 185 (for the ceiling construction)

$$\sum \frac{x}{k} = \frac{0.02}{1.2} + \frac{0.18+0.06}{1.75} + \frac{0.05}{0.03} + \frac{0.05}{1.75} + \frac{0.02}{0.7} = 1.8776 \text{ m}^2 \cdot \text{K/W}$$

$$\therefore R_a = 2.0476 \text{ m}^2 \cdot \text{K/W} \Rightarrow U_a = \frac{1}{R_a} = 0.488 \text{ W/m}^2 \cdot \text{K}, A_a = \frac{1}{5} A_{\text{tot}}$$

$$- R_b = R_{\text{inside}} + \sum \frac{x}{k} + R_{\text{outside}}$$

$$R_{\text{inside}} = 0.1 \text{ m}^2 \cdot \text{K/W}$$

$$R_{\text{outside}} = 0.07 \text{ m}^2 \cdot \text{K/W}$$

$$\sum \frac{x}{k} = \frac{0.02}{1.2} + \frac{0.18}{0.95} + \frac{0.06}{1.75} + \frac{0.05}{0.03} + \frac{0.05}{1.75} + \frac{0.02}{0.7} = 1.964 \text{ m}^2 \cdot \text{K/W}$$

$$R_b = 2.134 \text{ m}^2 \cdot \text{K/W} \Rightarrow U_b = 0.468 \text{ W/m}^2 \cdot \text{K}, A_b = \frac{4}{5} A_{\text{tot}}$$



$$\therefore U_{\text{ceiling}} = \frac{1}{5} * A_{\text{tot}} * 0.488 + \frac{4}{5} * A_{\text{tot}} * 0.468 = 0.472 \text{ W/m}^2.\text{K}$$

$A_{\text{tot}}$

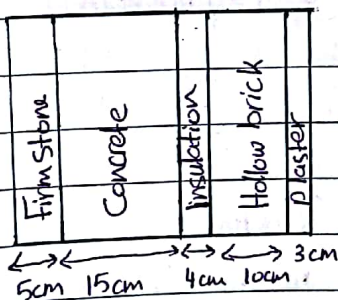
- Check Table 5-4 which gives the values of overall heat transfer Coefficient  $U_g$  for glass windows. Notice that the  $U$  values for windows are very high when compared to the  $U$  value of the wall =  $0.56 \text{ W/m}^2.\text{K}$  or the  $U$  value of the ceiling =  $0.472 \text{ W/m}^2.\text{K}$ . This means: more heat is lost through the windows, when compared with the heat loss through the walls or ceilings.

[\*] Regarding the First task in the project, we are required to calculate the heating load of the building:

- Assume outside design conditions  $T = 2.4^\circ\text{C}$ , wind speed =  $1.1 \text{ m/s}$

These values are obtained from Table A-7. Check the 4th table (Amman- University of Jordan). The minimum temperature  $T_{\text{min}} = 2.4$  occurs in January

- Use double glass, aluminum frame windows  $\Rightarrow U_g = 3.2 \text{ W/m}^2.\text{K}$
- The layers of the exterior walls (exposed to atmosphere)



$U_{\text{walls with insulation}} = 0.56 \text{ W/m}^2.\text{K}$

$U_{\text{walls without insulation}} = 2.3 \text{ W/m}^2.\text{K}$

- The layers of the interior walls: 3cm plaster - 10 cm hollow bricks - 3cm plaster
- We have to submit:

- The AutoCAD file of the plans, labeled with the names of the rooms
- Excel sheet, which contains the heating load (room by room), Summary per floor + Summary of the heating load of the building
- Report: Cover page + assumptions + Design conditions (inside + outside) Wall and windows layers +  $U$  values + Sample of calculations for a representative room



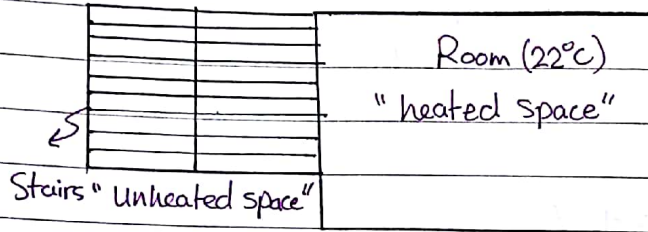
- Check Table 5-5 which shows the U values for doors. The table has 4 main columns:

Door type / without storm door / with "wood" storm door / with "metal" storm door

\* Storm door: an additional outer door for protection in bad weather

- Heating season with adjacent room unheated case:

$$T_{\text{outside}} = 0$$



For this case, the temp. difference across the separating walls or ceilings is given by:

$$\Delta T_{\text{adj}} = 0.5 (T_{\text{inside}} - T_{\text{outside}})$$

\* ملاحظة:

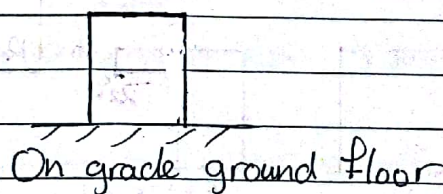
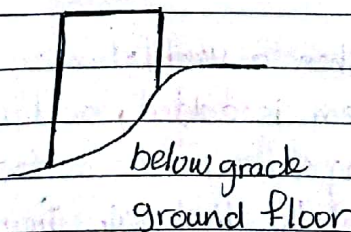
- المحررات بالمبنى ممكن اذفيم او ممكن ما اذفيم من بيزم ال heating load كالفرد المرفقة

- في الإسكانات كما أهم نظام التدفئة ما يفرض انه كل الشقق مدفئة لانه ممكن بسفحة مدفئة التدفئة سفالة من بالسفحة الى جنبها، النار ما فزبن فالتدفئة صحن سفالة، لكن عيبن حكومي يفرض انه كل الغرف مدفئة

- The ground temperature, needed for the calculations of the heat loss rates through ground floors directly on the ground or below grade walls, is found in Table A-7. If the ground temp. is not given in the table,  $T_g$  is taken 5 to 10°C above the outside air temperature.

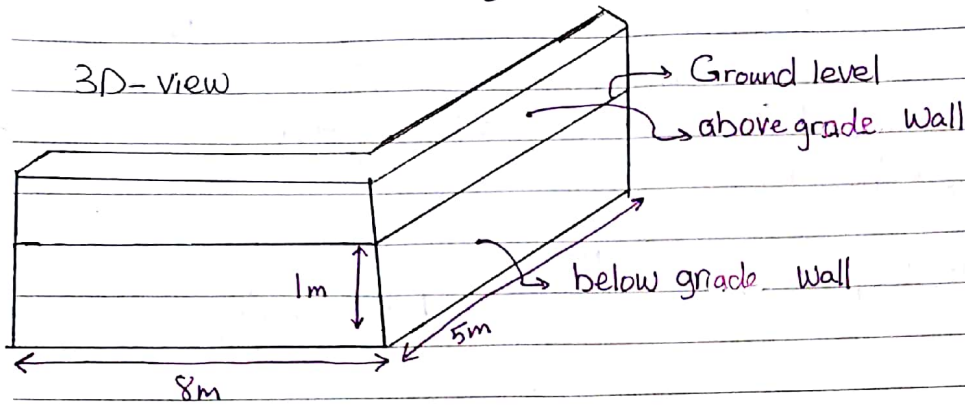
\* ملاحظة: لو في كراغ تحت الطابق الارضي، يفرض انه كراغ unheated space و يستعمل  $\Delta T_{\text{adj}}$

\* Note:

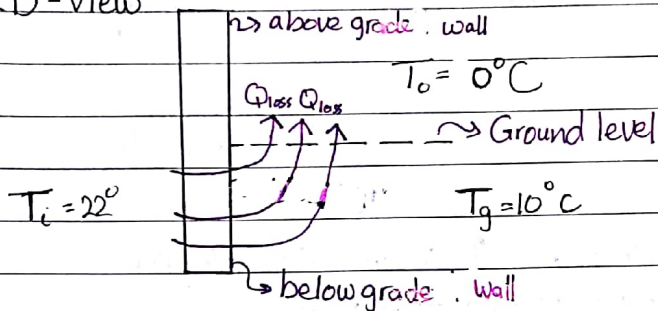




- Uvalue for walls below grade:



2D-View



\* As the depth increases, the path of the heat transfer becomes longer,  $\Rightarrow$  Thermal resistance  $\uparrow$   
 $\therefore$  Uvalue  $\downarrow$

\* A certain Uvalue is taken for every 30 cm below the ground

- Check Table 5-8, which gives the Uvalues for walls below grade.

The table is divided into 3 main columns:

- Depth below grade
- Un-insulated (If the walls are un-insulated, use these values)
- Insulation resistance (If the walls are insulated, use these values)

In order to select the correct Uvalue, you have to calculate the insulation resistance first. For example if the wall is insulated with polystyrene of thickness = 2cm

$$R_{\text{Polystyrene}} = \frac{x}{k} = \frac{0.02}{0.03} = 0.667 \text{ m}^2 \cdot \text{K/W}$$

This value is close to 0.73 m<sup>2</sup>·K/W

Table 5-8

Depth below grade

Uninsulated

use the values in this subcolumn

Insulation resistance m<sup>2</sup>·K/W

0.73 1.47 2.2

0-0.3

0.3-0.6

1st

2nd

3rd

Subcolumn

Subcolumn

Subcolumn



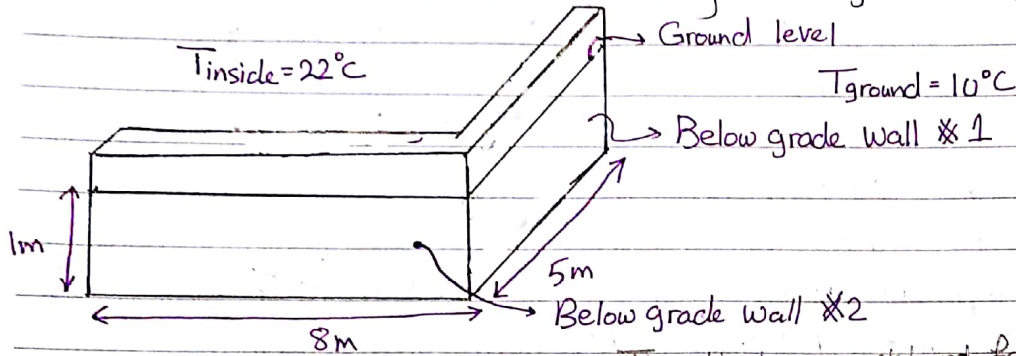
- If the wall is insulated with polystyrene of thickness = 5cm

$$R_{\text{Polystyrene}} = \frac{x}{k} = \frac{0.05}{0.03} = 1.667 \text{ m}^2 \cdot \text{K/W}$$

This value is close to  $1.470 \text{ m}^2 \cdot \text{K/W}$

Use the values in the 2nd subcolumn

Example: Find the heat loss for the following below grade walls (Assume un-insulated wall)



These U values are obtained from Table 5-8

$$0-0.3\text{m } Q_1 = U A \Delta T = 2.328 * (8+5) * 0.3 * (22-10) = 108.95 \text{ W}$$

$$0.3-0.6\text{m } Q_2 = U A \Delta T = 1.261 * (8+5) * 0.3 * (22-10) = 59.01 \text{ W}$$

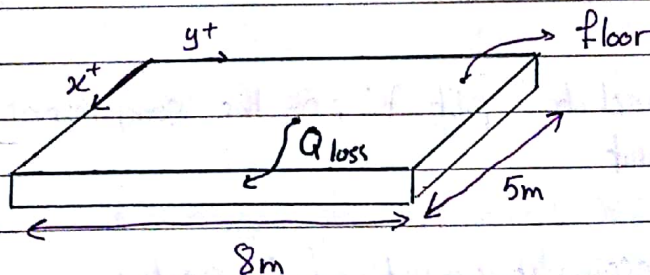
$$0.6-0.9\text{m } Q_3 = U A \Delta T = 0.88 * (8+5) * 0.3 * (22-10) = 41.18 \text{ W}$$

$$0.9-1.1\text{m } Q_4 = U A \Delta T = 0.676 * (8+5) * 0.1 * (22-10) = 10.54 \text{ W}$$

$$\therefore \text{Total heat loss through the wall} = Q_1 + Q_2 + Q_3 + Q_4 = 219.68 \text{ W}$$

- Check table 5-9, which gives the overall heat transfer coefficients for floors below grade. The U value depends on 2 factors:

- [1] Depth of the floor below the ground
- [2] Narrowest width of the house.



\* heat will be lost in the x-direction (not y-direction), because the path of heat transfer is shorter in the x-direction

\* For the above floor, the narrowest width = 5m

\* Note: If the floor is on grade (on ground), use the U values found in 1st row of table 5-9 (i.e use depth = 1.2m)

القيم التي لا تليها في الجدول 5-9 هي لـ أرضيات فوق الأرض

Floor



## \* Infiltration

- The last subtopic in the heating load topic is "infiltration".
- @ the beginning of the course, we discussed what does HVAC mean  
↳ Stands for ventilation
- Ventilation is defined as: Introducing fresh air into a space in order to improve indoor air quality
- We learnt how to determine the minimum ventilation requirement for a certain space, which was based on the number of persons + the area of the space
- Ventilation is desirable (wanted) + it can be controlled. On the other hand, infiltration is undesirable and it can't be controlled!

infiltration: تسرب نحو الداخل

exfiltration: تسرب نحو الخارج

- Infiltration is defined as the leakage of outside air through cracks or clearances around the windows and doors and due to door opening and closing
- The "total" heat loss (in winter) or the "total" heat gain (in summer) due to infiltration is given by:

$$\dot{Q}_{f,tot} = \dot{Q}_{f,sensible} + \dot{Q}_{f,latent} = \dot{m}_f (h_{inside} - h_{outside})$$

- The mass flow rate of the infiltrated air  $\dot{m}_f = \frac{\dot{V}_f}{v_{f, outside air}}$   $\dot{V}_f$   $\rightarrow$  Volumetric Flow rate  
 $v_{f, outside air}$   $\rightarrow$  specific volume

- The amount of the infiltrated air depends on:
  - [1] The wind speed
  - [2] pressure difference between inside and outside  $\Delta P$  (As  $\Delta P \uparrow$ , more infiltrated air will enter the space)
  - [3] Length of crack
  - [4] Height of the building (Floors at higher elevations are exposed to more infiltration)
  - [5] Whether the building is protected with its surroundings or unprotected

- "Air tightness" of windows with PVC frames are better.
- Air tightness (مقاومة التسرب): a building property, which measures the resistance to inward and outward air leakage through unintentional leakage points in the building envelope.



- High thermal insulation + High air tightness of the building envelope will reduce the heating load of the building significantly.

- Two methods are used to calculate the volumetric flow rate of the infiltrated air

[1] Air Change method (ACH): this method is accredited by ASHRAE and used in engineering offices in Jordan

[2] The crackage length method: this method is based on calculating the crackage length as well as the pressure difference between inside and outside. Method [1] is simpler and easier than method [2]. We will discuss both methods, but we will use the 1st method

[\*] The crackage length method:

In this method, the volume flow rate of the infiltrated air is given by:

$$\dot{V}_g = K L_c (\Delta P)^{2/3}$$

Where,

① K is the infiltration air flow coefficient which depends on the window or door clearance + the type of the window or door. The values of K is found in Table 6-3. To use this table, you have to determine:

[1] The window or door type

- Sliding type
  - a) Iron
  - b) Aluminum
- hing type
  - a) Iron
  - b) Aluminum (side pivoted)
  - c) Aluminum (horizontal pivoted)
  - d) PVC

[2] The accuracy of the dimensions of the window or the door

- If the dimensions of the window or the door are very accurate [i.e. it accurately fits its frame "low tolerance"]  $\Rightarrow$  use the "Minimum" values of K

- If the dimensions of the window or the door are inaccurate [i.e. it doesn't accurately fit its frame "high tolerance"]  $\Rightarrow$  Use the "Maximum" values of K

②  $L_c$  is the total crack length of windows or doors in the units of meters

③  $\Delta P$  is the pressure difference between inside and outside air in units of Pa. It is calculated using the following equation:

$$\Delta P = 0.613 (S_1 S_2 V_w)^2$$

where,

$S_1$  is a factor that depends on the topography (تضاريس) of the location of the building. Its value is obtained from table 6-4

$S_2$  is a factor that depends on the height of the building and the type of the surroundings that surround the building. Its value is ...



Obtained from Table 6-5. To determine the value of  $S_2$ , you have to know

[1] The height of the building

[2] The class of the location (1, 2, 3, 4) as well as its category (A, B, C)

\* Check page 220 to recognize the meaning of each class and each category

- The crackage length method yields better accuracy than that of the air change method, but it is time consuming. You have to follow the previous procedure for each window or each door found in the room.

[\*] The air change method.

- This method assumes that the air volume in a space is replaced by outside air at a certain number of times per hour

- Air changes per hour (N) is defined as: the number of complete changes of space air changes that occur each hour

- The volume flow rate of the infiltrated air is given by

$$\dot{V}_g = N * V_{room}$$

where,

① N is the number of air changes per hour. Its value is obtained from table 6-1. The value of N depends on the type of the space and the activity of occupants inside the space

②  $V_{room}$  is the volume of the room

- This method is less accurate but it requires less effort

- During the course use Table 6-1 to find the value of N. In engineering offices in Jordan, however, use  $N=0.5$  (in Summer)

$N=1$  (in winter)  $\rightarrow$  حالة القارة في الصيف  
حالة الرياح في الشتاء

- For rooms with weather stripped windows or storm sash use 2/3 of the values of N found in table 6-1



Weather stripping  
window: used to improve  
the sealing of the window



Storm sash: a window outside an ordinary  
window to protect against severe weather  
conditions



- Blower door test device: It is a device that measures the volumetric flow rate of the infiltrated air. It is a portable device. When this test is performed for a certain room, the windows of the room are closed, while the device is installed on the door of the room. The device is adjustable, i.e. you can change its dimensions such that it fits the door. A blower exists in this device, which draws the air from inside the room (It forms a vacuum inside the room). Due to the pressure difference between inside and outside, the leakage of outside air through the cracks will occur.

فرق الضغط هو الذي يجلب الهواء من الخارج إلى الداخل

- The amount of the infiltrated air entering the room can be calculated, given the speed of the blower and the pressure difference between inside and outside, then we can find the N value for this room. Using this device, Table 6 is constructed.

- Calculate the infiltration load for a classroom

-  $\dot{V}_p = N * V_{room}$ ;  $N = 1 / \text{hr}$  (room with windows or exterior doors on one side only)

$$V_{room} = 10 * 12 * 3 = 360 \text{ m}^3$$

$$\dot{V}_p = 1 * 360 = 360 \frac{\text{m}^3}{\text{hr}} \quad \text{"Don't forget to divide by 3600 to convert the unit from m}^3/\text{hr} \rightarrow \text{m}^3/\text{s}"$$

$$= 0.1 \text{ m}^3/\text{s}$$

- Assuming outside design conditions  $T = 0^\circ\text{C}$ ,  $\phi = 50\% \Rightarrow \rho_{\text{outside air}} = 0.775 \text{ kg/m}^3$

$$\dot{m}_p = \frac{\dot{V}_p}{\rho_{\text{outside}}} = \frac{0.1}{0.775} = 0.129 \text{ kg/s}$$

$$\dot{Q}_{p, \text{sensible}} = \dot{m}_p C_{p, \text{air}} (T_{\text{inside}} - T_{\text{outside}}) = 0.129 \frac{\text{kg}}{\text{s}} * 1 \frac{\text{kJ}}{\text{K} \cdot \text{kg}} (22 - 0) \text{ K}$$

$$= 2.86 \text{ kW}$$

Note:

$$\dot{Q}_{p, \text{tot}} = \dot{m}_p (h_{\text{inside}} - h_{\text{outside}}) \quad \text{while} \quad \dot{Q}_{p, \text{sensible}} = \dot{m}_p C_p (T_{\text{inside}} - T_{\text{outside}})$$

- In winter, when you calculate the heating load, you have to calculate  $\dot{Q}_{p, \text{sensible}}$  only not  $\dot{Q}_{p, \text{tot}}$ , because the heating devices (such as radiators) cannot treat the latent heating load  $\dot{Q}_{p, \text{latent}}$ . They can only treat the sensible heating load  $\dot{Q}_{p, \text{sensible}}$ , since they don't involve humidification.

- On the other hand, split units are cooling + dehumidification devices.  $\rightarrow$



Hence, in Summer, when you calculate the cooling load, you have to calculate

$$\dot{Q}_{f, \text{tot}} [\dot{Q}_{f, \text{tot}} = \dot{Q}_{f, \text{sensible}} + \dot{Q}_{f, \text{latent}}]$$

- To reduce  $\dot{Q}_f$ , use weather stripped windows or storm sash

### [\*] Heating systems

- Designing a heating system involves 2 steps

Step #1: Calculating the heating load, which is achieved as follows:

- Determine the inside and outside design conditions [your design is based on the inside and outside design conditions, hence, determining them must be the first step]
- Calculate the U values of the components of the building envelope, such as: Floors, exterior walls, interior walls, ceilings, doors, windows, etc.
- Calculate the heat loss that occurs through the building envelope components

$$\dot{Q}_{\text{loss}} = U C_p \Delta T$$

- Calculate the infiltration load. To calculate the infiltration load  $\dot{Q}_f$  for a certain room:

→ Multiply the area of the floor by the height of the room to find its volume  $V_{\text{room}}$

→ Multiply  $V_{\text{room}}$  by the N value (found in Table 6-1) and divide by 3600 in order to convert the unit from  $\text{m}^3/\text{hr}$  to  $\text{m}^3/\text{s}$  (i.e. in this step,

we calculate the volumetric flow rate of the infiltrated air  $\dot{V}_p$ )

→ Divide  $\dot{V}_p$  by the specific volume of outside air, in order to find  $\dot{m}_p$ .

→ Multiply  $\dot{m}_p$  by  $C_p \Delta T$  to get  $\dot{Q}_f$ . [ $\dot{Q}_f = \dot{m}_p C_p (T_{\text{inside}} - T_{\text{outside}})$ ]

- The total heating load  $\dot{Q}_{\text{tot}} = \dot{Q}_{\text{loss}} + \dot{Q}_f$

→ This represents the total heat loss from the space.

If we didn't provide the space with this amount of heat, the temperature of the space will drop below the inside design temperature.

- Calculating the total heating load of a building can be carried out using room by room analysis

Step #2: Selecting the suitable heating system, which has a heating capacity  $\geq$  total heating load. Following are types of heating systems:

→ Central heating (تدفئة مركزية)

→ Reversible heat pumps (مضخات الحرارة العكسية)

→ Under Floor

→ Gas heater (مدفئة الغاز) - مشع على شكل أنفثة الساكنة

→ Hot water heating system (Radiators + boiler)



• We will consider the most famous heating system used in public and residential buildings: "hot water heating system"

• Hot water heating system includes several components. The component which exists inside the space is the radiator.

• Radiators represent the "delivery system" [Any heating system involves a delivery system, which delivers the required heat to the space to be heated]

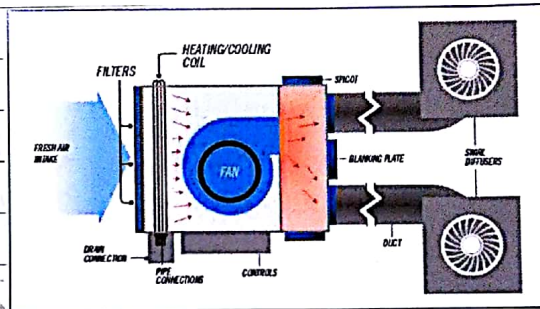
• Examples of delivery systems:

→ Radiators

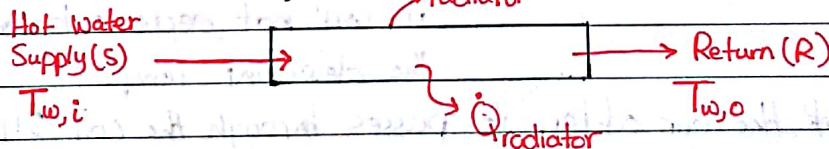
→ Central air handling unit

→ Fan coil unit. It is a device that uses a coil and a fan to heat or to cool a room. The air moves over the coil, which heats or cools the air, then it is pushed into the room by the fan. The fan increases the rate of heat transfer (it increases the convective coefficient of heat transfer "h")

Fan coil unit



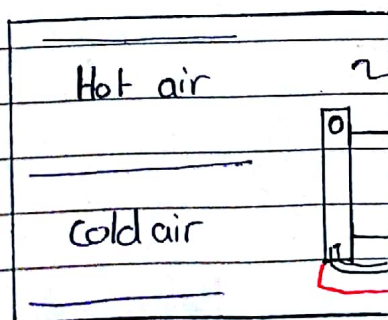
• Radiators are heat exchangers.



- Heat exchange occurs between the water inside the radiator and the air inside the space.

-  $\dot{Q}_{\text{radiator}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}}$  [heat transfer occurs mainly by convection. Radiation also takes place. Conduction may occur if somebody touches the radiator "direct contact"  $\dot{Q}_{\text{cond}} \approx 5\%$ ]

2D view of a room



ظاهرة تسمى الطبقاتية أو الاستراتيفيكاسيون

→ This phenomenon is called stratification (طبقاتية أو استراتيفيكاسيون)

- When the cold air touches the radiator, it becomes hot + its density decreases, hence, it moves upward. (Natural convection occurs)

→ side view of a radiator



- Stratification means: the formation of layers. In our case, the hot air layer is formed above the cold air layer
  - The rate of heat transfer from the radiator  $\dot{Q}_R = U A_R (T_{\text{radiator}} - T_{\text{room}})$
- Where,
- $U$  is the  $u$  value of the radiator
  - $A_R$  is the surface area of the radiator [the contact area between the radiator and the air]
  - $T_{\text{radiator}} = \frac{T_{w,i} + T_{w,o}}{2}$ ,  $T_{w,i}$  = inlet water temperature  
 $T_{w,o}$  = Outlet water temperature

Note:

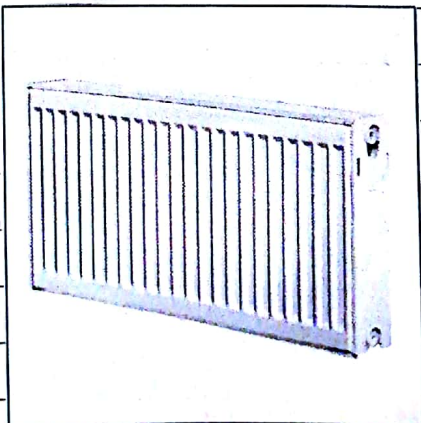
- $U$  value of the radiator must be high in order to increase the rate of heat transfer
- $U$  value of the exterior walls must be minimized in order to prevent the heat loss (in winter).
- We can conclude that some applications require high  $U$  value, while other applications do not.
- Understanding the concept of  $U$  value enables you to select the suitable material for your application

- Since radiators must have high  $U$  value, following are some materials that have high thermal conductivity

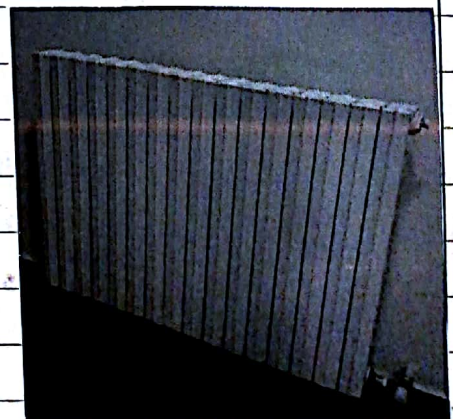
- |                                                                                                                                                                                                                                                                  |                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| <ol style="list-style-type: none"> <li>1] Copper (very expensive)</li> <li>2] Aluminium (Also expensive. However, it is used in some applications)</li> <li>3] Cast iron (relatively expensive + Its weight is heavy)</li> <li>4] Sheet metal (cheap)</li> </ol> | <p>cost decreases</p> <p>↓</p> |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|

Commonly used types of radiators

pressed sheet metal (light weight)



Cast iron (heavy weight)





- Before you use the catalogue, you have to know the following pieces of information:

[1] The heating load of the room

[2]  $T_{room}$  (room temperature)

[3]  $\Delta T_{water} = T_{supply} - T_{return}$  or  $\Delta T = T_{radiator} - T_{room}$

- Notes:

→ Typical values for  $T_{supply}$ ,  $T_{return}$ :  $T_s = 85^\circ\text{C}$ ,  $T_R = 75^\circ\text{C}$   
 $T_s = 80^\circ\text{C}$ ,  $T_R = 70^\circ\text{C}$

→ In Jordan, hot water heating system design is based on  $\Delta T_{water} = 10^\circ\text{C}$ . However, in Europe, the design is based on  $\Delta T_{water} = 15^\circ\text{C} - 20^\circ\text{C}$ .

→ If  $T_s$ ,  $T_R$  are known, we can find  $T_{radiator}$

eg:  $T_s = 80^\circ\text{C}$ ,  $T_R = 70^\circ\text{C} \Rightarrow T_{radiator} = \frac{T_s + T_R}{2} = 75^\circ\text{C}$

If  $T_{room} = 20^\circ\text{C} \Rightarrow \Delta T = T_{radiator} - T_{room} = 55^\circ\text{C}$

→ If your design was based on  $T_s = 80^\circ\text{C}$ ,  $T_R = 70^\circ\text{C}$ . How can you ensure that  $T_s = 80^\circ\text{C}$ ,  $T_R = 70^\circ\text{C}$  in reality?

•  $T_{supply} = 80^\circ\text{C}$  is fixed. We cannot control it. It represents the temperature of the hot water delivered from the boiler

\*  $T_{supply} \leftarrow$  البوتر هو الذي يتحكم فيها كما يتحكم فيها

•  $T_{return}$  is controlled by controlling the mass flow rate of the flowing water.

$m_{water} = \frac{\text{mass of flowing water}}{\text{time}}$  (assume this value is fixed)

If the flowing water passes through the radiator quickly (i.e.  $\text{time} \downarrow \Rightarrow m_{water} \uparrow$ )  
the temperature of the hot water will drop slightly (i.e.  $T_{return}$  will be close to  $T_{supply}$ )  
 $\Delta T_{water} \downarrow$  if  $m_{w} \uparrow$

If the flowing water passes through the radiator slowly (i.e.  $\text{time} \uparrow \Rightarrow m_{water} \downarrow$ )  
the temperature of the hot water will drop more ( $\Delta T_{water} \uparrow$  if  $m_{water} \downarrow$ )



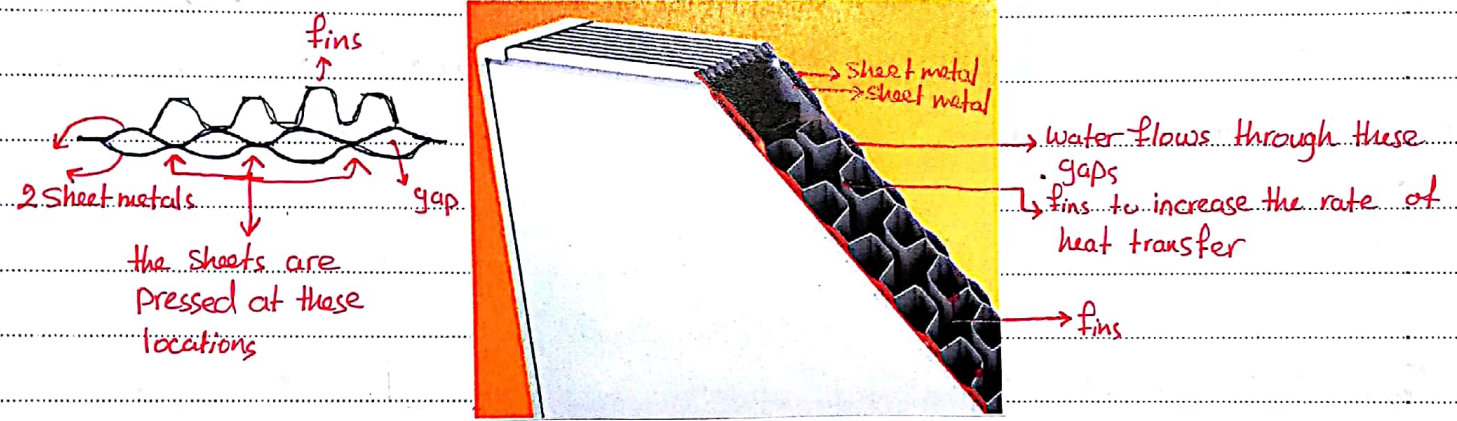
→ Radiators are placed in the rooms at locations where thermal loss + infiltration are high. This is why radiators are "often" placed under windows.

هذه الأماكن تكون فيها الخسائر الحرارية + التسرب عالية. لهذا يتم وضع المشع تحت النوافذ.

المكان يكون فيه فقدان الحرارة + التسرب عالي.

لذلك يتم وضع المشع في هذه الأماكن.

- The following figure shows a sectional view of a pressed sheet metal radiator.



- Figure (a) shows how hot water flows through the pressed sheet metal radiator
- Figure (b) shows different configurations of pressed sheet metal radiator

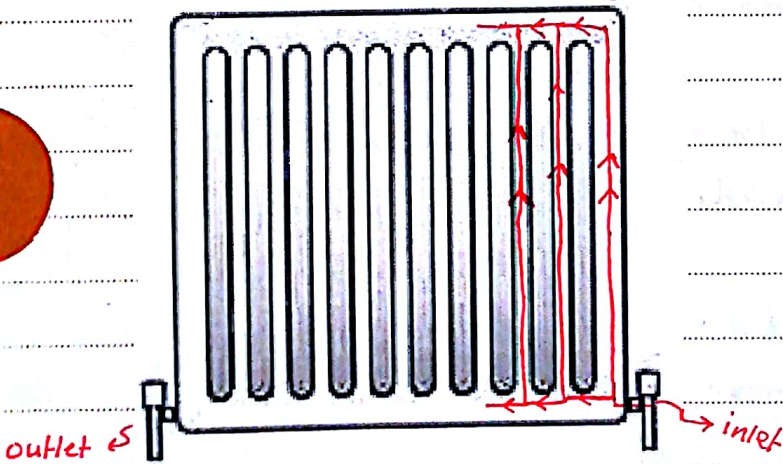


Figure (a)

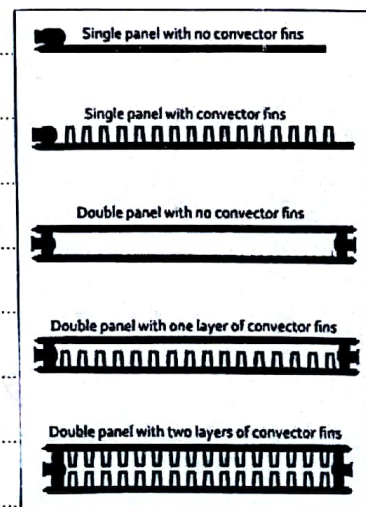


Figure (b)



- The table shown below represents a catalogue of pressed sheet metal radiator
- $90-70^{\circ}\text{C}$  are  $T_s$  and  $T_R \Rightarrow \text{Radiator} = 80^{\circ}\text{C}$
- $10^{\circ}\text{C}, 12^{\circ}\text{C}, 15^{\circ}\text{C}$  ... represent the room temperature  $T_{\text{room}}$
- Notice that, in order to use the catalogue, you have to know  $T_s, T_R, T_{\text{room}}$
- Notice that, as  $T_{\text{room}}$  decreases,  $\Delta T = T_{\text{room}} - T_{\text{radiator}}$  increases, hence, the heat output increases.
- The heat output is given in Watts and kcal/hr

Check Appendix B in your book (Page 522), to obtain the following relation:

$$1 \text{ Cal} = 4.1868 \text{ J}$$

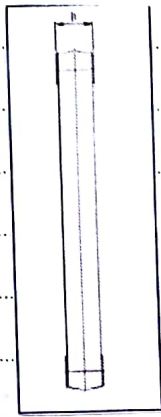
$$1 \text{ kcal} = 4186.8 \text{ J} \Rightarrow \frac{1 \text{ kcal}}{\text{hr}} = \frac{4186.8 \text{ J}}{3600 \text{ s}} \Rightarrow \frac{1 \text{ kcal}}{\text{hr}} = 1.16 \text{ J/s} = 1.16 \text{ Watt}$$

- This table can be used for  $T_s = 85^{\circ}\text{C}, T_R = 75^{\circ}\text{C}$  since for these temperatures  $\text{Radiator} = 80^{\circ}\text{C} \Rightarrow$  وهي نفسها درجة حرارة الرادياتر التي أشرت عليها البيانات في الجدول

| TECHNICAL PROPERTIES (HEAT CAPACITY 90-70°C) Room Temperature |        |      |        |      |        |      |        |      |        |      |        |      |        |      |        |      |        |
|---------------------------------------------------------------|--------|------|--------|------|--------|------|--------|------|--------|------|--------|------|--------|------|--------|------|--------|
| Type                                                          | Height | 10°C |        | 12°C |        | 15°C |        | 18°C |        | 20°C |        | 22°C |        | 24°C |        | 26°C |        |
|                                                               | mm     | watt | kcal/h | watt | kcal/h | watt | kcal/h | watt | kcal/h | watt | kcal/h | watt | kcal/h | watt | kcal/h | watt | kcal/h |
| 10-P                                                          | 400    | 712  | 612    | 685  | 589    | 647  | 556    | 609  | 524    | 585  | 503    | 561  | 482    | 535  | 460    | 510  | 439    |
|                                                               | 500    | 896  | 771    | 851  | 741    | 813  | 700    | 768  | 661    | 737  | 634    | 703  | 605    | 672  | 578    | 640  | 551    |
|                                                               | 600    | 1035 | 891    | 998  | 858    | 942  | 810    | 887  | 763    | 850  | 731    | 814  | 700    | 777  | 668    | 741  | 627    |
|                                                               | 900    | 1507 | 1296   | 1452 | 1249   | 1370 | 1178   | 1289 | 1109   | 1235 | 1062   | 1183 | 1017   | 1129 | 971    | 1076 | 925    |
| 11-PK                                                         | 400    | 1197 | 1025   | 1167 | 956    | 1079 | 928    | 1012 | 870    | 968  | 832    | 925  | 796    | 880  | 757    | 837  | 720    |
|                                                               | 500    | 1394 | 1200   | 1341 | 1154   | 1262 | 1086   | 1183 | 1018   | 1133 | 975    | 1082 | 931    | 1030 | 886    | 980  | 843    |
|                                                               | 600    | 1633 | 1404   | 1571 | 1351   | 1478 | 1271   | 1386 | 1192   | 1326 | 1140   | 1268 | 1090   | 1206 | 1037   | 1148 | 987    |
|                                                               | 900    | 2288 | 1968   | 2201 | 1893   | 2071 | 1781   | 1943 | 1671   | 1859 | 1599   | 1776 | 1527   | 1691 | 1454   | 1609 | 1384   |
| 21-PKP                                                        | 400    | 1641 | 1411   | 1578 | 1357   | 1484 | 1276   | 1392 | 1197   | 1332 | 1145   | 1271 | 1083   | 1211 | 1041   | 1151 | 990    |
|                                                               | 500    | 2110 | 1816   | 2031 | 1748   | 1915 | 1648   | 1800 | 1549   | 1724 | 1484   | 1650 | 1420   | 1571 | 1352   | 1497 | 1288   |
|                                                               | 600    | 2162 | 1859   | 2079 | 1788   | 1956 | 1682   | 1835 | 1578   | 1756 | 1510   | 1676 | 1441   | 1597 | 1373   | 1519 | 1305   |
|                                                               | 900    | 2912 | 2504   | 2801 | 2409   | 2637 | 2258   | 2476 | 2129   | 2368 | 2035   | 2261 | 1944   | 2156 | 1854   | 2050 | 1763   |
| 22-PKPK                                                       | 400    | 2298 | 1975   | 2211 | 1901   | 2083 | 1791   | 1956 | 1682   | 1873 | 1611   | 1790 | 1539   | 1705 | 1466   | 1623 | 1396   |
|                                                               | 500    | 2674 | 2301   | 2567 | 2209   | 2415 | 2078   | 2272 | 1955   | 2175 | 1872   | 2075 | 1787   | 1961 | 1705   | 1881 | 1619   |
|                                                               | 600    | 3227 | 2775   | 3103 | 2669   | 2920 | 2511   | 2740 | 2356   | 2521 | 2254   | 2504 | 2153   | 2384 | 2050   | 2267 | 1950   |
|                                                               | 900    | 4271 | 3573   | 4107 | 3532   | 3852 | 3321   | 3621 | 3114   | 3463 | 2978   | 3307 | 2844   | 3147 | 2706   | 2982 | 2573   |
| 33-PKPKPK                                                     | 400    | 3390 | 2915   | 3262 | 2805   | 3072 | 2642   | 2886 | 2482   | 2763 | 2376   | 2641 | 2271   | 2516 | 2164   | 2396 | 2061   |
|                                                               | 500    | 3993 | 3436   | 3839 | 3304   | 3515 | 3111   | 3394 | 2921   | 3215 | 2798   | 3107 | 2674   | 2998 | 2546   | 2818 | 2425   |
|                                                               | 600    | 4549 | 3912   | 4376 | 3763   | 4119 | 3542   | 3867 | 3326   | 3700 | 3182   | 3536 | 3041   | 3358 | 2896   | 3204 | 2755   |
|                                                               | 900    | 5563 | 4784   | 5349 | 4600   | 5031 | 4327   | 4718 | 4057   | 4512 | 3580   | 4310 | 3707   | 4101 | 3527   | 3898 | 3352   |



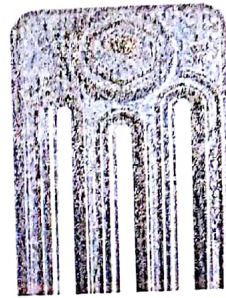
- Figure(a) shows the main component of cast iron radiators. This component is called section. Figure(b) shows side view of different sections. Each section consists of columns.



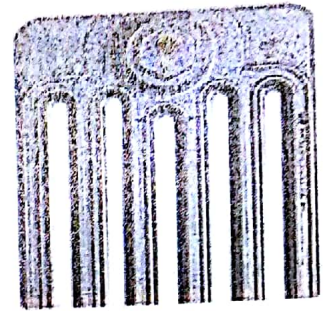
Figure(a): single section of Cast iron radiator.

If the heat output of single section = 100 Watt and the heating load of a room = 1700 Watt, 17 sections are required to heat the room.

4 Columns



6 Columns



Figure(b): columns of different sections. Hot water flows through these columns.

### - Notes:

→ The sections of cast iron radiators are joined manually, hence these jobs require skillful persons.   
 \* Cast iron ← sections ← pressed sheet metal ← بيجي لاجل دال دال

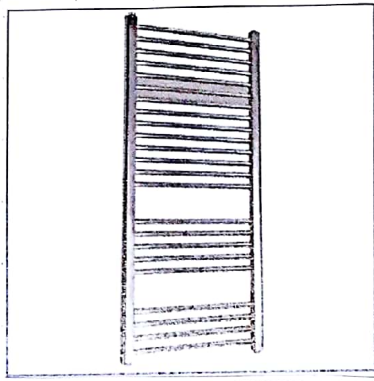
→ When you design a hot water heating system for a public building, all radiators must have the same height. However, the number of sections will vary from room to room, depending on the heating load of each room.

→ In addition to cast iron radiators, there exist ? : cast aluminum radiators which are more expensive. However, they are lighter + they transfer heat more effectively when compared to cast iron radiators. In addition, cast aluminum radiators don't rust, hence, they can be used in bathrooms.

سبائك الحديد ← Cast iron

→ For bathrooms, towel radiators can be used. They have small widths (50-60cm), hence they can be used for small bathrooms.





⇒ Towel radiator

- Check Table 7-5 in your book page 285, which gives specifications of Commercial Cast iron radiators based on mean temperature difference of  $60^{\circ}\text{C}$   
 $\Delta T = T_{\text{radiator}} - T_{\text{room}}$

• Notice that For:

\* Two water columns per section, height = 630mm ⇒ Output per section = 90.4 W

\* Three water columns per section, height = 630mm ⇒ Output per section = 124.9 W

∴ For the same height, as the number of water columns per section ↑, the Output per section ↑, because the surface area of the section gets larger as the number of columns per section is increased.

- The following table represents a catalogue of Pressed Sheet metal radiator

| APOLLO LUX         | H<br>mm. | I<br>mm. |                     | L mm.<br>ELEM.                           | 400<br>s    | 500<br>s     |
|--------------------|----------|----------|---------------------|------------------------------------------|-------------|--------------|
| <b>22 - DK</b><br> | 300      | 250      | EN 442<br>NBN - 236 | Watt $\Delta T$ 50<br>Watt $\Delta T$ 60 |             | -            |
|                    | 400      | 350      | EN 442<br>NBN - 236 | Watt $\Delta T$ 50<br>Watt $\Delta T$ 60 |             |              |
|                    | 500      | 450      | EN 442<br>NBN - 236 | Watt $\Delta T$ 50<br>Watt $\Delta T$ 60 | 636<br>916  | 794<br>1146  |
|                    | 600      | 550      | EN 442<br>NBN - 236 | Watt $\Delta T$ 50<br>Watt $\Delta T$ 60 | 641<br>1063 | 926<br>1329  |
|                    | 800      | 750      | EN 442<br>NBN - 236 | Watt $\Delta T$ 50<br>Watt $\Delta T$ 60 | 930<br>1367 | 1162<br>1708 |



• H represents the height of the radiator, L = 400mm, 500mm represents the length of the radiator, I represents the spacing of connectors (There are 2 connectors, one at the top and at the bottom. The distance between them is designated by I)

• These radiators were tested under different standards

EN = European Standards

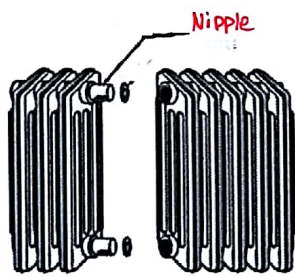
NBN: Belgian Standards



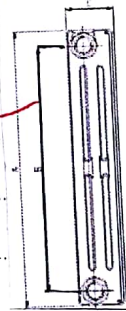
- The following table represents a catalogue of cast iron radiator

| Model | Columns | Height (A)<br>(mm) | Tapping Centers (B)<br>(mm) | Depth (C)<br>(mm) | Width (D)<br>(mm) | Nipple<br>(inch) | Heating Surface Area<br>(m <sup>2</sup> ) | Water Content<br>(lit) | Maximum Working Pressure<br>(bar) | Maximum Working Temperature (with Mantis)<br>(°C) | Maximum Working Temperature (with SA)<br>(°C) | Heat Output of Elements<br>(kW) |
|-------|---------|--------------------|-----------------------------|-------------------|-------------------|------------------|-------------------------------------------|------------------------|-----------------------------------|---------------------------------------------------|-----------------------------------------------|---------------------------------|
| 3/500 | 3       | 572                | 500                         | 98.2              | 60                | 1"               | 0.200                                     | 0.78                   | 7                                 | 110                                               | 130                                           | 101                             |
| 3/623 | 3       | 694                | 623                         | 98.2              | 60                | 1"               | 0.240                                     | 0.94                   | 7                                 | 110                                               | 130                                           | 120                             |
| 3/813 | 3       | 885                | 813                         | 98.2              | 60                | 1"               | 0.310                                     | 1.13                   | 7                                 | 110                                               | 130                                           | 149                             |
| 4/500 | 4       | 572                | 500                         | 134               | 60                | 1"               | 0.240                                     | 1.00                   | 7                                 | 110                                               | 130                                           | 126                             |
| 4/623 | 4       | 695                | 623                         | 134               | 60                | 1"               | 0.310                                     | 1.22                   | 7                                 | 110                                               | 130                                           | 153                             |
| 4/813 | 4       | 884                | 813                         | 134               | 60                | 1"               | 0.400                                     | 1.45                   | 7                                 | 110                                               | 130                                           | 187                             |

- For model 3/623 → represents tapping centers dimension  
 represents the number of columns per section
- Nipple: represents the length of the connection between 2 sections
- Water Content: represents the volume of water that can fill the radiator. It is measured in liters.



This dimension is called tapping centers.

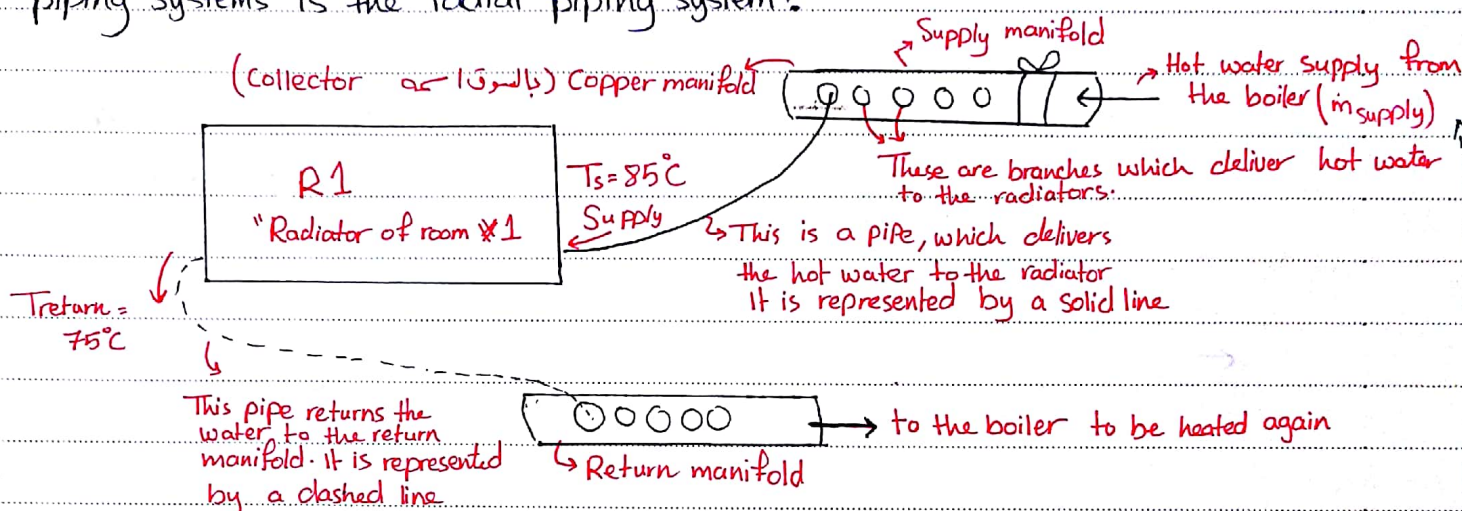


### - Notes

→ Each radiator has 2 regulating valve + air vent. The regulating valve on the outlet side is adjusted to "balance" the heating system. This value is adjusted only once before turning on the heating system for the first time. "Balancing" means adjusting the flow of water through the radiators, so they all heat up at the same rate. Adjusting this valve controls the "maximum" flow of hot water out of the radiator. The regulating valve on the inlet side also controls the flow of the hot water to control the temperature of the individual radiator or turn on/off the radiator.



→ Hot water heating system requires piping system. One of the most famous piping systems is the radial piping system:



• The above figure shows the radial piping system. If the total heating load for a house  $\dot{Q}_{tot} = 16.4 \text{ kW}$

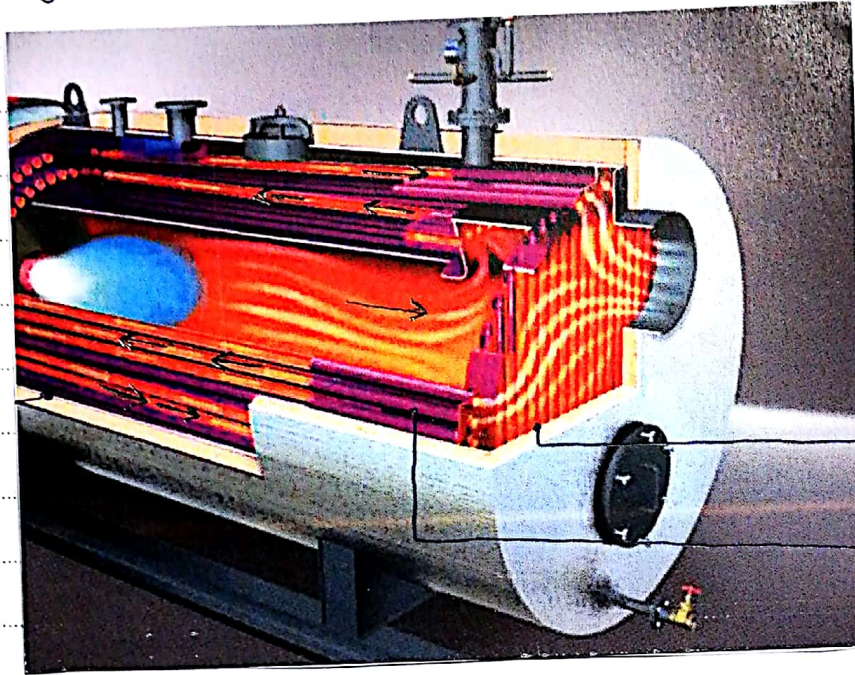
$$\dot{Q}_{tot} = \dot{m}_{supply} * C_{p, water} * \Delta T_{water}$$

$$16.4 = \dot{m}_{supply} * \frac{4.18 \text{ kJ}}{\text{kg} \cdot \text{K}} * 10 \text{ K} \Rightarrow \dot{m}_{supply} = 0.35 \text{ kg/s} = 0.35 \text{ L/s}$$

- The next step after we find  $\dot{m}_{water, supply}$  is to determine the diameter of the pipes + size the pumps used in the system.
- As we said before, radiators represent the delivery system, which delivers the required "heat" to the space to be heated. This delivery system must be connected to a heat generation system. Diesel boiler is an example of a heat generation system.
- A boiler is a closed vessel in which water is heated. A burner is connected to the boiler, which is a mechanical device that supplies the required amount of fuel and air and creates a good mixing between the air and the fuel in order to increase the combustion efficiency.



- The following figure shows a diesel boiler



2. This is a fire tube boiler

→ Shell

→ Tubes

- This boiler routes hot combustion gases through metal tubes. The tubes run through a shell filled with water. During operation, fuel and air enters the combustion area, the burning fuel transfers heat to the water in the shell. The hot gases flow through the tubes and hence, additional heat is transferred to the water surrounding them. Each time the hot gases are routed through the shell it's called a pass. The gases pass through 3 times in the above figure so it is called 3 pass boiler.

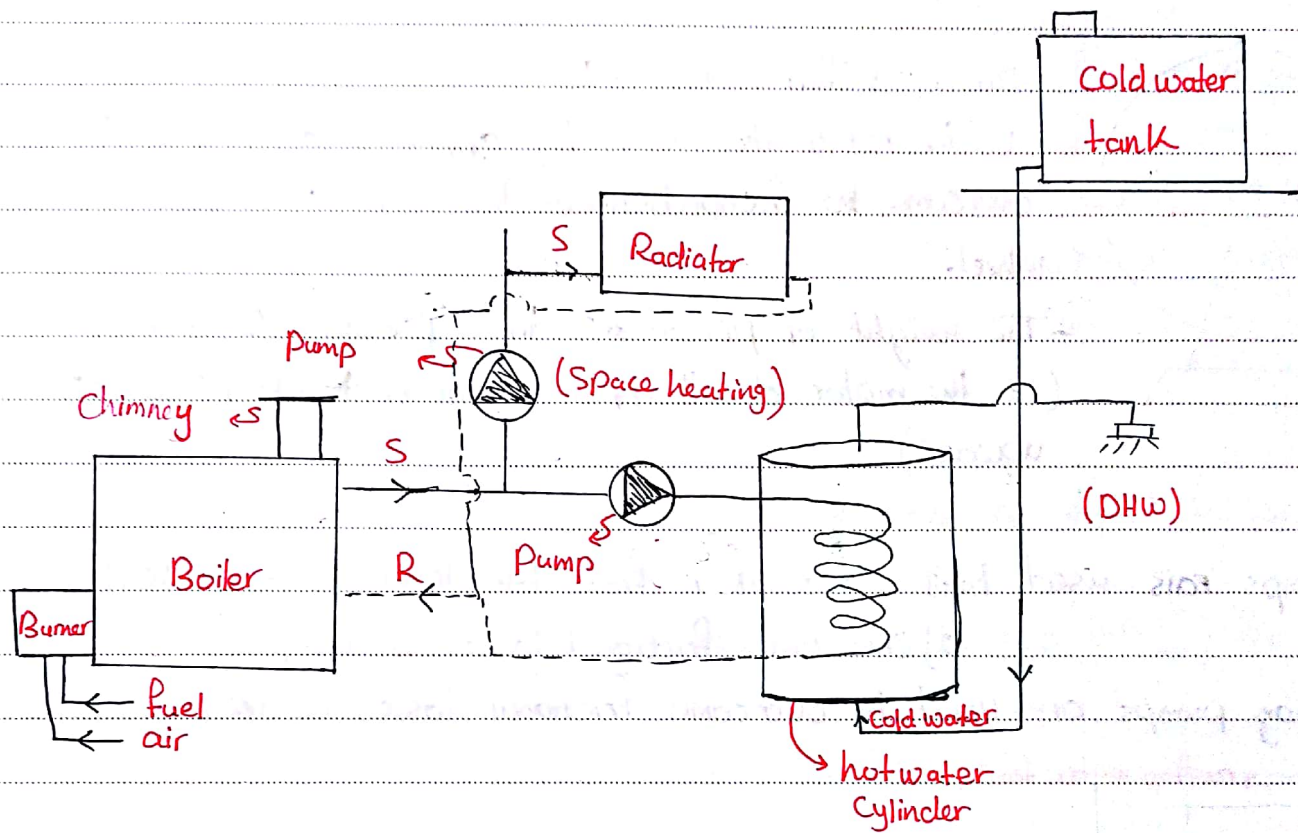
- A flue gas analyzer is installed on the chimney of the boiler to analyze the emissions of the hot gases (e.g.  $\text{CO}_x$ ,  $\text{NO}_x$ ,  $\text{CO}_2$ ,  $\text{CO}$ )

- If the  $\text{CO}$  percentage is high, this indicates that incomplete combustion occurs in the boiler. Hence, the burner must be calibrated to supply the required amount of  $\text{O}_2$ .

- With the passage of time, soot will be formed in the tubes, which acts as thermal resistance, thus  $\eta_{\text{boiler}} \downarrow$ . To reduce this effect, boilers must be cleaned as needed.



The following figure shows the configuration of space heating system + domestic hot water (DHW) system



Notice the following:

- The hot water used in sinks, showers, and baths are different from the hot water heated by the boiler.
- A pump is used to deliver the hot water to radiators.
- The pump symbol:  The direction of the arrow indicates the direction of the flow.
- Another pump is used for DHW.
- Sometimes, one pump is used for space heating + DHW instead of 2 pumps.

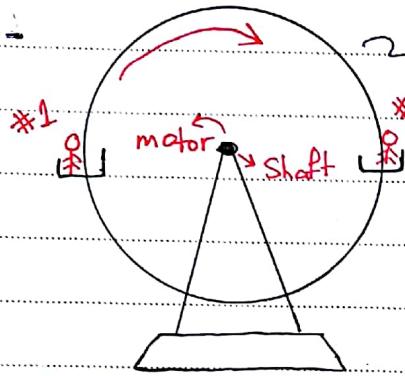


- The pumps used are called circulating pumps.



- There are 2 types of pumps
- lift pumps
  - circulating pump

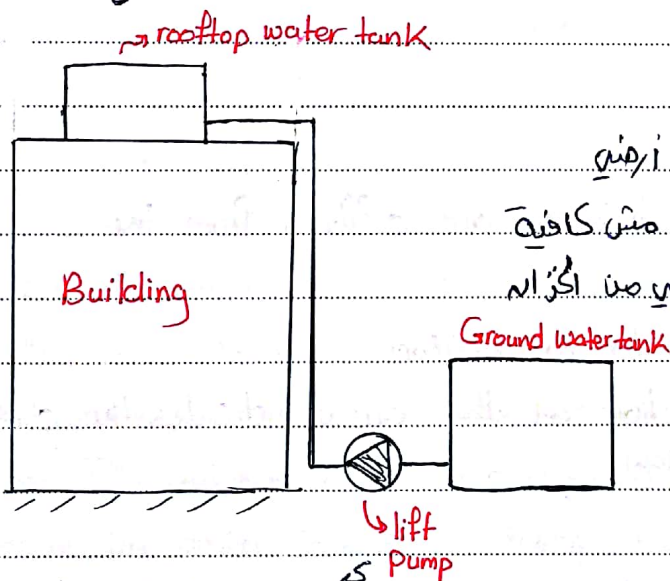
What is the difference between them?



→ This is a Ferris wheel. The function of the motor is to rotate the wheel by applying a moment to overcome the friction between the shaft and the wheel.

- The weight of person #2 lifts person #1 upward (i.e. the motor doesn't apply a moment to lift person #1 upward)

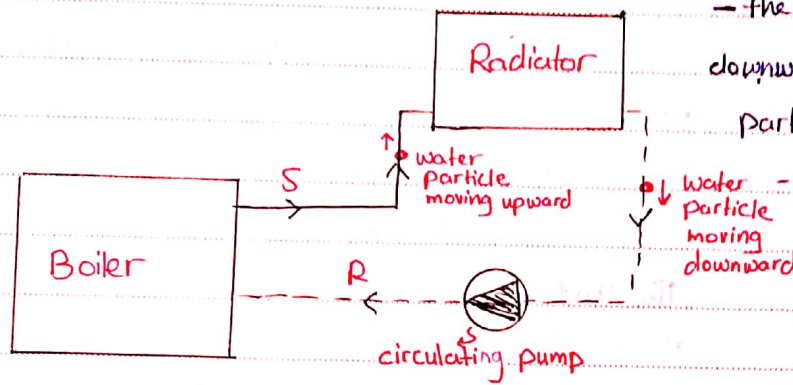
- lift pumps are used to:
  - 1] raise a fluid from low level to high level
  - 2] Overcome frictional losses in the pipes
- Circulating pumps are used to overcome frictional losses in the pipes only



\* مخطط المباني به بكونها خزانه ارضيه  
لانه المي الي يتيجي للخزان العلوي من كافيه  
المياه الي متزكيا عنها ترفع المي من الخزان  
السفلي للعلوي فلي  
lift pump

This pump raises the water from low level to high level + overcomes friction of pipes



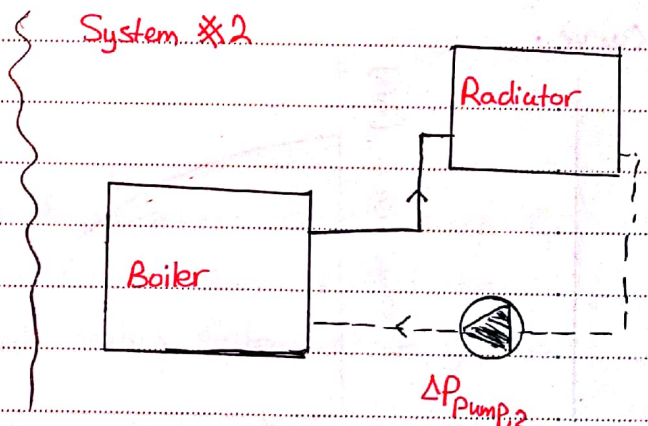
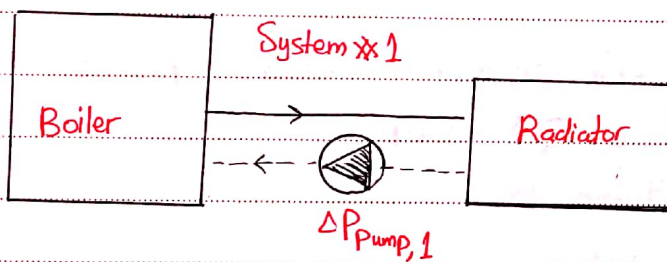


- The weight of a water particle moving downward lifts the weight of a water particle moving upward.

- Hence, the function of a circulating pump is to overcome friction of the piping system, since it circulates the water within a closed loop.

- Notes.

- The pressure rise caused by the circulating pump must be equal to (or slightly greater than) the pressure drop caused by frictional losses.
- For the same piping system length, the required pressure rise  $\Delta P_{\text{pump}}$  for the following 2 systems is the same.



In system #1, water flows horizontally, while it flows vertically in system #2. If both piping systems have the same length,  $\Delta P_{\text{pump},1} = \Delta P_{\text{pump},2}$ .

- Any pump has 2 parts  $\left\{ \begin{array}{l} \rightarrow \text{mechanical} \\ \rightarrow \text{electrical} \end{array} \right.$

- On the pump nameplate, you can find the following information: Voltage, frequency, maximum flow rate, IP number.

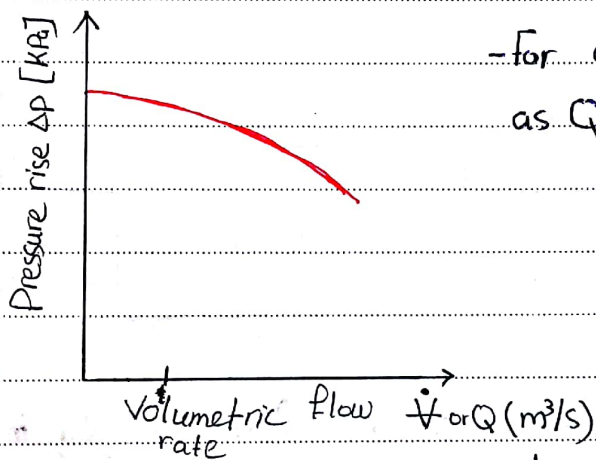
↳ IP number contains 2 numbers (e.g. IP44). It indicates the level of protection provided by the housing of the pump.



- Any pump should have 2 valves attached; one at the inlet and the other at the outlet. These 2 valves are closed when the pump requires maintenance or replacement, hence you don't need to drain the system in such these cases.

The valves are also used to change the flow rate of the flowing water.

- The performance of pumps can be shown graphically on a characteristic curve.

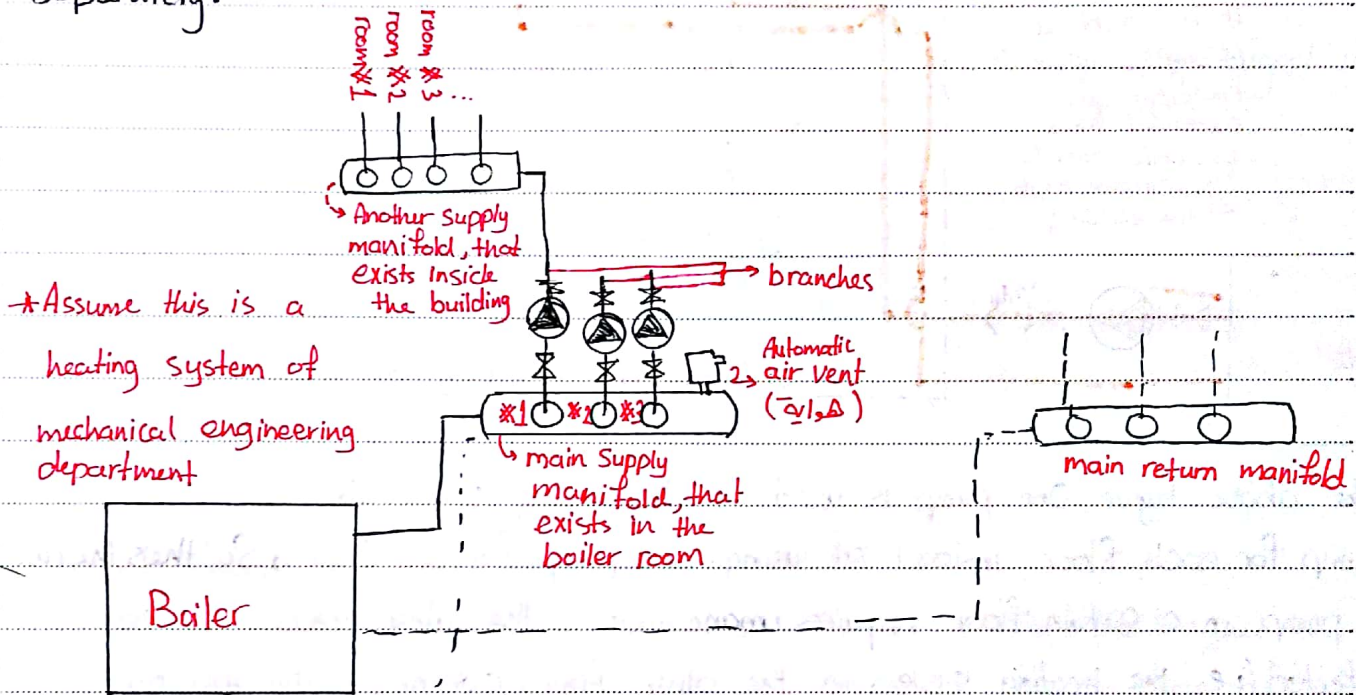


- For centrifugal circulating pumps,  
as  $Q \uparrow \Rightarrow \Delta P \downarrow$

- The main circulating pump is usually installed on the main return pipe, because it operates at lower temperature compared to the temperature of the main supply pipe.



- Sometimes, a main supply manifold is directly installed after the boiler in the boiler room as shown below. In this case, a circulating pump is used for each branch. This condition is called "Zoning", since the heating system breaks the building into different areas or "Zones", each controlled separately.

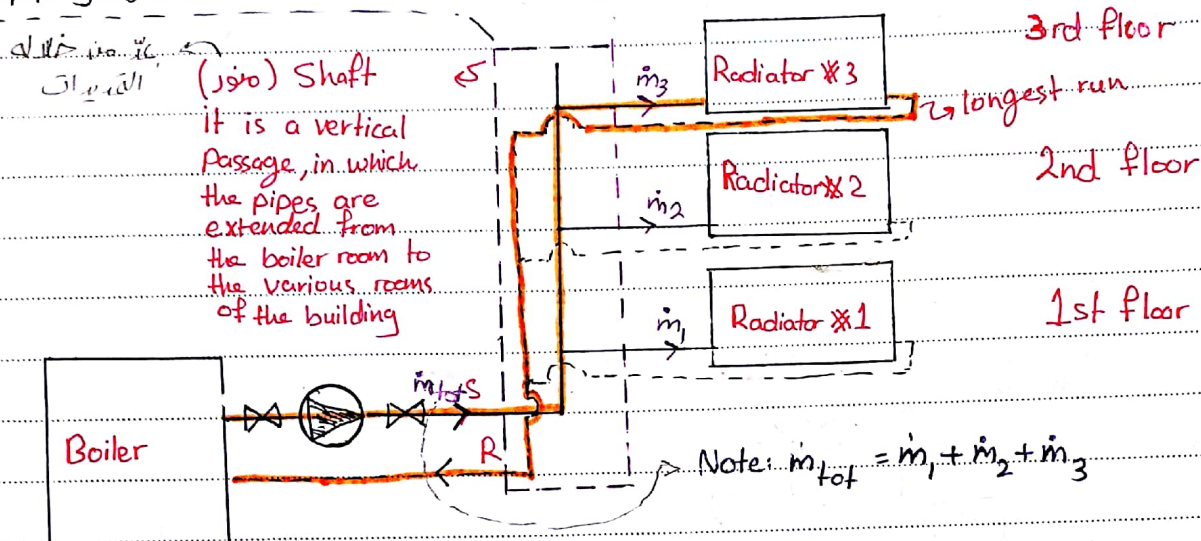


Branch \*1 will feed the supply manifold of professors' offices. Branch \*2 will feed the supply manifold of lecture rooms. Branch \*3 will feed the supply manifold of labs. Notice that "Zoned" heating systems allows you to control each zone or area separately.



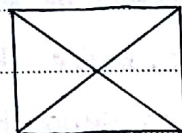
The following figure shows the piping of heating system in a building

→ This is called a riser diagram. It is a diagram (2-dimensional, in a vertical plane) which shows the piping system in the shaft of a building; displays floor by floor the supply and return pipes.



- In the above figure, one pump is used in the heating system. You can install one pump for each floor instead of using one pump for all floors. In that case, if the pump in a certain floor requires maintenance, the other floors will not be affected (i.e. the heating system in the other floors continues its operation)
- Sometimes, the amount of pressure rise required to be achieved by the pump is small, hence, it is not economically feasible to use a pump for each floor.
- The top view of the shaft looks like this

المشاهدة من أعلى



- The Friction of a piping system increases as the length of the pipes increases.
- If the pump is able to circulate the fluid through the longest pipe loop, it is able to circulate the fluid through the shorter pipe loops.
- The longest pipe loop is called longest run. It is designated by orange pipe in the above figure (The longest run passes through radiator #3).
- The shorter pipe loops are those which pass through radiators #1 and #2.
- To select the suitable pump; 2 pieces of information are required
  - 1] The pressure drop of the fluid flowing through the longest run
  - 2] The mass flow rate of the fluid passing through the pump



- In the previous figure,  $m_{tot}$  passes through the pump. Assuming that the total heating load of the building is  $\dot{Q}_{tot} = 92 \text{ kW}$ , then:

$$\therefore m_{tot} = \frac{\dot{Q}_{tot}}{c_p \Delta T} = \frac{92}{4.18 \times 10} = 2.2 \text{ kg/s}$$

- To find the total pressure drop of the fluid flowing through the longest run, you have to know:

[1] The amount of pressure drop per unit length. Assume  $\Delta P = 400 \text{ Pa/m}$  (later we will learn how to find this value)

[2] The total equivalent length of the longest run (EL). EL is given by

$$EL = S + R + \text{Fittings} + \text{boiler} + \text{radiator}$$

where,

- $S$  = the length of the supply pipe of the longest run
- $R$  = the length of the return pipe of the longest run
- Fittings = the equivalent length of the fittings found through the longest run.

[The equivalent length of a fitting is the length of straight pipe of a given diameter that would have the same pressure drop as that of the fitting of the same diameter. Later, we will discuss how to find it]

- boiler = the equivalent length of the boiler pipes
- radiator = the equivalent length of the radiator pipes

Assume that  $EL = 180 \text{ m}$

$$\therefore \text{The total pressure drop through the longest run} = \frac{400 \text{ Pa} \times 180 \text{ m}}{1 \text{ m}} = 72000 \text{ Pa} = 72 \text{ kPa}$$

- Note: Selection of pumps is always based on the pressure drop that occurs through the "longest run", because as we said before, if the pump is able to circulate the water through the longest run, it will be able to circulate the water through the shorter runs.

$$\therefore m_{tot} = 2.2 \text{ kg/s}$$

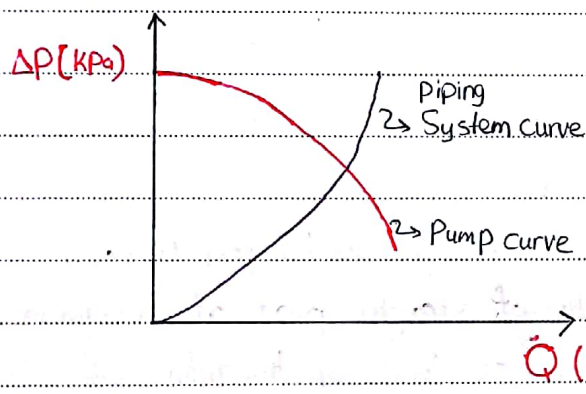
$$\Delta P_{drop} = 72 \text{ kPa}$$



- If you check a pump catalogue, you will find a family of pump curves as shown below. Each curve represents the performance curve of a type of pump manufactured by the manufacturer.

\* Note: the pump curves are shown in the next page

- Let's take a look at a single pump curve



- From the pump curve, as the flow rate of water increases, the ability of the pump to rise the pressure  $\Delta P$  decreases.

- From the piping system curve, as the flow rate of water increases, the pressure drop that occurs in the system  $\Delta P$  increases.

- The point of intersection between these 2 curves represents the operating point

because at this point, the pressure drop in the piping system = the pressure rise achieved by the pump.

- Sometimes, the pressure rise of a pump is given in units of m instead of kPa

Recall from Fluid mechanics:

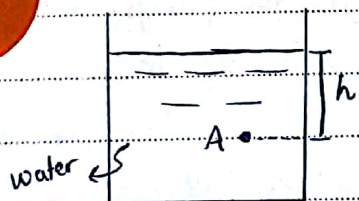
the static pressure at point A

$$P_A = \rho g h \quad (\text{gauge pressure})$$

$$\rho = \text{density of the fluid} = 1000 \text{ kg/m}^3 \quad (\text{for water})$$

$$g = 9.81 \text{ m/s}^2 \quad (\text{gravity acceleration})$$

$h$  = the height of fluid above the point being examined





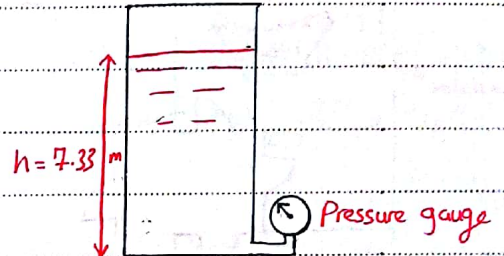
- In the previous pages, we calculated the pressure drop  $\Delta P_{\text{drop}} = 72 \text{ kPa}$ .

We can calculate the pressure drop in meters instead of kPa as follows:

$$P = \rho g h$$

$$72000 \text{ Pa} = 1000 * 9.81 * h \Rightarrow h = 7.33 \text{ m}$$

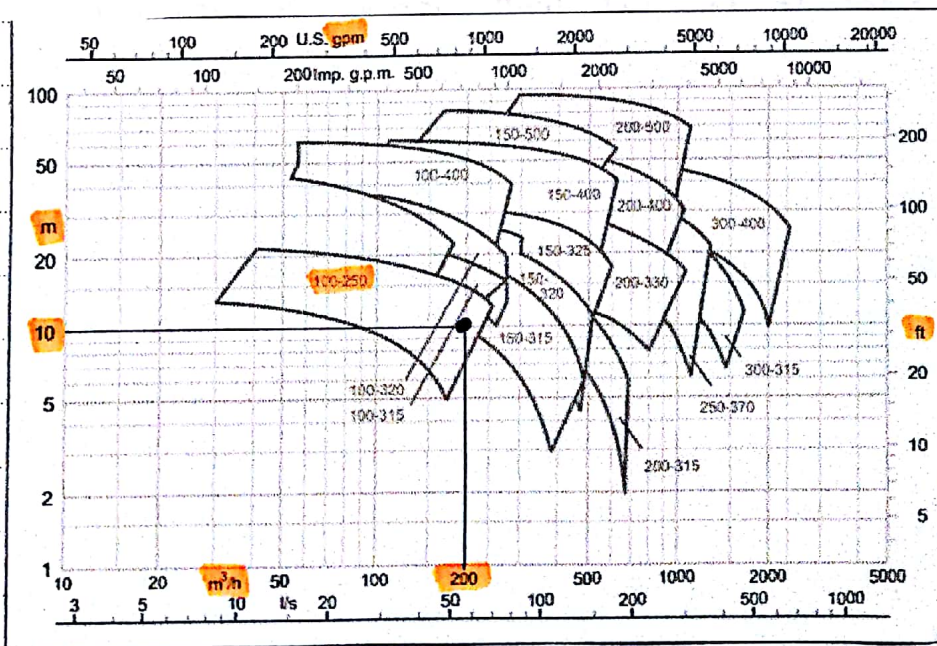
A column of water of 7.33 m will have a gauge pressure at the base of 72 kPa. Therefore, a 72 kPa system pressure drop = 7.33 meters of head.



### \* Pump Selection.

- When selecting pumps, the flow rate of the pump must match the flow rate required by the application or system.
- In addition, the pressure rise achieved by the pump must be equal to or more than the required pressure for the system at the desired flow rate.

### Example:



- This figure shows a family of pump curves.
- The pressure rise is given in units of m or ft.
- The flow rate is given in  $\text{m}^3/\text{h}$  or gpm (gallons per minute).
- If

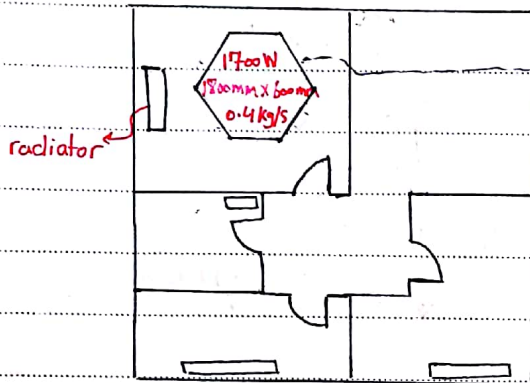
$$\Delta P_{\text{pump}} = 10 \text{ m}$$

$$Q = 200 \text{ m}^3/\text{hr}$$

Pump 100-250 is suitable for this application.



- Note: The following figure shows a plan for a floor in a building. When the location of the radiators are determined in the various rooms, a polygon must be drawn for each radiator, which contains some information about that radiator (The polygon is shown for one radiator only in the following figure)



- 1700 W represents the heat delivered by the radiator
- 1800 mm x 600 mm represents the dimensions of the radiator
- 0.4 kg/s (or 0.4 L/s) represents the flow rate of the hot water flowing through the radiator

## [\*] Components of heating systems:

- Many components can be found in heating systems such as: boiler, burner, chimney, piping system, Fittings, Fuel tank, radiators, hot water cylinders, circulating pump, Valves, etc.
- Two types of devices must exist in any mechanical system

[1] Controllers: e.g: temperature sensor. If the hot water reaches the required temperature, the sensor produces a signal to turn off the boiler. If the temperature of the hot water decreases, the sensor produces a signal to turn on the boiler.

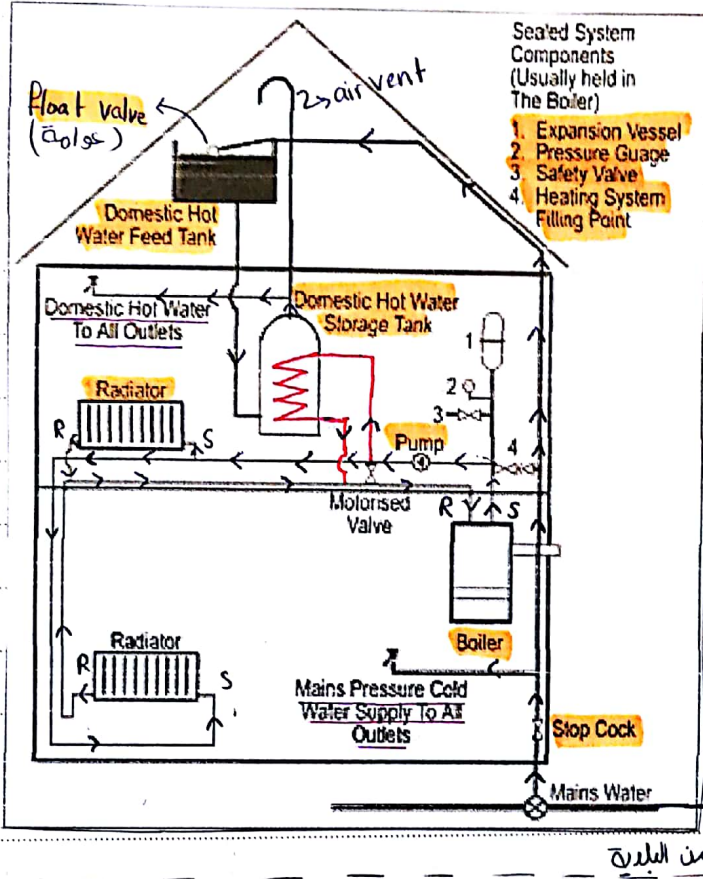
## [2] Safety devices: e.g:

- pressure relief valve: is a type of safety valve, used to control or limit the pressure in a system, otherwise, the pressure may increase, causing failure in the parts of the system. The pressure is relieved by allowing the pressurised fluid to flow from a passage out of the system. The relief valve is designed to open at a certain pressure to protect the system from being subjected to pressures that exceed their design limits.
- Fire extinguisher: it extinguishes fire resulting from boiler explosion
- If fire occurs, a sensor produces a signal to stop supplying the burner with fuel



- Safety measure devices such as pressure gauges.

- The following figure shows the components of heating system:



- The components shown in the figure: Boiler, Pump, a coil for heating the cold water, DHW storage tank, DHW feed tank (or cold water tank), radiators.
- Follow the arrows, to see how the system works. (You can start tracking the arrows from the supply side of the boiler).
- There is a component designated by 1, which is called expansion vessel. Notice that the hot water heating system forms a closed loop.

→ When the boiler is turned off, the water temperature inside the heating system =  $20-25^{\circ}\text{C}$ . When it is turned on, the water temperature will increase  $T = 60-70^{\circ}\text{C}$ . In addition, the water will expand. Since this system forms a closed loop, there is no volume for the hot water to expand. Therefore, the pressure inside the system will increase and explosion might occur if the pressure increases significantly. To maintain a constant pressure, every hydronic heating system needs expansion vessel, to contain the increase in the water volume as it expands as it heats up.

\* Note: hydronic system means: heating or cooling system in which heat is transported using circulating water.

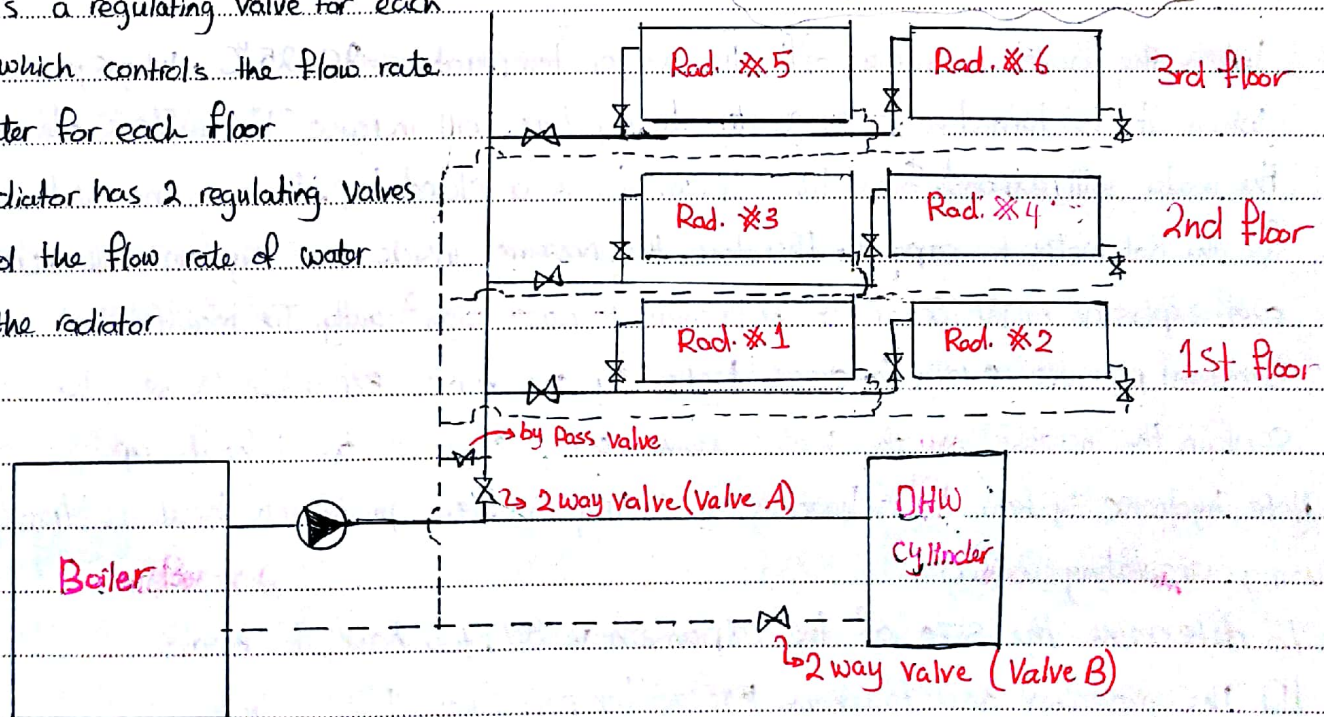
• To determine the size of the expansion vessel, you have to know:

- [1] The minimum and maximum water temperatures  $T_{\min}$ ,  $T_{\max}$ .
- [2] The expansion coefficient of water.



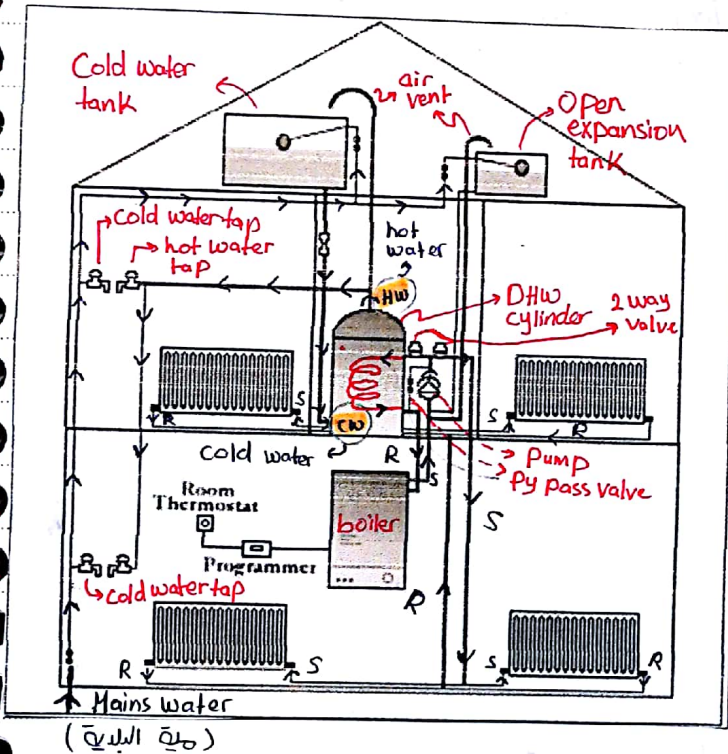
- The expansion coefficient describes the change in the volume of water per unit change in temperature. The size of expansion vessel = expansion coefficient multiplied by  $(T_{max} - T_{min})$ .
- The expansion vessel can be installed anywhere in the closed loop.
- Check the previous figure and detect the following valves:
  - ① Stop cock: it is a valve for turning on/off the main cold water supply.
  - ② Float valve: it is a valve for filling water tanks, while avoiding overflow.
  - ③ There is a valve designated by "4". It represents the heating system filling point (i.e. the heating system is filled with water for the first time before operation from this valve).
  - ④ There is a valve designated by "3". It represents a safety valve (or pressure relief valve). If the expansion vessel is undersized, or if the temp. of hot water increases beyond the supposed maximum temperature  $T_{max}$ , the pressure inside the system will increase, hence, a safety valve must exist for such emergency cases. Safety valves are designed to open at 3 bars for residential projects, 5-6 bars for larger projects.
- The following figure shows another heating systems.

- There is a regulating valve for each floor which controls the flow rate of water for each floor.
- Each radiator has 2 regulating valves to control the flow rate of water through the radiator.





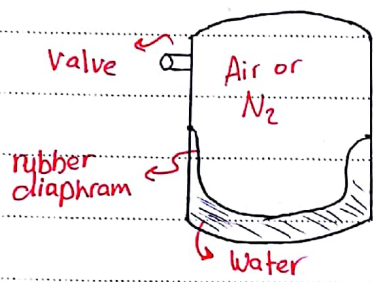
- The valve which connects the supply pipe with the return pipe is called by pass valve.
- There are two 2-way valves which control the flow rate of water used for space heating and DHW purposes.
- If you want to turn on the boiler for DHW only, you can close valve A and keep valve B open.
- The following figure shows another hot water heating system.



- In this system, there is no expansion vessel. Instead, there is an open expansion tank.
- When the hot water inside the system expands, the excessive volume of water flows towards the expansion tank. When the hot water cools down and contracts, the open expansion tank supplies the system with the required amount of water.
- If the temperature of the water reaches  $100^{\circ}\text{C}$ , boiling will occur, because this system is open to atmosphere.

- Hence, open expansion tanks are suitable for a hot water temperature range of  $70^{\circ}\text{C} - 90^{\circ}\text{C}$  (low temperature heating).
- Expansion vessel is used when higher water temperatures are required since the heating system forms a closed loop, and the pressure of the system might be greater than the atmospheric pressure, thus, the boiling point will be greater than  $100^{\circ}\text{C}$ , and higher water temperatures can be achieved.
- In general, both open expansion tank and expansion vessel are necessary to be installed to protect from damage caused by volume change due to temperature variation of hot water during the operation of the system.





→ This is a schematic diagram of an expansion vessel. Expansion vessels consist of a cylinder, which is divided into 2 compartments separated by a rubber sheet called diaphragm. Inside the vessel, there is water on one side and air or inert gas (such as  $N_2$ ) under pressure on the other side. An air valve similar to those

found on bicycle and car tyres is provided on the air side to allow the system to be repressurised. When the water in a closed loop system of pipes heats up, its pressure increases. Eventually, the pressure exceeds that of the air, causing the diaphragm in the expansion vessel to bend back into the air space, compressing the air and creating more room in the ~~sea~~ system to cope with the expanded water.

### \* Pipe system arrangements

The piping system of hot water heating system has several arrangements:

Single pipe system arrangement, double pipe system arrangement, radial plastic pipe system arrangement.

#### I Single pipe system arrangement

— In this arrangement, the hot water passes through all radiators in a serial manner, i.e. hot water exiting from one radiator enters the next radiator as shown in Figure (a), or water branches from the main supply into each radiator, but the water that exits from each radiator joins the main flow in the single supply pipe as shown in Figure (b).

— This arrangement is called "single pipe" because the supply pipe is the same as return pipe.

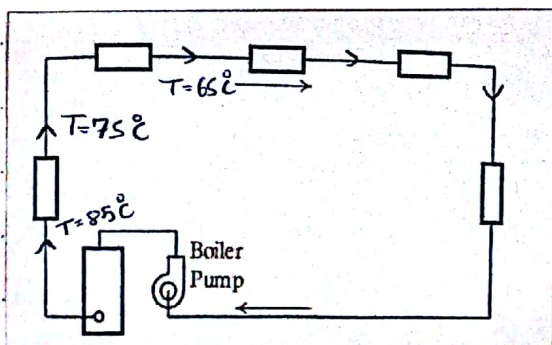


Figure (a)

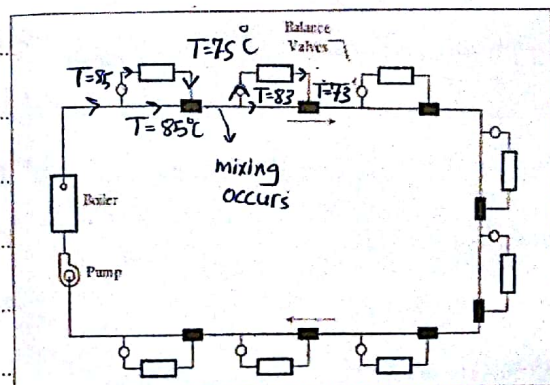


Figure (b)



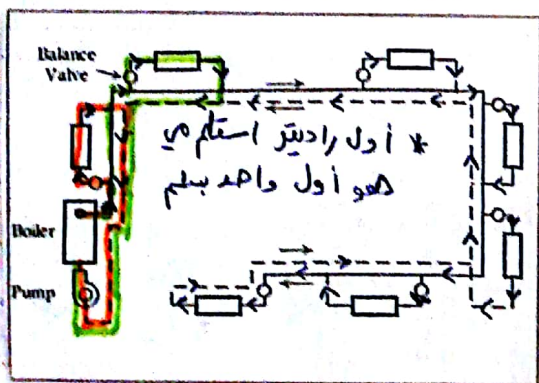
- Advantages of this arrangement: saving of pipe lengths and installation cost as compared to the cost of the other pipe arrangement.
- Disadvantages of this arrangement: the need to install radiators with relatively increased sizes as the distance of the radiator from the boiler increases; because the inlet temperature of the circulating water to any radiator decreases as a result of the heat dissipated in the previous radiators [i.e.  $Q_{\text{radiator}} = UA_R(T_{\text{radiator}} - T_{\text{room}})$ ], as the distance of the radiator from the boiler increases  $T_{\text{radiator}} \downarrow \Rightarrow Q_{\text{radiator}} \downarrow$   
 $\therefore$  the size of the radiator is increased  $A_{\text{radiator}} \uparrow$  to maintain the required  $Q_{\text{radiator}}$

## [2] Double pipe system arrangement:

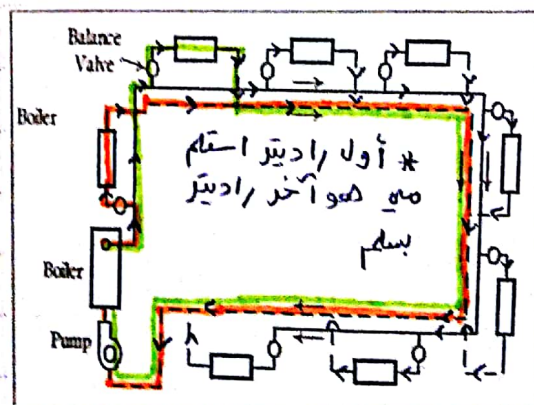
- This arrangement, is called "double pipe", because it consists of 2 separate supply pipe network, which is used to deliver hot water to each radiator, and return pipe network, which is used to collect the hot water leaving each radiator.
- Advantages of this arrangement: the temperature of water entering each radiator is nearly the same for all radiators. The small temperature differences at the inlet of each radiator are due to heat losses from the pipes connecting the radiators.
- Disadvantages: requires more pipe length than that of single pipe system.
- This arrangement has 2 types:

(a) Direct return pipe system

(b) Reversed return pipe system



The orange loop is the circuit of the 1st radiator, the green loop is the circuit of the 2nd radiator



The orange loop is the circuit of the 1st radiator, the green loop is the circuit of the 2nd radiator



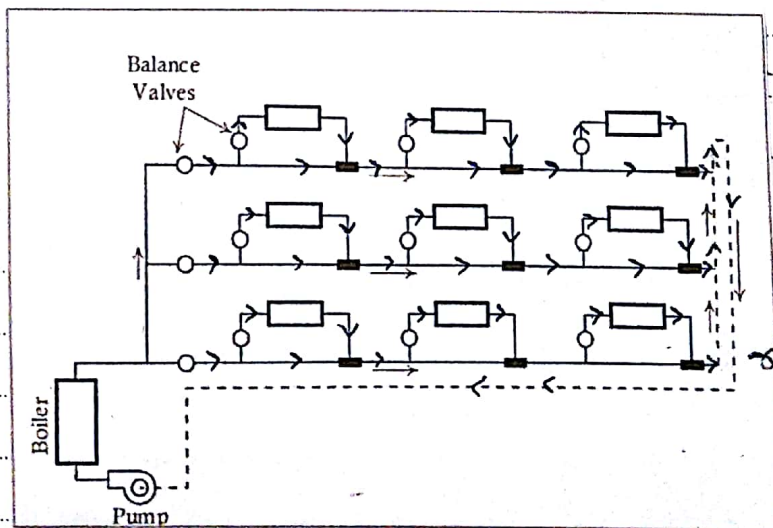
### (a) Direct return pipe system:

- In this system, hot water flows through each radiator and returns to the boiler inlet directly.
- All pipe circuits of radiators for this pipe system have different pipe length as measured from the boiler exit  $\rightarrow$  through the radiator  $\rightarrow$  back to boiler inlet. Hence, the pressure drop is not the same for each radiator circuit. Therefore, this system requires balancing valves to supply the required mass flow rate for each radiator.

### (b) Reversed return pipe system

- In this system, all radiators' circuits have the same length from the boiler exit to boiler inlet, which is the reason for calling it 'Self balanced system'.
- The assumption of equal pressure drop is justified in the design of these systems.
- This system requires more pipe length than that of direct return. Since both systems require balancing valves, it is preferable to design direct return system, since it requires less pipe length.

• The following system is a combination of single pipe and double pipe systems

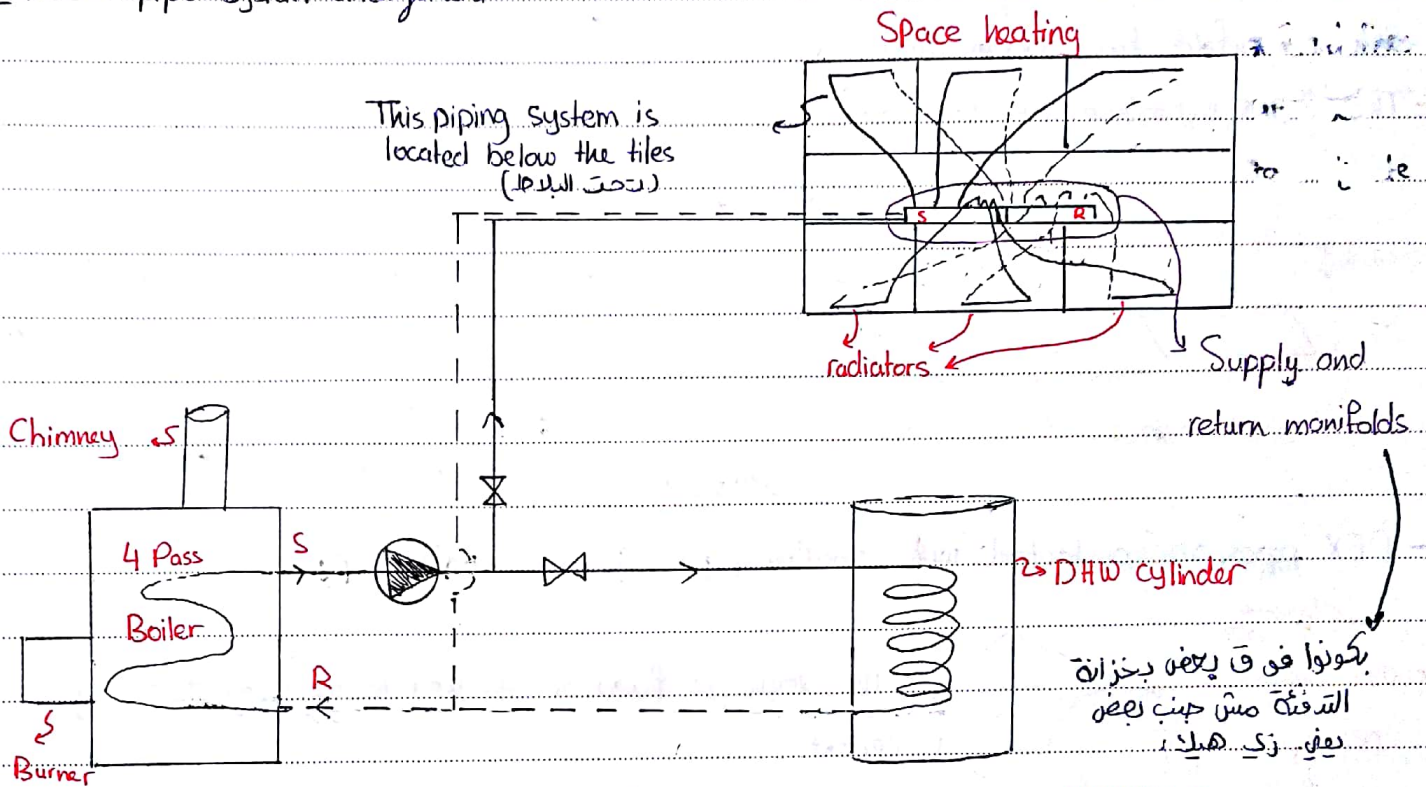


أول طابق بـ  
هو آخر طابق  
بـ

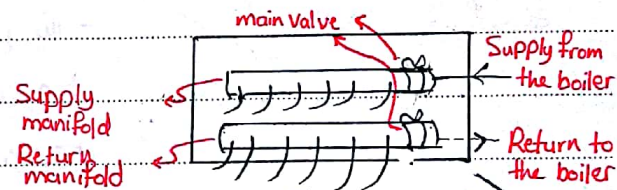
The piping system in each floor is a single pipe system, the whole system is a reversed return pipe system.



### 13 Radial pipe system arrangement



- The above piping system is called radial system.
- Solid lines are used to designate supply pipes while dashed lines are used to designate return pipes.
- This system uses thermoplastic pipes (PEX pipes) instead of metal pipes. Thus, when you draw these pipes on the plan, don't draw straight lines with sharp edges to represent them. Instead, draw curvy lines similar to "S" and "C" letters.



Space heating

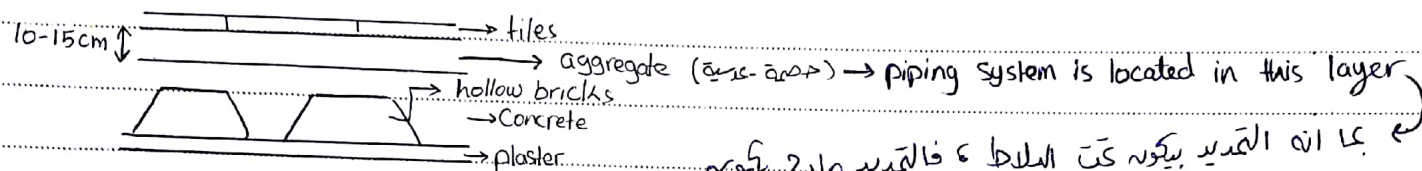
pressure drop

تقر بيا مساوي

- The size of the chimney is proportional to the size of the boiler. Large boilers require large chimneys. Its size is inversely proportional with the height of the chimney. The height difference causes a pressure difference, thus, the flow of hot gases out of the boiler will be easier.

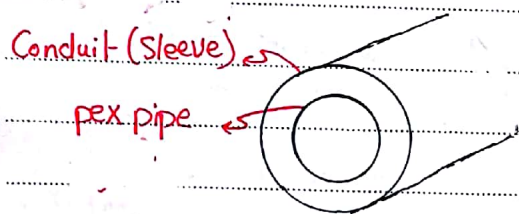


- Each radiator has 2 regulating valves (بالسوق بسوونم طقم رادياتر)
- Each manifold has a min. valve
- This the construction of the floor.



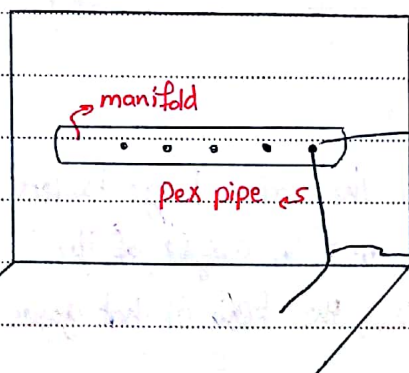
بما انه التمدد يكون تحت البلاط ، فالتمدد مارج يكون  
مقيد بالحواجز بين الغرف (الجدران) ، يعني مستقيم  
و مشوي بمسار من الباب ، منحفر بالجدار و منحدر

- PEX pipes are protected with another pipes surrounding them



- The sleeve is fixed or stacked to the ground using cement
- The PEX pipe is free to move, and hence it can be drawn easily from the conduit if it requires replacement.

- The diameter of the sleeve  $\approx 5\text{cm}$ . Hence, avoid intersection between the pipes, because the thickness of the aggregate layer  $\approx 10-15\text{cm}$ .



- The PEX pipes are connected to the manifold using compression joints (موصلة ضغط)
- To change the direction of the pipe, an elbow might be used or the pipe itself is bent.



## [\*] Steel and thermoplastic pipes.

- The most common metal pipe for hot water heating systems is steel.
- Table 7-1 gives Standard data for medium and heavy wall thickness steel pipes.

- Steel pipes has 2 types:

[1] Galvanized: Coated with zinc layer to protect it from bad weather conditions.

Galvanized steel pipes have silver colour. They are used for DHW and cold water supply applications. These pipes are called Class A pipes.

[2] Ungalvanized: They are black pipes and they are used for hot water space heating systems. These pipes are called Class B pipes.

- Steel pipes have high tensile strength. Hence, they can be used for high pressure applications.

- Steel pipes have rough internal surface which results in large pressure drops.

- Steel pipes for hot water lines are used with threaded fittings.

labor cost ↑ ← threading ← steel pipe

- Steel pipes are more suitable for exterior piping systems. However, they are suitable for interior piping systems, since they get rusted.

- Thermoplastic pipes are currently used in hot water heating systems.

- They are flexible, lighter, easy to handle, cheap and have smooth internal surfaces.

- Plastic pipes have many types:

- PVC = Polyvinyl chloride

- CPVC → بالمواد البلاستيكية

في شركة موديل Channel كائن تصفها

CPVC = compressed PVC. It looks like steel pipes. It can withstand higher pressures and temperatures when compared to PVC pipes. It is not suitable for exterior plumbing (piping) systems, since it can't withstand UV rays.

- PEX pipes

- PEX Aluminum pipes (PAP): It has combined properties of plastic (corrosion resistance, flexibility) and aluminum (high tensile strength) by laminating aluminum layer between layers of plastic.

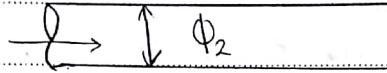
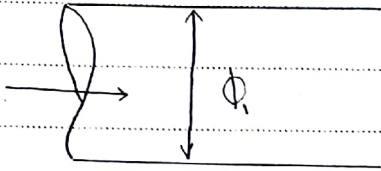


## \* Pipe sizing

- For the same flow rates, we have 2 options regarding pipe sizing

Option A

Option B



|                                                                                            |                                                                    |                                                                         |
|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------|-------------------------------------------------------------------------|
| * Diameter: $\Phi_1$                                                                       | $\Phi_2$                                                           | $\Phi_1 > \Phi_2 \therefore$ pipe cost for option A is more             |
| * Volume flow rate: $\dot{V}_1$                                                            | $\dot{V}_2$                                                        | $\dot{V}_1 = \dot{V}_2$                                                 |
| * Velocity of the flow: $\dot{V}_1 = v_1 A_1$<br>$A_1 \uparrow \Rightarrow v_1 \downarrow$ | $\dot{V}_2 = v_2 A_2$<br>$A_2 \downarrow \Rightarrow v_2 \uparrow$ | $v_2 > v_1$                                                             |
| * pressure drop: $\Delta P_1$                                                              | $\Delta P_2$                                                       | $\Delta P_1 < \Delta P_2$ because $\Delta P \propto v^2$                |
| * pump cost (initial cost) $\$_1 \downarrow$                                               | $\$_2 \uparrow$                                                    | Since $\Delta P_1 < \Delta P_2$ , a small pump is required for option A |
| * Energy consumption of the pump                                                           | less energy consumption                                            | more energy consumption                                                 |

- Optimization must be done in pipe sizing. Large pipe size is not desirable since it becomes expensive. Small pipe size is not desirable because it requires large pumps, and hence, electricity consumption increases

- The pressure drop in the pipes depends on the length of the pipe  $L$ , friction factor  $f$ , internal diameter of the pipe  $D$ , the flowing water density  $\rho$  and its velocity  $v$

$$\Delta P = f \left( \frac{L}{D} \right) \left( \frac{1}{2} \rho v^2 \right)$$



- As the pressure drop increases, the head of the pump must increase.

- In the piping system, there are

[1] Straight pipes (causing major losses)

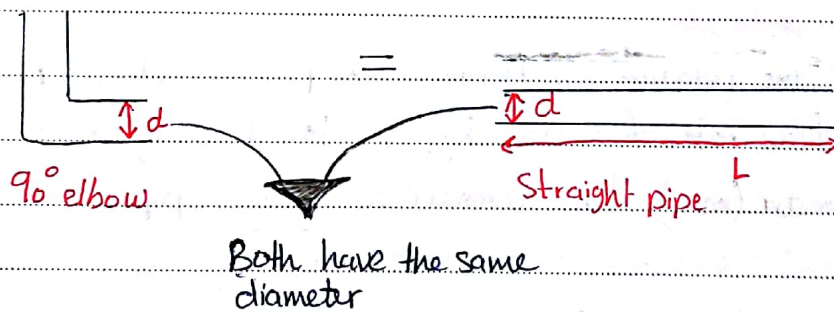
[2] Fittings (causing minor losses)

- As we said before, the total pressure drop in the piping system is

Total pressure drop = pressure drop per unit length  $\times$  longest run

- The longest run = the longest pipe circuit = Supply straight pipe length + Return straight pipe length + equivalent length of fittings + equivalent length of boiler pipes + equivalent length of radiator

- Equivalent length of fitting: is the length of straight pipe of a given diameter that would have the same pressure drop as that of the fitting of the same diameter.

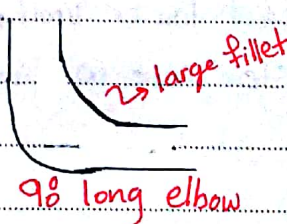
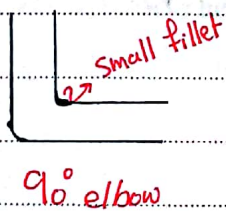


\* The pressure drop across the 90° elbow equals the pressure drop across the straight pipe. The length of the straight pipe "L" is called the equivalent length of the fitting.

- Table 7-4 gives the equivalent length of various pipe fittings in meters.

[1] For a 90° steel elbow with diameter = 25mm, the equivalent length = 0.63 m

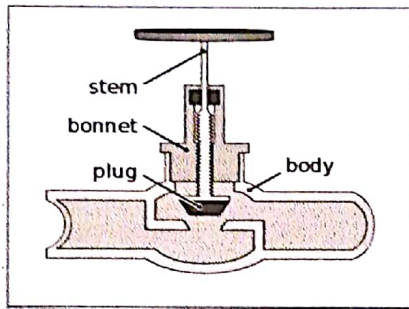
[2] For a 90° long steel elbow with diameter = 25mm, the equivalent length = 0.3 m (less pressure drop)





[3] For steel globe valve with diameter = 25mm, the equivalent length = 7.5m! (high pressuredrop)

[4] For steel gate valve with diameter = 25mm, the equivalent length = 0.3m



→ Globe Valve



→ gate valve

- Equivalent length of radiators + boiler pipes are obtained from their catalogues

- To find the pressure drop per unit length, you have to find the mass flow rate of water. Assume that the total heating load of a building  $\dot{Q}_{tot} = 330$

$$\dot{m}_w = \frac{\dot{Q}_{tot}}{c_p \Delta T} = \frac{330}{4.18 \times 10} = 7.9 \text{ kg/s} = 7.9 \text{ L/s}$$

This is the mass flow rate of the hot water flowing through the main supply pipe.

- Check Figure 7-11 which represents the relationship between the pressure drop per unit length (Pa/m), the mass flow rate of water (kg/s), the velocity of the flow (m/s) and the pipe diameter (mm) for commercial steel pipes

• for  $\dot{m}_w = 7.9 \text{ kg/s}$

when  $d = 100 \text{ mm}$

$\Delta P = 100 \text{ Pa/m}$

$d = 80 \text{ mm}$

$\Delta P = 350 \text{ Pa/m}$

$d = 65 \text{ mm}$

$\Delta P = 1000 \text{ Pa/m}$

diameter ↓

Pressure drop ↓

- Recommended pressure drop per unit length = 200 - 400 Pa/m

If the value of the pressure drop selected for the design of a heating system is less than the recommended lower limit, the pipe diameters will be large and the piping system cost will increase



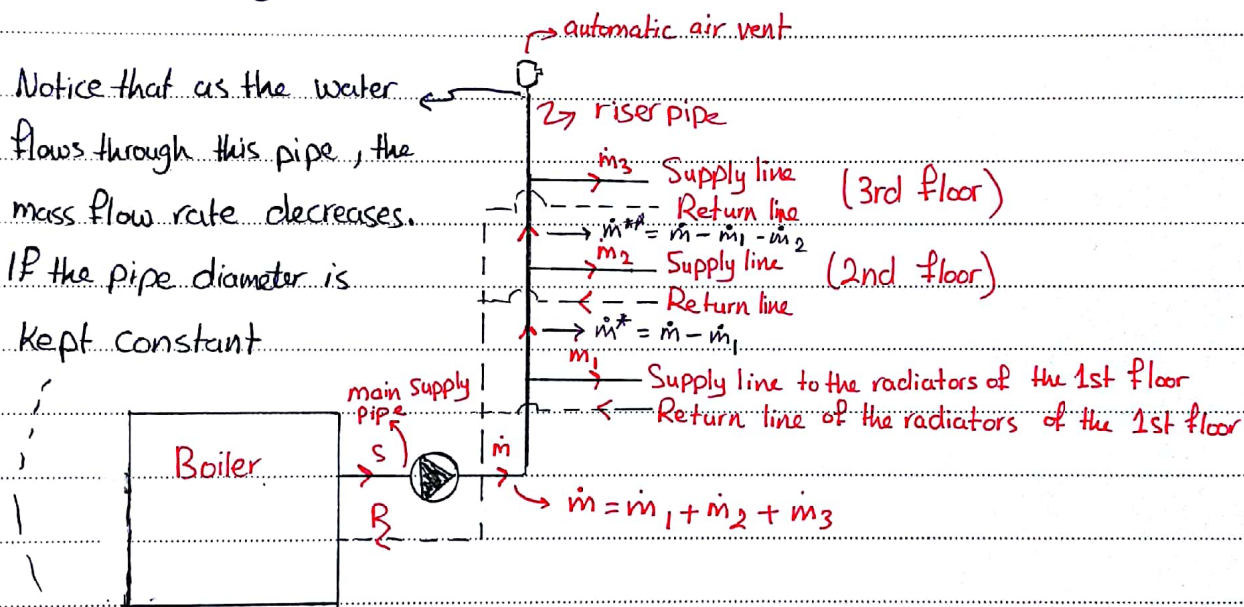
- On the other hand, if the pressure drop value is taken to be larger than the recommended upper limit, the resulting pressure drop will be large, and hence, the pump cost becomes very high.

- For the previous example, Select  $d = 80 \text{ mm}$   $\Delta P = 350 \text{ Pa/m}$

- Once the total pressure drop is calculated, you can select the suitable pump.

- Figures 7-12, 7-13(a), 7-13(b) give the pressure drop per unit length for flow of water in Copper tubes, standard plastic pipes and commercial thermoplastic pipes respectively.

- The following diagram Shows the riser diagram of hot water heating system:



the pressure drop per unit length will increase (Check Figure 7-11 and notice that if the diameter is kept constant, while the mass flow rate is decreased, the pressure drop per unit length will increase).

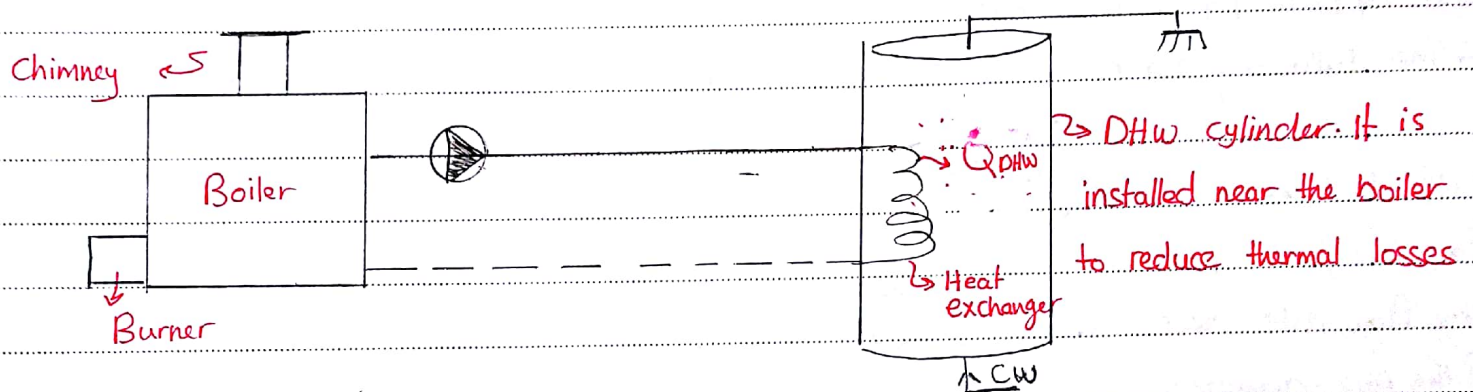
Hence, the riser pipe diameter must decrease as we go up, to maintain a constant pressure drop per unit length.

If the riser pipe diameter is kept constant, water won't flow upward, since the pressure drop per unit length gets larger. Water favors to flow through the loop which has the least pressure drop (least resistance).



## \* Domestic Hot water heating load:

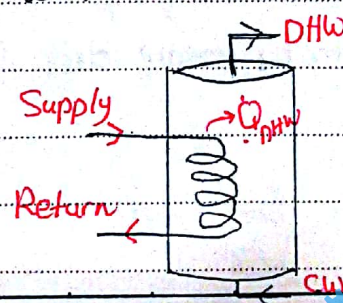
- Domestic hot water (DHW) is the hot water used in sinks, showers and baths in any type of building.
- The same boiler used for space heating can be used to provide DHW. Also, Electric heaters and solar thermal collectors (المسخنات الشمسية) can also be used to provide DHW. We will not discuss them because they are beyond the scope of this course. We will only discuss providing DHW using boilers.



- The hot water provided by the boiler does not mix with the cold water to be heated.
- Two types of heat exchangers are used for DHW purposes.

### I Immersed coil heat exchanger

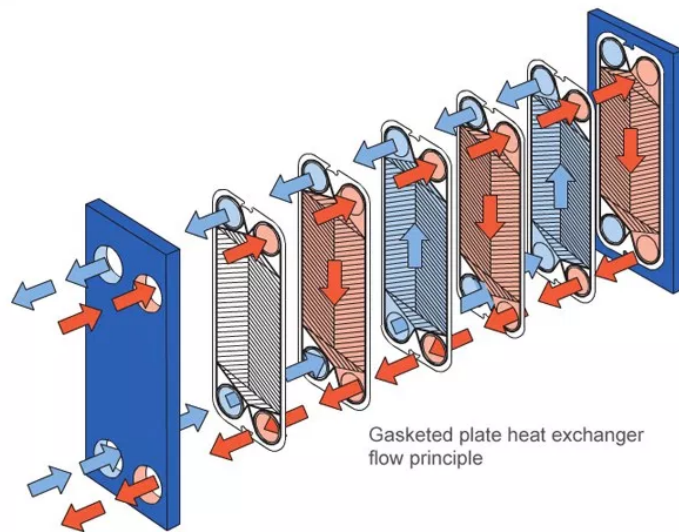
- It is made from copper (it has high thermal conductivity).
- The heating capacity of the coil is proportional to its length and surface area. [i.e. A coil with heating capacity of 15 kW is larger than a coil with heating capacity of 5 kW]. Therefore, you have to select the suitable coil size.
- The coil size must be compatible with the size of the boiler.
- Since this type of heat exchanger is immersed within the DHW cylinder, its size must also be compatible with the size of DHW cylinder.



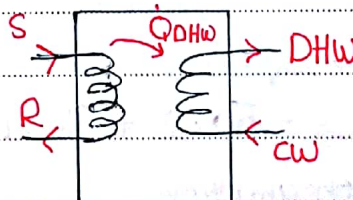


## 2] Plate heat exchangers

- This type of heat exchangers is installed outside the DHW cylinder. It has high heating capacity, hence it can be used in applications that require heating of large amounts of water  $\Rightarrow$  (المساحة) و (السرعة)
- plate heat exchanger uses ~~the~~ metal plates (stainless steel plates) to transfer heat between 2 fluids
- The following figure shows the working principle of plate heat exchanger



- The symbol of plate heat exchanger



- Plate heat exchangers can be used for cooling + heating
- Note: Shell and tube heat exchangers are used in chillers
- How can we calculate the DHW load  $Q_{DHW}$ ?

$$Q_{DHW} = M_{daily} * C_{p_w} * (T_{hot} - T_{cold})$$

$Q_{DHW}$   $\equiv$  DHW load in units of KJ/day

$M_{daily}$   $\equiv$  Constant daily consumption of DHW. Assumption is made to obtain this value



$T_{hot}$  is the supplied hot water temperature

$T_{cold}$  is the temperature of the cold water that must be heated to  $T_{hot}$

- If the number of family members is known, a daily consumption of 50 to 75 Liter per day for each of the "first" two members of the family and 30 to 50 Liter per day for each additional person in the family is used

Example Assuming a family of 6 members

In the case of: [1] Low consumption [2] High consumption

1st member 50

2nd member 50

3rd member 30

4th member 30

5th member 30

6th member 30

75 } → يغطي الاستهلاك

75 } الشخصين في احتياجات البيت

50 } (حمام + غسيل + ...)

50 } يغطي الاستهلاك

50 } الشخص من الماء

50 }

• In the case of Low consumption:

$$M_{daily} = \text{daily consumption} = 50 \times 2 + 30 \times 4 = 220 \frac{\text{L}}{\text{day}} = 220 \frac{\text{kg}}{\text{day}}$$

• In the case of high consumption

$$M_{daily} = \text{daily consumption} = 75 \times 2 + 50 \times 4 = 350 \frac{\text{L}}{\text{day}} = 350 \frac{\text{kg}}{\text{day}}$$

• Assuming  $T_{hot} = 45^\circ\text{C}$ ,  $T_{cold} = 15^\circ\text{C} \Rightarrow \Delta T = 30^\circ\text{C}$

• In the case of low consumption

$$Q_{DHW} = (220) \frac{\text{kg}}{\text{day}} * 4.18 \frac{\text{kJ}}{\text{K} \cdot \text{kg}} * 30 \text{K} = 27588 \frac{\text{kJ}}{\text{day}}$$



- The daily domestic hot water  $M_{\text{daily}}$  will be consumed during one day (24 hr), while the boiler is usually required to heat this amount of DHW in one hour only and not 24 hrs. Thus, the heating load due to domestic hot water, based on one hour is given by

$$\dot{Q}_{\text{DHW}} = \frac{M_{\text{daily}} * C_p * (T_{\text{hot}} - T_{\text{cold}})}{3600} \quad [\dot{Q}_{\text{DHW}}] = \text{KW}$$

- ote: read section 6.2 (Page 226)  
- For the previous example

$$\dot{Q}_{\text{DHW}} = \frac{27588}{3600} = 7.66 \text{ KW} \equiv \text{the heating capacity of the heat exchanger if the daily amount of DHW is heated in one hour}$$

- If the daily amount of DHW is heated in 2 hours

$$\dot{Q}_{\text{DHW}} = \frac{27588}{2 \times 3600} = 3.83 \text{ KW} \rightarrow \text{the heating capacity of the heat exchanger is reduced}$$

\* لمبنى سكني الطالبات (المشروع) يفرض على boiler رفع سخن الماء خلال ساعتين أو 3 ساعات لأنه لو فرضت ساعة رفع تكون قدرة heat exchanger كبيرة كثير

### [\*] Boiler heating Capacity:

The heating Capacity of the boiler:

$$\dot{Q}_{\text{Boiler}} = (\dot{Q}_{\text{space heating}} + \dot{Q}_{\text{DHW}}) * SF$$

SF = Factor of Safety = 1.1 - 1.15

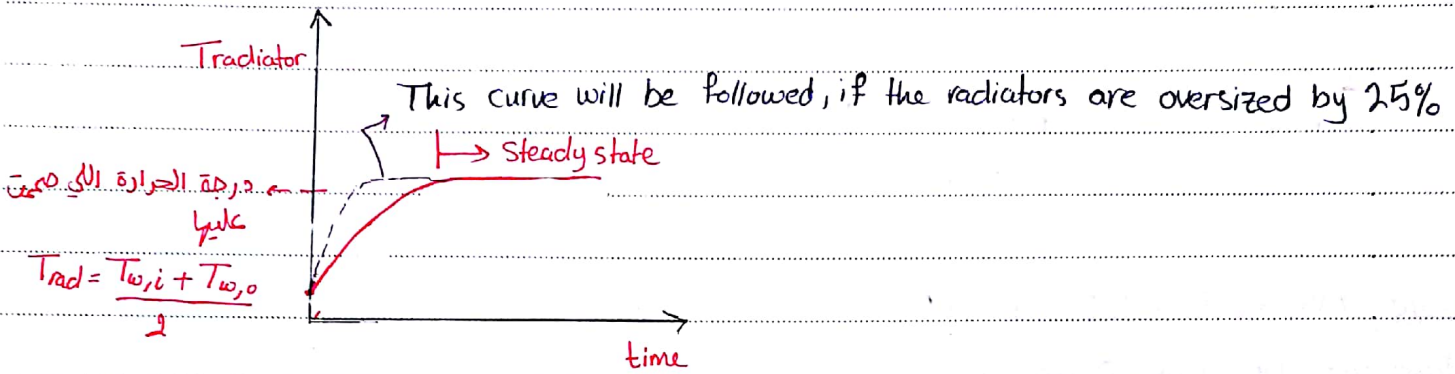
→ The heating capacity is increased by 10-15% to take into consideration:

[1] The heat losses

[2] The reduction in the efficiency of the boiler with time



- Note: The design of space heating introduced in our book is based on the assumption that the boiler is turned on 24 hours a day.  
For intermittent operation

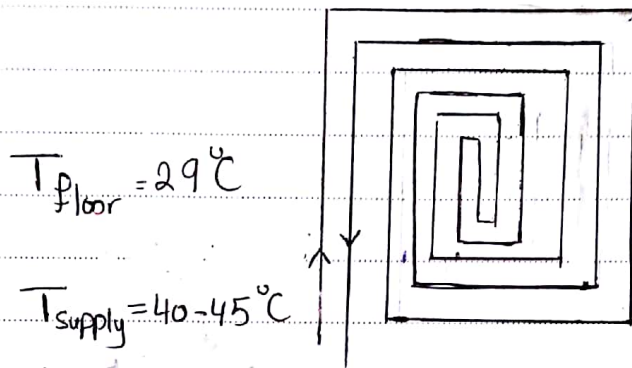


- If the boiler is turned on for 2 hours only, 30 minutes might be required. In order to reach the steady state conditions faster, we increase the size of the radiators by 25%.



## Underfloor heating system

- In hot water heating system (HWHS), radiators are used to heat the spaces.
- In underfloor heating system (UFHS), the space is heated using warm water flowing in pipes that are found below the tiles of the floor.
- The piping network that is found under the floor has several configurations. One of them is shown below:



\*  $T_{\text{supply}}$  is relatively low.

\* If  $T_{\text{supply}}$  is high,  $T_{\text{floor}}$  becomes high, and hence, the occupants will not be able to walk on the floor.

- The design of underfloor heating system is based on determining the length of the pipes + the spacing between the pipes.

e.g

- Room A: Floor area =  $20\text{m}^2$ , heating load =  $1500\text{ W}$  (larger heating load)
- Room B: Floor area =  $20\text{m}^2$ , heating load =  $800\text{ W}$

Undoubtedly, the length of the pipes that are required for room B is less than that of room A. The spacing between the pipes in room B is greater than that of room A.

- Advantages of underfloor heating system:

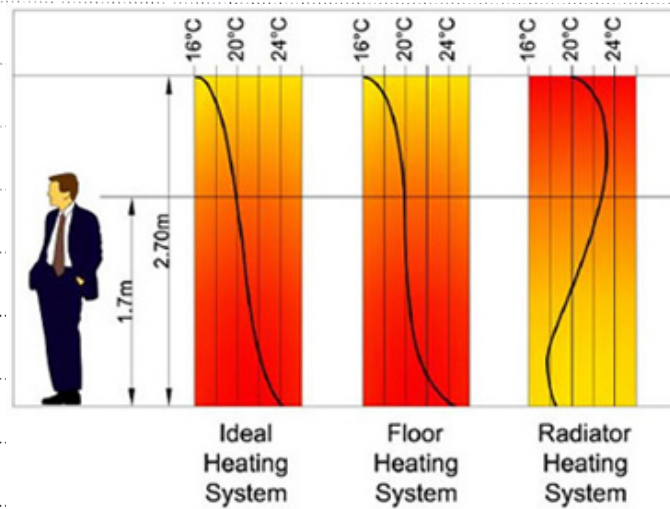
- Better heat distribution
- It frees your walls from radiators, making more space for the furniture.
- The tiles of the floor have good thermal inertia, hence it takes more time for the floor to cool down when the boiler is turned off.

- Disadvantages:

- Slow dynamic response (i.e. the system must be turned on, for 8 hours to reach thermal comfort)



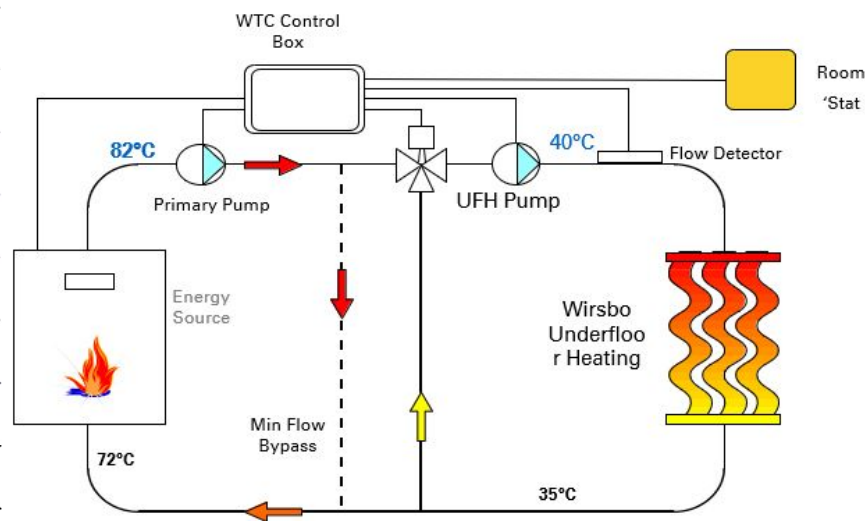
→ The following figure shows the temperature profiles of the air inside the space when radiators and UFHS are used for space heating.



- As we can see, UFHS provides an optimum thermal environment
- Radiators create natural convection. Cold air flows through the radiator, it becomes warm and its density decreases, hence, it rises upward towards the ceiling (i.e. maximum air temperature is found at a height greater than the height of the occupant)
- Ideally, the warm air must exist at low levels, so thermal comfort can be provided to the occupants. This can be achieved using UFHS as described below:
  - The floor is heated by the pipes found beneath it
    - ↓
    - The cold air, which is in contact with the floor, gets warm
      - ↓
      - ∴ warm air is obtained at low levels
- Temperature distribution of UFHS is similar to the ideal temp distribution



## → General schematic diagram of underfloor heating system.



- Conventional diesel boiler provides hot water at a temperature  $80 - 85^{\circ}\text{C}$ .

This hot water is provided directly to the piping system that exists inside the room, otherwise, the floor temperature becomes very hot.

- A 3-way valve mixes the hot water provided by the boiler with relatively cold water, to supply the piping system with warm water ( $T_{\text{supply}} = 40^{\circ}\text{C}$ ).
- As the water flows through the pipes, its temperature decreases and it becomes  $T_{\text{return}} = 35^{\circ}\text{C}$ .

→ This water is mixed with the hot water supplied by the boiler

- A thermostat is installed in each room. When the air around the thermostat reaches the set temperature, it sends a signal to the boiler and the pumps to stop.
- Sometimes, a condensing boiler is used instead of conventional boilers, since it provides water at lower temperatures.

\* Homework: Condensing boiler manufacturers claim that the efficiency of condensing boilers is greater than 100%. Is that true?

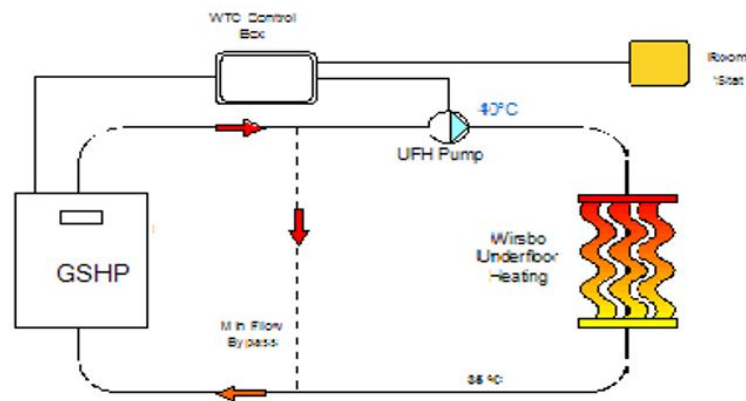
- We can see in the above figure a bypass pipe. It allows the flow of water through it when the main pipe is closed or block, hence, hot water



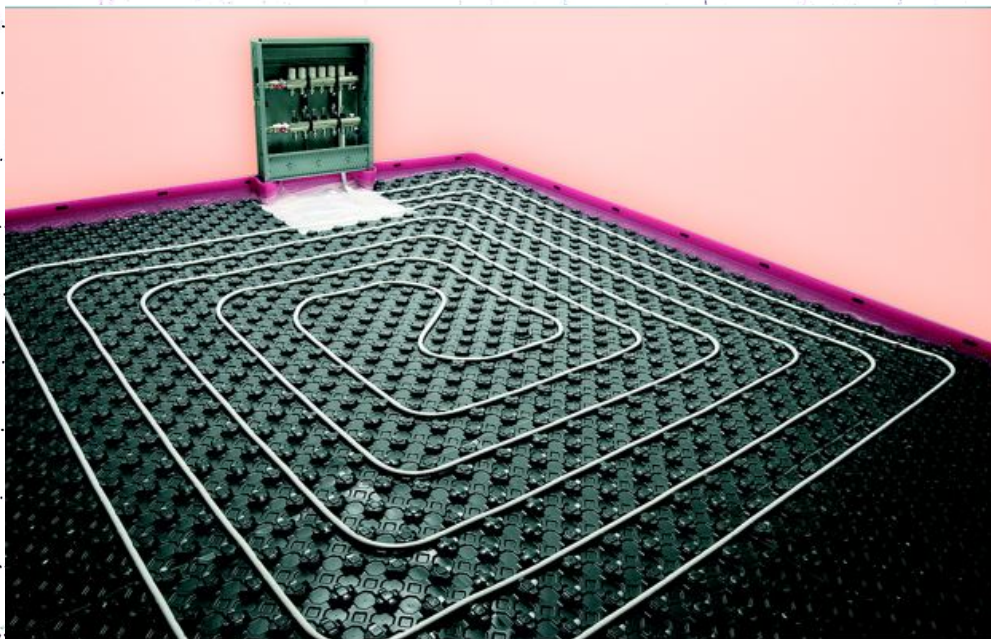
will return to the boiler. The controller of the boiler will send a signal to turn off the boiler.

→ "Electric" under floor heating system is one of the types of space heating systems, in which electric wires are installed beneath the floor.

→ Sometimes, Ground source heat pump (GSHP) is used as a heat source instead of the conventional boiler since it provides warm water ( $T_{\text{supply}} = 40-45^\circ\text{C}$ ), thus, the water is sent directly to the piping system as shown below.



→ A pipe positioning plate is used to fix the pipes in the desired positions.

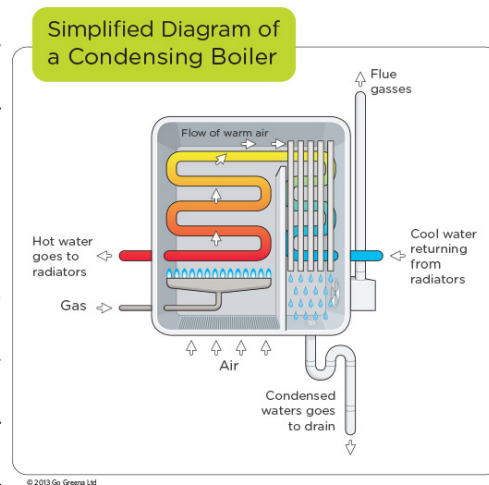




## \* Condensing boilers

→ How do they work?

A condensing boiler has 2 main heat exchangers. Initially the return water enters the secondary chamber (condensing chamber) picking up latent heat from the hot flue gases as they cool. The moisture in the flue gases condenses into droplets that form at the bottom of the heat exchanger. The condensate is expelled to drain. From there, the water enters the primary heat exchanger to collect more heat before flowing to the radiators.



→ For effective condensation, the temperature of the return water must be below the dew point ( $T_{\text{dewpoint}} \approx 55^\circ\text{C}$ ). This indicates that condensing boilers operate at lower temperatures.

→ Manufacturers claim that condensing boilers have efficiency greater than 100%. Is that true?

First, we have to consider 2 new terminologies which are related to combustion of fuels. They are:

1- Lower heating value (LHV)

2- Higher heating value (HHV)  
↓  
Calorific value

Combustion process releases water, which is subsequently evaporated. The process of water evaporation consumes some of the heat.



released by fuel combustion. That heat is known as 'latent heat of vaporization'. If the water vapor in the flue gases is expelled out of the combustion chamber, the latent heat of vaporization is lost.

If the water vapor is condensed before expelling it out of the combustion chamber, the latent heat of vaporization is recovered.

$$\text{HHV} - \text{LHV} = \text{latent heat of vaporization}$$

- The efficiency of the boiler is given by  $\eta = \frac{\text{Output}}{\text{Input}} = \frac{m_w C_{p,w} (T_{\text{supply}} - T_{\text{return}})}{m_{\text{fuel}} (\text{HV})}$   
(heating value)

if we want to calculate the efficiency of a condensing boiler, HHV must be used in calculations, because, the water vapor in the flue gases is condensed (i.e. the latent heat of vaporization is recovered). If the LHV is used instead (which is wrong), the efficiency gets larger than 100%.

e.g.

-  $\text{CH}_4$  (methane) has  $\text{HHV} = 55 \text{ MJ/kg}$ ,  $\text{LHV} = 50 \text{ MJ/kg}$

- If the "gross" efficiency (based on HHV) of a condensing boiler is 91.2%:

$$\eta_{\text{Gross}} = 91.2\% = \frac{\text{Output}}{\text{Input}}, \text{ Assume that 1 kg of fuel is burnt}$$

$$\frac{91.2}{100} = \frac{\text{Output}}{1 \text{ kg} \times \frac{55 \text{ kJ}}{\text{kg}}} \Rightarrow \text{Output} = 50.16 \text{ MJ}$$

- For the same output, the "net" efficiency (based on LHV) is

$$\eta_{\text{net}} = \frac{\text{Output}}{\text{Input}} = \frac{50.16 \text{ MJ}}{1 \text{ kg} \times \frac{50 \text{ kJ}}{\text{kg}}} = 100.3\%$$



### \* Notes:

- The calculated efficiency is called gross efficiency if the HHV is used in calculation. If the LHV is used instead, it is called net efficiency.
- Under floor heating system is suitable to be used in sport halls. Sometimes, unit heaters are used as space heating system in sport halls.  
Unit heater = heating coil + axial fan  
→ creates airflow with a high flow rate
- Chilled beam ceiling is a type of HVAC systems designed to cool large buildings. pipes of water are passed through a beam (heat exchanger) which is integrated into a suspended ceiling. (Notice that chilled beam ceiling system is similar to under floor heating system)

### Chapter 9: Cooling load calculation

- Cooling load calculation is very complex
- Rule of thumb: 1 ton of refrigeration is required per 16-20 m<sup>2</sup>

→ قاعدة إبهام: 1 طن تبريد  
يحتاج 16-20 م<sup>2</sup>

#### Cooling load

External load (External gain)

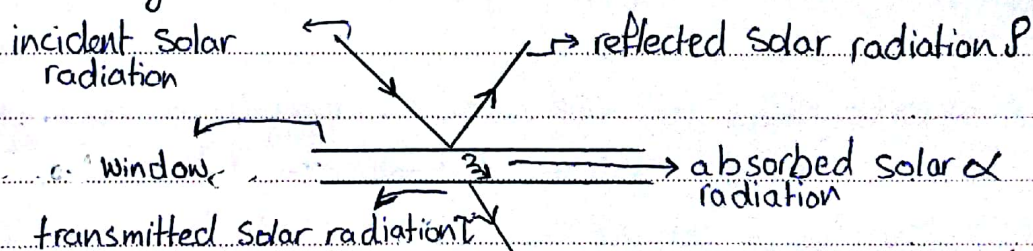
Internal load (Internal gain)

### \* External load: it involves

#### 1- Solar radiation

- Solar radiation has 2 effects:

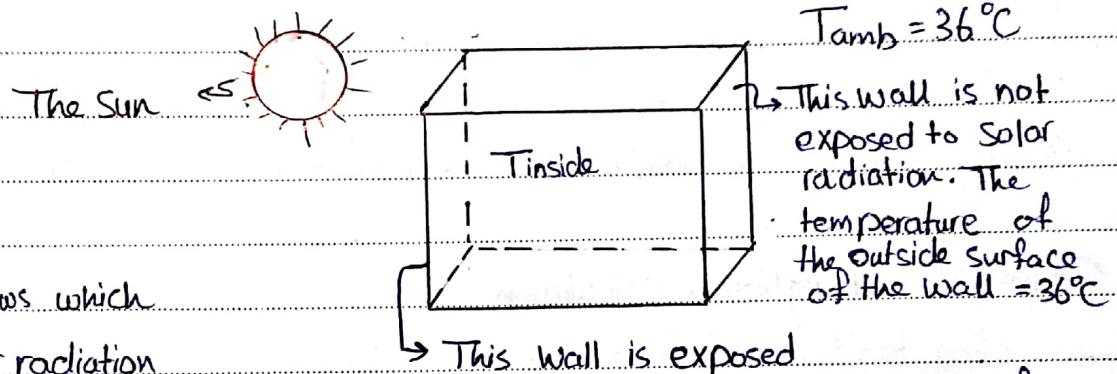
- It can be transmitted through the windows into the air conditioned space:





This transmitted solar radiation is initially absorbed by the inside space surfaces and furniture. After they become heated due to solar radiation, they start emitting thermal energy into the space, which causes an increase in the temperature of the space. [Notice that Solar radiation doesn't cause an "instantaneous" increase in the space temperature]

- Solar radiation is also absorbed by exterior walls, doors, roofs which are exposed to solar radiation



- Notes:

\* Walls, roofs and windows which are exposed to solar radiation are called sunlit walls, sunlit roofs and sunlit windows.

\* As noticed from the adjacent figure, we can't use the conventional  $\Delta T = T_{amb} - T_{inside}$  in order to calculate the rate of heat transfer through the sunlit wall. We will use

a special type of  $\Delta T$  which will

take the solar radiation effect into consideration. This type of  $\Delta T$  is called "cooling load temperature difference" and it is designated by CLTD



Continue: External loads

2- Heat transfer through exterior walls, floors and ceilings, which are not exposed to solar radiation. In this case, we use the conventional  $\Delta T = T_{amb} - T_{inside}$ .

3- Infiltration:

It includes the sensible and latent heat gains brought into the space as a result of infiltration of air through windows and doors cracks or when they are opened and closed.

\* How Can we reduce the external gains?

[1] The incident solar radiation can be divided into 3 main components.

- Ultra violet (UV): it "only" represents 6.4% of the total Solar radiation
- Visible: it represents 48% of the total incident solar radiation
- Infrared: it represents 45% of the total incident solar radiation. This component doesn't provide visible light. It only provides heat or thermal energy.

We can use special types of windows, which prevent the infrared radiation to enter the space, but allow the visible light to enter the space

[2] Adding insulation within the layers of the walls and roofs. This will reduce the overall coefficient of heat transfer "U", which in turn reduces the heat gain through the walls and roofs.

[3] Improving the air tightness of the building envelope in order to reduce infiltration.

Note: The infiltration load in Summer is less than in winter, because the wind speed in summer < wind speed in winter, hence, the pressure difference between outside and inside will be less in summer.



This will reduce the leakage of the outside air through the cracks.

#### [4] Using passive cooling methods.

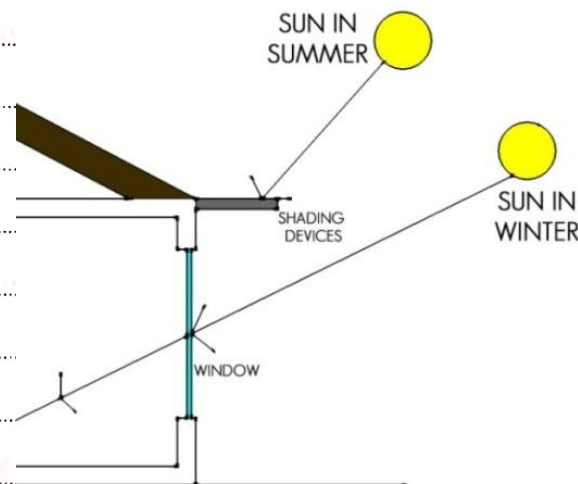
- There are 2 types of cooling techniques

[1] Active cooling techniques: refer to cooling technologies that depend on external mechanical devices such as fans.

[2] Passive cooling techniques: are least expensive methods of cooling a space, which maximizes the efficiency of the building envelope without any use of mechanical devices.

example: Shading devices (overhang)

The design of shading devices is based on studying the sun path diagram. Higher sun angle in the summer causes the solar radiation to be blocked by the overhang. Lower sun angle in winter causes the solar radiation to enter the space as shown below



#### \* Internal loads

1. Sensible and latent heat produced by the occupants. Recall:

the sensible heat produced by the occupants is multiplied by the cooling load factor (CLF) because, sensible heat rates are delayed due to the storage of the energy in the furniture of the space.

In other words, part of the generated sensible heat is first absorbed by the surroundings, and then gradually released into the air (delay)

2. lighting

3. Appliances



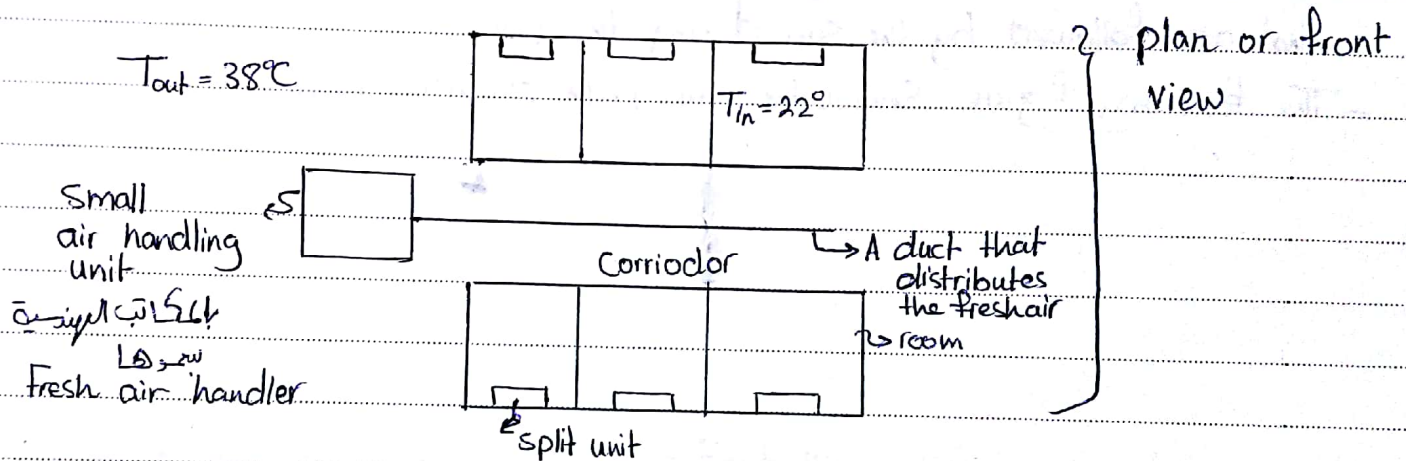
\* Notes:

- The air conditioning system in server rooms must stay turned on even if the outside temperature is low. Air conditioning devices are designed to turn off automatically if the ambient temperature is low. A "low ambient kit" is installed within the AC device to prevent the automatic turning off.

- Split units don't provide ventilation. How can we achieve ventilation when split units are used for space cooling?

There are 2 methods:

### 1 Common Ventilation System



- The split units have to supply cold air at a temperature  $T_{supply} = 14^{\circ}\text{C}$ . This cold air will keep the inside temperature constant ( $T_{inside} = 22^{\circ}\text{C}$ ) by removing the heat gained by the space.

- The air handling unit have to supply fresh air at a temperature  $= T_{inside} = 22^{\circ}\text{C}$  [i.e. it cools the air from  $T_{outside} = 38^{\circ}\text{C} \rightarrow T_{inside} = 22^{\circ}\text{C}$ ; it will not cool the air to  $T = 14^{\circ}\text{C}$ , because the purpose of this unit is to supply "fresh" air not "cold" air.]

### 2 Direct ventilation system

- A fan is installed instead of the air handling unit. It introduces fresh air into the space at a temperature  $T_{out} = 38^{\circ}\text{C}$ . However, the capacity of the split units must be increased to treat the introduced fresh air.

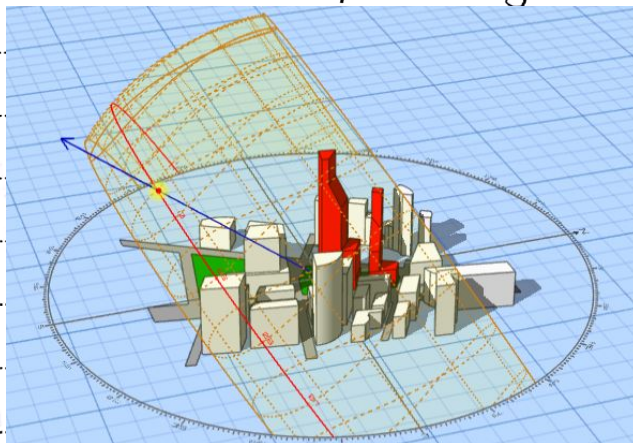


→ As we said before, calculating the cooling load is complex due to several reasons. One of these reasons is that the incident solar radiation on a certain space is variable, because of the sun motion during the day. This indicates that, the cooling load of that space is not constant and we have to calculate the cooling load hourly in order to determine the peak value of the cooling load.

→ It is important to study the sun path diagram in order to understand the effect of solar radiation on the cooling load of a certain space

- Sun path diagram is a graphical representation of the paths that are followed by the sun during the year

- The following figure shows the sun path diagram in Jordan



From the above figure notice the following:

- The sun rises in the east and sets in the west. It only rises due east and sets due west on 2 days of the year [spring and fall equinoxes]

يُفِيّ الشَّمْسُ بِتَشْرِيقٍ مِنْ "الْجِهَةِ الشَّرْقِيَّةِ" وَتَغْرِبٍ مِنْ "الْجِهَةِ الْغَرْبِيَّةِ" كُلَّ يَوْمٍ.  
لَكِنْ فِي يَوْمَيْنِ فَقَطْ مِنْ السَّنَةِ الَّتِي هِيَ الْعَتَايَيْنِ الرَّبِيعِيِّ وَالْخَرِيفِيِّ،  
الشَّمْسُ تَشْرِيقٌ مِنَ الشَّرْقِ تَمَاماً وَتَغْرِبٌ مِنَ الْغَرْبِ تَمَاماً.

- In winter, the sun exists at low altitudes in the sky and the sun path is short.



- In Summer, the sun exists at high altitudes in the sky and the sun path is long

- The sun paths are tilted towards the south

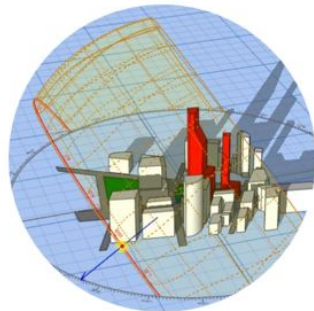
[\*] The impact of solar radiation on the sides of the building:

1- In winter,

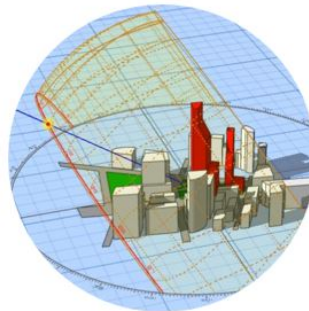
- In the morning, the solar radiation affects the eastern side of the building

- At noon, the solar radiation affects both the southern side and the roof top of the building. However, its effect on the southern side is more.

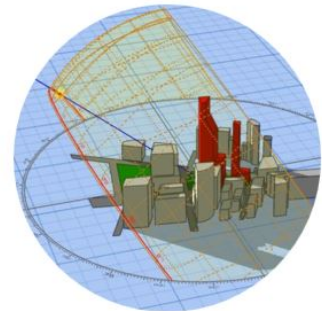
- In the evening, the solar radiation affects the western side of the building



In the morning



At noon



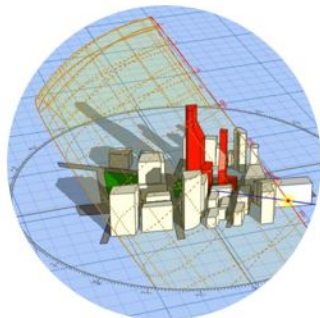
In the evening

2- In Summer

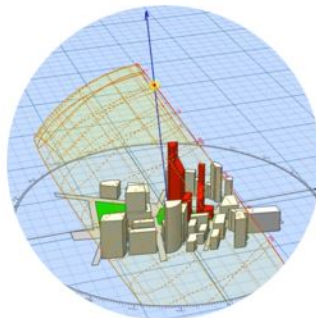
- In the morning, the solar radiation affects the eastern side of the building

- At noon, the solar radiation affects both the southern side and the roof top of the building. However, its effect on the rooftop is more, because the sun exists at higher altitudes in the sky in Summer

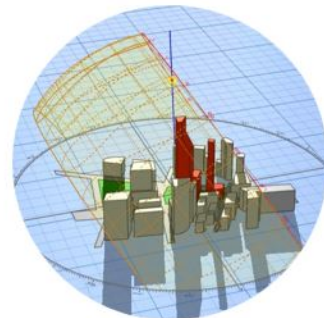
- In the evening, the solar radiation affects the western side of the building.



In the morning



At noon



In the evening



→ We are concerned with the impact of solar radiation on the sides of the building during summer only, because we calculate the cooling load in summer (not in winter).

→ From the previous discussion, we can conclude that:

- The peak cooling of a room in a building depends on which walls of the room are exposed to atmosphere. For instance:
  - If the eastern wall of a room is exposed to atmosphere, it is expected that the peak load of that room will occur in the morning.
  - If the western wall of a room is exposed to atmosphere, it is expected that the peak ~~for~~ cooling load of that room will occur in the afternoon.
- The peak cooling load of the different rooms in a building doesn't occur simultaneously. However, in winter, the peak heating load of the rooms in the building does occur simultaneously; When the outside temperature is minimum.

$$Q = UA (T_{\text{inside}} - T_{\text{outside}})$$

As  $T_{\text{out}} \downarrow \Rightarrow Q \text{ (heating load } \uparrow)$

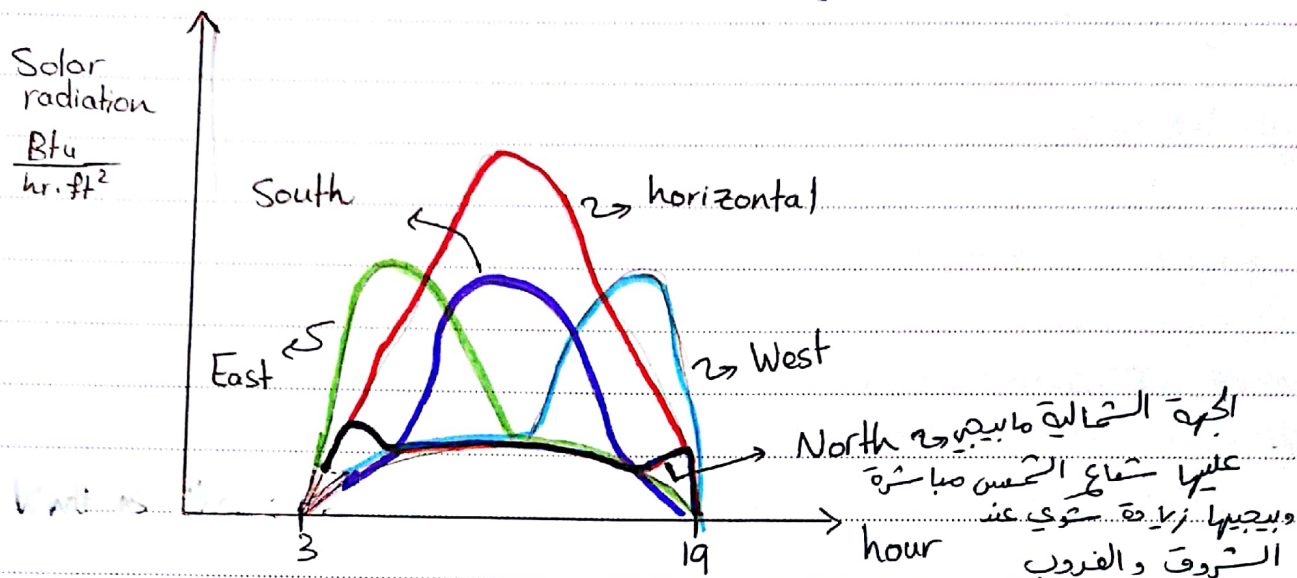
→ The cooling load of a certain space depends on

- [1] The orientation of the space
- [2] The sides of the space which are exposed to atmosphere
- [3] Thermal mass of the building envelope (or thermal inertia)

Thermal mass is a property of a building which enables it to store thermal energy instead of allowing it to be transferred into the space. A building of high thermal mass helps in keeping the inside temperature of a building stable.



→ The following figure shows the amount of incident solar radiation on the different sides of a building in July



→ What is the difference between the heat gain and the cooling load?

- Space heat gain is defined as the "instantaneous" rate at which heat enters into the space and that is generated within the space at a given time.

- heat may enter the space as solar radiation through transparent surfaces or heat transferred through exterior walls and roofs.
- heat may be generated within the space by occupants, lights, motors and appliances

- Cooling load is defined as the rate at which heat must be removed from the space to maintain its inside temperature constant. The cooling load takes the "delay" in the sensible heat into consideration

e.g

heat gain due to "occupants" = latent heat + sensible heat

Cooling load due to "occupants" = latent heat + sensible heat \* CLF



→ Calculating the cooling load can be done using softwares (such as HAP: hourly analysis program which calculates the cooling load hourly and specifies the peak cooling load of a certain space) or manually.

→ The cooling load due to solar heat gains can be calculated by one of the following methods:

[1] Carrier method: the heat transfer through sunlit walls, roofs, ... is given by

$$Q = UA(ETD)$$

↳ Equivalent temperature difference. This temperature difference takes the solar radiation into consideration

[2] Transfer function method (TFM): this method is used in HAP.

[3] Cooling load temperature difference method (CLTD):

- We will use this method when we want to calculate the cooling load due to solar heat gain.

- the rate of heat transfer through sunlit walls, roof, ... etc. is given by

$$Q = UA(CLTD)$$

↳ cooling load temperature difference. This temperature difference takes the solar radiation into consideration.

- The values of CLTD are found in tables that are published by ASHRAE.

- These values were obtained from studies performed on many buildings in the USA

- If we want to use the CLTD values to calculate the cooling load of a building in another country, the values of CLTD must be corrected.

Actually, there are several correction factors that must be considered such as:

1- Latitude factor

\* الظروف التي انبث عليها قيم ال CLTD

2- Color of the roof

الموجودة في الجداول يمكن تختلف عن

3- Tinside, Toutside

الظروف للمبنى التي يدي احسبه

4- attic Factor (attic = علبة) correction

ال cooling load  
عوامل هي لا يتم اعدل



\* مثلاً موقع المبنى  $T_{inside}$  و  $T_{outside}$  و لون المبنى الذي يربط أحسنه قيمة CLTD يمكن  
يختلف عن موقع المبنى  $T_{inside}$ ,  $T_{outside}$ , لون المبنى الذي انبثت عليه قيم CLTD  
الموجودة في الجداول عشان هيك منقول Correction

Hence, the previous equation becomes

$$Q = UA(CLTD)_{corr.}$$

↳ Corrected CLTD.

### [\*] Heat gain rate due to sunlit roofs

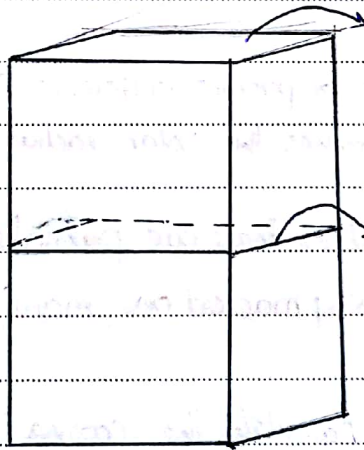
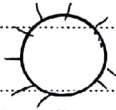
→ The values of CLTD for "Flat" sunlit roofs are obtained from Table 9-1

→ The table is divided into 2 Sub-tables:

- Roofs without suspended ceiling → عبارة عن عتبة خرسانية مقبورة من غير سقف ثانوي
- Roofs with suspended ceiling → يكون عبارة عن سقف ثانوي فوقه عديرات فوقه العتبة الخرسانية

→ For a given roof construction, the CLTD values vary with the "Solar hour."

→ Note:



This is a sunlit flat roof.

Here, we have to use the CLTD value when we calculate Q

Here, we use the conventional  $\Delta T$  (not CLTD), since it is not exposed to solar radiation.

→ Referring to table 9-1 (Page 354), Check the following roof constructions:

1- Steel sheet with 50.8 mm insulation ( $U_{ov} = 0.704 \text{ W/m}^2 \cdot \text{K}$ )

8- 203.4 mm L.W. concrete ( $U_{ov} = 0.715 \text{ W/m}^2 \cdot \text{K}$ )

- Notice that both roof constructions have approximately the same U value. However, the values of CLTD of concrete is less than the corresponding values of steel sheet.



- This is because: the thermal inertia of concrete > thermal inertia of the steel sheet. [i.e. concrete is able to store more thermal energy instead of allowing it to be transferred into the space]

- Also, notice that:

For steel sheet with 50.8 mm insulation roof construction, the maximum value of CLTD occurs at 2:00 pm

For 203.4 mm LW concrete roof construction, the maximum value of CLTD occurs at 7:00 pm!

\* Conclusion: As the thermal inertia of the building envelope increases, the maximum value of CLTD gets delayed

هذه التأخير ناتج لأن كتلة الجدران والسطح أكبر  
بما أن الهواء البارد فيتمدد الحرارة تنتقل من جدران البيت للخارج

→ If the given roof construction is different from those found in table 9-1, then use Table 9-3, which classifies the roof construction as follows:

- Light weight roof construction. The mass per  $m^2$  of this wall is  $50 \text{ kg}/m^2$  or less
- Medium weight wall construction. The mass per  $m^2$  of this wall ranges between  $200 - 400 \text{ kg}/m^2$
- Heavy weight wall construction. The mass per  $m^2$  of this wall ranges between  $500 - 650 \text{ kg}/m^2$

\* Note: if the mass per  $m^2 = 100 \text{ kg}/m^2$ , assume that the roof is light weight [because your design must be based on worst case scenario]

→ Hence, the CLTD value of flat sunlit roof is obtained either from Table 9-1 (if the given roof construction is found in Table 9-1) or Table 9-3 (if the given roof construction is not found in Table 9-1)



→ This CLTD value must be corrected.  $(CLTD)_{corr.}$  is calculated from the following equation

$$(CLTD)_{corr} = (CLTD + LM)K + (25.5 - T_i) + (T_{o,m} - 29.4)f \quad \text{eq (9-3)}$$

- CLTD is obtained from Table 9-1 or Table 9-3
- LM : Latitude month Correction Factor (found in Table 9-2)
- K : Colour adjustment factor
- $T_i$  : Inside design temperature ( $^{\circ}\text{C}$ )
- $T_{o,m}$  : Outside mean temperature ( $^{\circ}\text{C}$ )
- f : attic or roof fan factor

→ We will discuss the above parameters in details in the following example

Example : A building is located in dead sea. The inside design temperature is  $24^{\circ}\text{C}$ . Calculate the maximum heat gain rate through the roof.

The following data are given:

- A roof without suspended ceiling. Type is No. 4, light colour

Solution:

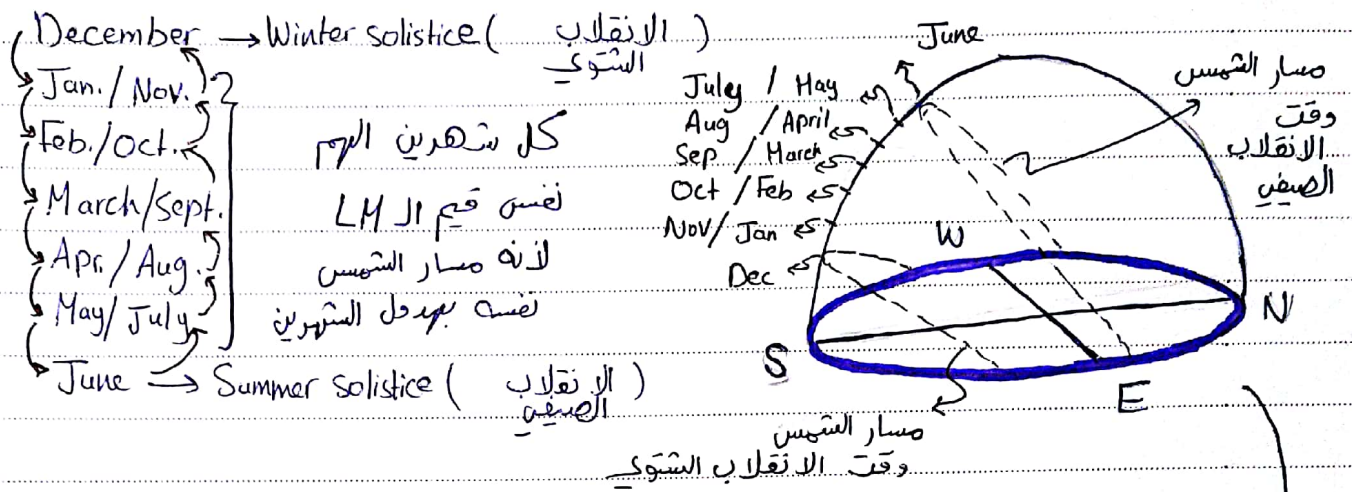
1- From Table 9-1, the maximum CLTD for roof construction No. 4 occurs at 4:00 pm  $\Rightarrow CLTD = 37^{\circ}\text{C}$

2- Check Table 9-2, which gives the values of LM factor and notice the following

- The values found in Table 9-2 can only be used for Countries which are located in the northern hemisphere, as indicated in the caption of the table.
- First you have to determine the latitude angle (زاوية العرض) of the location of the building. From Appendix A-7, latitude angle  $\phi = 32^{\circ}$  [Dead sea resort area, check page 519]



- Notice that the months in Table 9-2 are given in pairs [except for December and June]:



March ← Feb ← Jan ← Dec → June ← May ← April ←  
 Oct ← Sep ← Aug ← July ← June → Dec ← Nov ←

- In addition, Notice that the LM values are the same for E, W walls, because the sun path is symmetric →  
 لانه مسار الشمس متناظر، مقدار السطاح الشمسي الذي يسقط على واجهة الشرق = مقدار السطاح الشمسي الذي يسقط على واجهة الغرب. عندها هك الهم نفس ال LM

- Since we want to find the LM factor for a flat roof, we have to look at the last column of Table 9-2.

- From Appendix A-7 (P.519), the "maximum" outside temperature occurs in August ( $T_{max} = 37.7^\circ\text{C}$ ) → Our design must be based on worst scenario.  
 $\therefore$  LM factor @ ( $\phi = 32$ , Month = Aug) = -0.5

3- Color adjustment factor k

k=1 for dark coloured roof

k=0.5 for light coloured roof → Since the roof in the example has light color  $\therefore k=0.5$



4 - Inside design temperature  $T_i = 24^\circ\text{C}$

5 -  $T_{o,m}$  = mean outside temperature =  $\frac{T_{\max} + T_{\min}}{2}$

the values of  $T_{\max}$ ,  $T_{\min}$  are obtained from Appendix A-7 (Page 519)  
 $T_{\max} = 37.3^\circ\text{C}$ ,  $T_{\min} = 23.2^\circ\text{C}$  in August

$$\therefore T_{o,m} = \frac{37.3 + 23.2}{2} = 30.25^\circ\text{C}$$

6 -  $f$  = attic or roof fan factor

$f = 1$  if there is no attic or roof fan (Such as most buildings in Jordan)

$f = 0.75$  if there is attic or roof fan

$$\therefore f = 1$$

Now, calculate  $(CLTD)_{\text{corr.}}$

$$(CLTD)_{\text{corr.}} = (37 - 0.5) \times 0.5 + (25.5 - 24) + (30.25 - 29.4) \times 1 = 20.6^\circ\text{C}$$

$\therefore$  The maximum rate of heat transfer through that roof  $Q = UA(CLTD)_{\text{corr.}}$

[\*] Heat gain rate due to sunlit walls:

→ The values of CLTD for "vertical" sunlit walls at a given solar hour are obtained from Table 9-4 according to the wall orientation (i.e N, S, E, ... etc) and wall construction group. The details and description of wall construction groups are found in Table 9-5.

→ If the given wall construction details is different from those found in Table 9-5, then Table 9-6 can be used, which classifies the wall construction as follows:



- Light weight wall construction. The mass per  $m^2$  is  $50 \text{ kg/m}^2$  or less
- Medium weight wall construction. The mass per  $m^2$  ranges between  $200-400 \text{ kg/m}^2$
- Heavy weight wall construction. The mass per  $m^2$  ranges between  $500$  and  $650 \text{ kg/m}^2$

→  $(CLTD)_{\text{corrected}}$  is calculated using eq (9-3),  
 ↳ roof الجدران السقفية

$$(CLTD)_{\text{corr}} = (CLTD + LM)K + (25.5 - T_i) + (T_{o,m} - 29.4)F$$

- CLTD is obtained from Table 9-4 or Table 9-6

- LM is obtained from Table 9-2

- K colour adjustment factor has 3 values

$K=1$  for dark colour walls

$K=0.83$  for medium colour walls

$K=0.65$  for light colour walls

} However, for sunlit roofs, there are only 2 values for K.

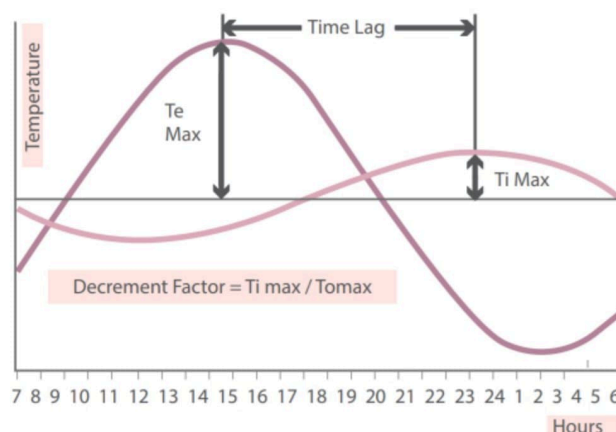
-  $T_i$  = inside design temperature

-  $T_{o,m}$  = mean outside temperature, can be calculated with the help of Appendix A-7

- F = attic factor

→ Check example 9-1

→ The following figure shows the variation of  $T_{\text{outside}}$  and  $T_{\text{inside}}$  of certain space during the day.



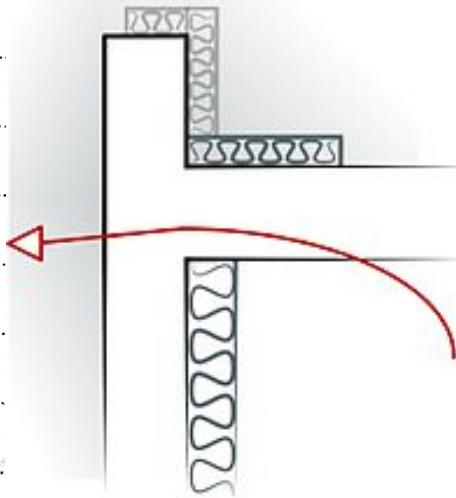


- Notice there is a time lag or delay between the peak of the inside temperature and the peak of the outside temperature due to the thermal inertia of the building.
  - As the thermal inertia of the building increases, the peak of the inside temperature decreases and gets more delayed. This fact can be noticed from Table 9-3 and Table 9-6. Notice from Table 9-3, for instance, that:
    - For a given solar time, as the mass per  $m^2$  of the roof increases (thermal inertia increases), CLTD value decreases
    - For light weight roof construction max CLTD occurs at 16:00
    - For medium weight roof construction max CLTD occurs at 18:00
    - For heavy weight roof construction max CLTD occurs at 20:00
- ↓ gets more delayed

### \* New terminology: Thermal bridge

Thermal bridge is an area or component of an object which has higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer

Thermal bridge can occur at several locations within the building envelope such as at the junction between the ceiling and the wall [because no insulation is set at the junction]





## \* Heat gain rate due to sunlit glass surfaces

→ The glass material may be classified as:

- Clear glass material which transmits more than 80% of incident solar radiation
- Tinted glass is available in many colours which differ in the amount of solar radiation they transmit and absorb.
- Coated glass is used to affect transmission of solar radiation and it can be highly reflective (such as mirrors)
- Patterned glass which has decorative patterns



Tinted glass



Clear glass

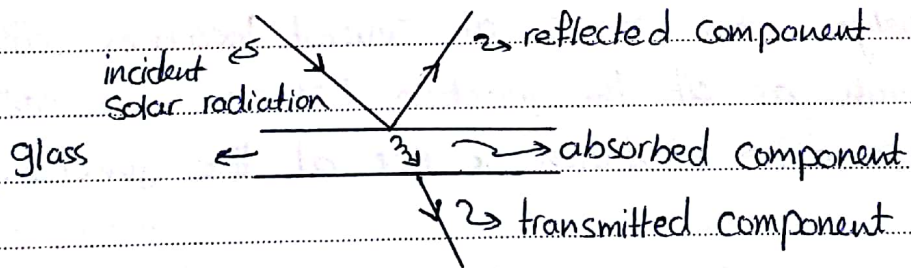


Coated glass



Patterned glass

→ Recall: The incident solar radiation on glass surfaces has 3 components:



→ The heat gain rate due to transmission of solar radiation through glass is given by:

$$Q_{tr} = A(SHG)(SC)(CLF)$$

Where:

- A is the 'area' of the window. As the area of the window ↑, the transmitted solar radiation ↑



- SHG is the Solar heat gain rate or Solar radiation in units of  $W/m^2$ .  
Table 9-7 gives the maximum values of SHG if the glass orientation and the month are known.

We determine the month based on Appendix A-7. You have to look for the month which has the maximum recorded temperature.

Notice from Table 9-7:

- During Summer, the SHG on a horizontal surface is high, because the sun exists at higher altitudes in the sky during Summer.
- The SHG values for E/W windows are the same, because the sun path is symmetric.
- The SHG values found in Table 9-7 are only applicable for latitude angle =  $32^\circ N$  as indicated in the caption of the table.

- SC: Shading coefficient factor. The values of SC are obtained from Table 9-8 for glass windows or glass doors without interior shading. If the glass window has interior shading, then, the values of SC are obtained from Table 9-9.

The types of interior shadings presented in Table 9-9 are

1- Venetian Blinds

2- Roller shade  $\rightarrow$  Opaque  $\rightarrow$  translucent



Venetian blinds



Roller shade

- CLF: When solar radiation is transmitted through the window of a certain space, it is initially absorbed by the furniture of the space, then,



The furniture starts emitting thermal energy into the space (There is a delay).

Thus,  $\dot{Q}_{tr}$  must be multiplied by CLF. The values of CLF are obtained from Table 9-10 for windows without interior shades  
Table 9-11 for windows with interior shades

\*Note:

- There are 2 types of shading devices:

1- Interior shading devices such as curtains, Venetian blinds, roller shades

2- Exterior shading devices such as: overhang, Grapevines

بالصيف

بالشتاء

بالشتاء

- Exterior shading devices reduce the solar heat gain more effectively than interior shading, because, interior shading devices prevent solar radiation to enter the space. However, interior shading devices, such as curtains, initially absorb the solar radiation, then, they emit thermal energy into the space (They cause a delay)

→ The heat gain rate through glass surfaces is given by

$$\dot{Q} = UA(CLTD)_{corr.}$$

where

$$(CLTD)_{corr.} = (CLTD + LM) * k + (25.5 - T_i) + (T_{out} - 29.4)$$

obtained from Table 9-12

←  $k=1$   
obtained from Table 9-2

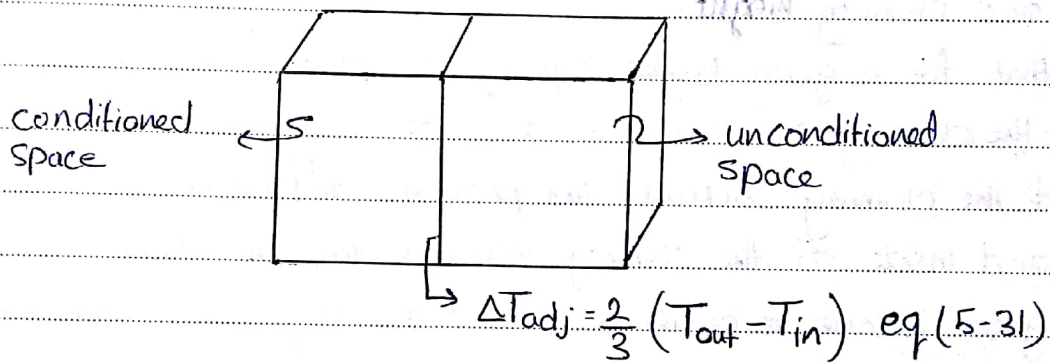


### \* Notes:

- The calculation of various components of the cooling load of the building must be carried out on a room by room basis.
- The cooling load calculations of the components of the room are tabulated in Table 9-17.
- When we want to calculate the cooling load of a room, we have to consider the following:

(1) External cooling loads, which include:

(a) Convection (heat gain) due to  $(T_{adj} - T_{in}) = \Delta T_{adj}$



(b) Solar effects, which include

- (i) Transmitted heat gain → for windows only
- (ii) Convection (heat gain) due to CLTD → for walls, roofs, windows

(2) Internal cooling loads

For residential applications, internal cooling loads are mainly due to occupants and lightings.

(3) Infiltration → قبة ال N بال Infiltration بالصف الفروق  
 لهذا تكون بالصف أقل من الشتاء 6 س اكلنا بها 2 نفوذ في الصيف

→ After calculating the cooling loads of the different components, you can compute the following:



Continue:

$$\dot{Q}_{\text{sensible, total}} \div \dot{Q}_{\text{latent total}}, \text{SHR (sensible heat ratio)} = \frac{\dot{Q}_{\text{sensible, total}}}{\dot{Q}_{\text{sens, tot}} + \dot{Q}_{\text{lat, tot}}}$$

هنا القيمة بدعمني لانها ما آتتني أشتري مكيف  
بكونه قيمة SHR معينة

→ Check example 9-4

### \* Chimney sizing

→ Table 7-8 gives the chimney cross sectional area in units of  $\text{cm}^2$ , according to the Jordanian code as a function of boiler heating capacity and chimney height.

→ Notice that for a given boiler capacity as the chimney height increases, the chimney cross sectional area decreases, because when the height of the chimney increase, the pressure difference between outside and inside of the chimney increases, thus, the flow of exhaust gases becomes easier  $\Rightarrow$  no need for large cross sectional area.

→ if the boiler capacity = 60 kW, chimney height = 10 m, the chimney cross sectional area =  $330 \text{ cm}^2$

$$A_c = \frac{\pi}{4} d_c^2 \Rightarrow 330 = \frac{\pi}{4} d_c^2 \Rightarrow d_c = 20.49 \text{ cm} \\ = \frac{20.49}{2.54} \text{ in}$$

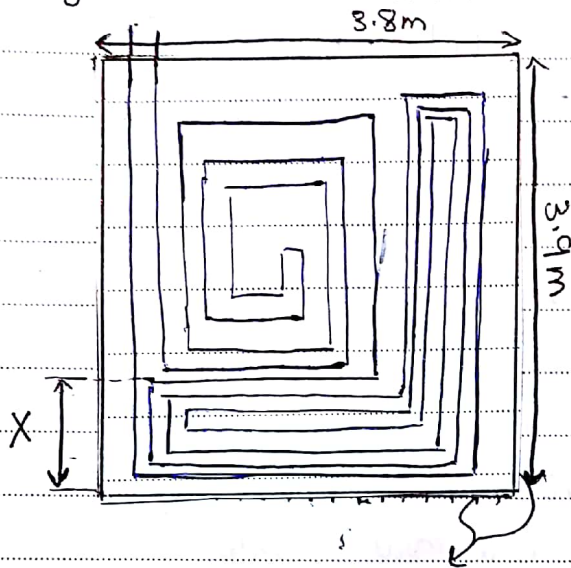
(The diameter of the chimney in inches)  $d_c = 8 \text{ in}$



\* ملاحظة الهنـس عبر اللابـس عن الـ under floor heating

→ Recall: in under floor heating System, a pipe network is installed under the floor.

→ Example: The heating load and the floor area of a room is 2.3 kW and 3.8 m x 3.9 m respectively. It is desired to design an under floor heating system as shown below:



The specifications of the pipes:

1- 16mm diameter

2-  $q = 24 \text{ W/m}$  [1 meter of the pipe produces 24W]

3- The main spacing (main pitch) between the pipes = 20cm, while the space between the pipes at the edges = 10cm

- Find the length of the pipe that must be installed to cover the heating load

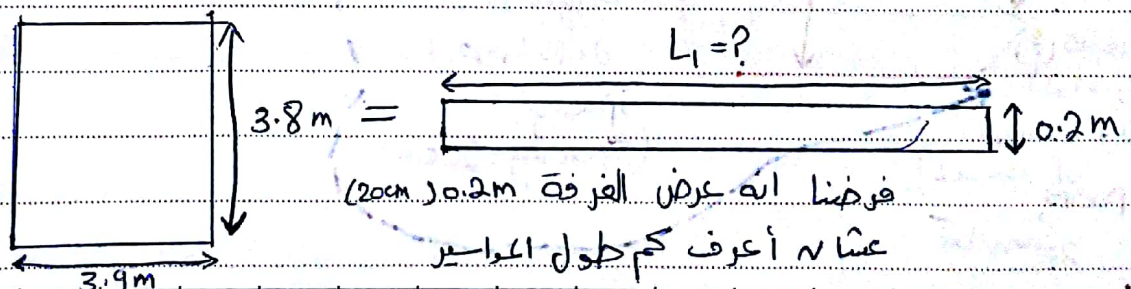
- Find the dimension X shown in the adjacent figure

These 2 walls are exposed to atmosphere.

This is why the density of the pipes at the edges is greater

First, we will assume that the spacing between the pipes is 20 cm (even at the edges), the length of the pipe that can be installed in the room:

$$L_1 = \frac{3.9 \times 3.8}{0.2} = \frac{14.8}{0.2} = 74 \text{ m}$$



الي ممكن أمدّها جوا الغرفة



- The heating load of the room =  $2.3 \text{ kW} = 2300 \text{ W}$
- The total pipe length that is required to cover the heating load of the room is calculated as follows:

$$Q = L_{\text{total}} * q$$

$$2300 \text{ W} = L_{\text{total}} * 24 \frac{\text{W}}{\text{m}} \Rightarrow L_{\text{total}} = 95.4 \text{ m}$$

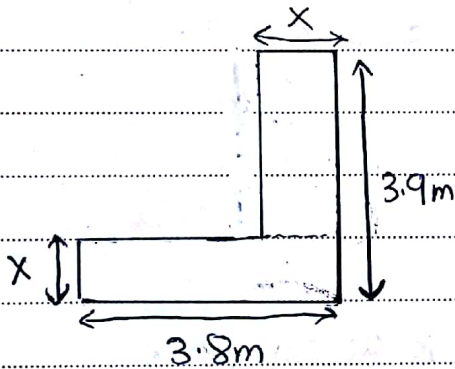
$$L_{\text{total}} = 95.4 = L_1 + L_2$$

$$95.4 = 74 + L_2 \Rightarrow L_2 = 21.4 \text{ m}$$

Calculated  
in the previous  
page

This additional length of pipes will be installed at the edges. The length  $L_2$  determines the value of the dimension  $X$ .

\* احسنا بالازدول مدنيًا مواسير طولها 74 متر بكل الغرفة. عيب انه ال Spacing بيننا 20cm هلا بدنا عند مواسير! خلاصة طولها 21 متر عند الحواف و لانه عند الحواف ال Spacing بيكون 10cm يعني بقدر اضيف مواسير

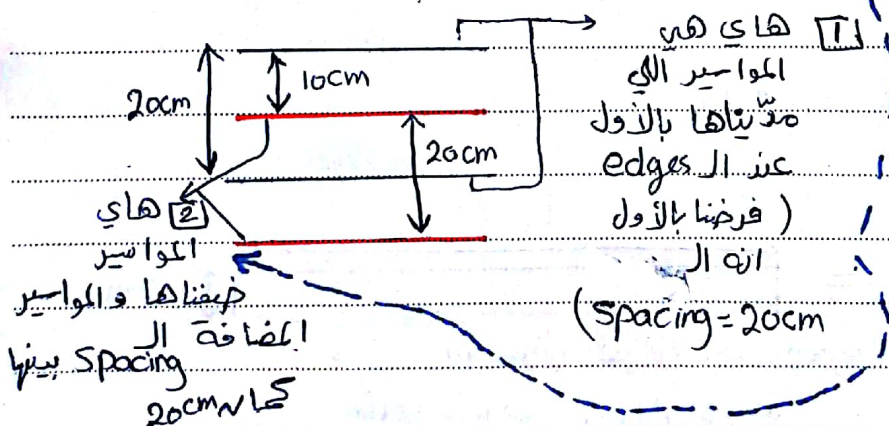


$$L_2 = X * (3.9 - 0.2) + X * (3.8) = 21$$

$$X = 7.1 \text{ m (rejected, because } X < 3.9 \text{ m)}$$

$$X = 0.6 \text{ m}$$

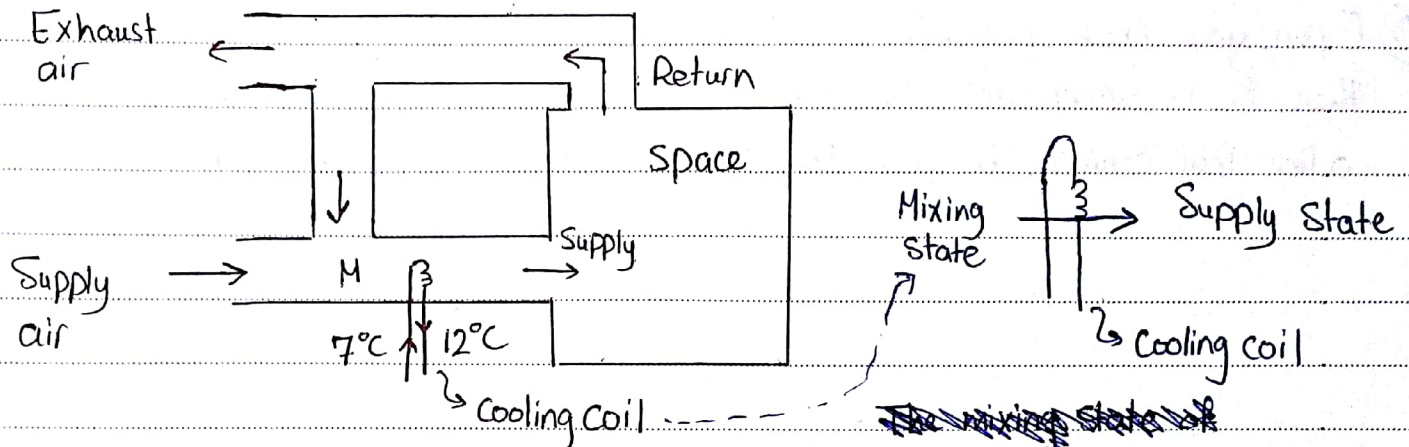
بعد الفرفة





## \* The last lecture:

Notes:



- The mixing state of the flowing air is called ON coil
- The supply state of the flowing air is called OFF coil

→ Example: The cooling load of the space shown in the above figure is  $\dot{Q}_{tot} = 300 \text{ kW}$ ,  $\dot{Q}_{sensible} = 270 \text{ kW}$

The inside design conditions  $T_{in} = 22^\circ\text{C}$ ,  $RH = 50\%$

The mixing state properties  $T_M = 27^\circ\text{C}$ ,  $RH = 50\%$

$T_{supply} = 14^\circ\text{C}$ , Find the capacity of the cooling coil  $\dot{Q}_{cc}$ ?

$$\dot{Q}_{cc} = \dot{m}_{air} (h_{\text{mixing state}} - h_{\text{supply}})$$

- mixing state  $T_M = 27^\circ\text{C}$ ,  $RH = 50\%$  →  $h_{\text{mixing}} = 56 \text{ kJ/kg dry air}$
- We cannot find  $h_{\text{supply}}$ , because we have only one property  $T_{\text{supply}} = 14^\circ\text{C}$
- In addition,  $\dot{m}_{air}$  is unknown
- First, let's find  $\dot{m}_{air}$

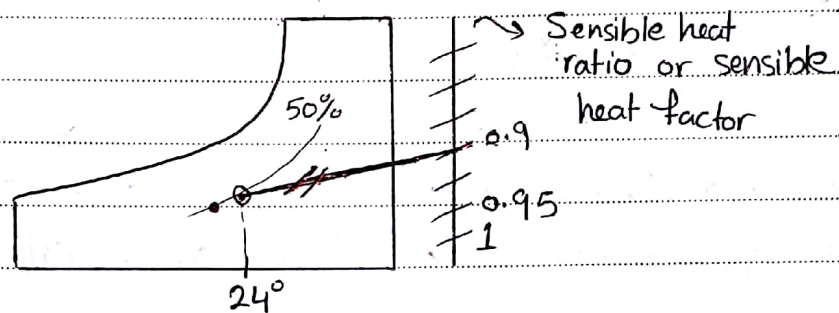
① Find the sensible heat ratio or sensible heat factor:

$$SHR = \frac{\dot{Q}_{sen}}{\dot{Q}_{tot}} = \frac{270}{300} = 0.9, \text{ SHR ranges between } 0.7-0.9$$

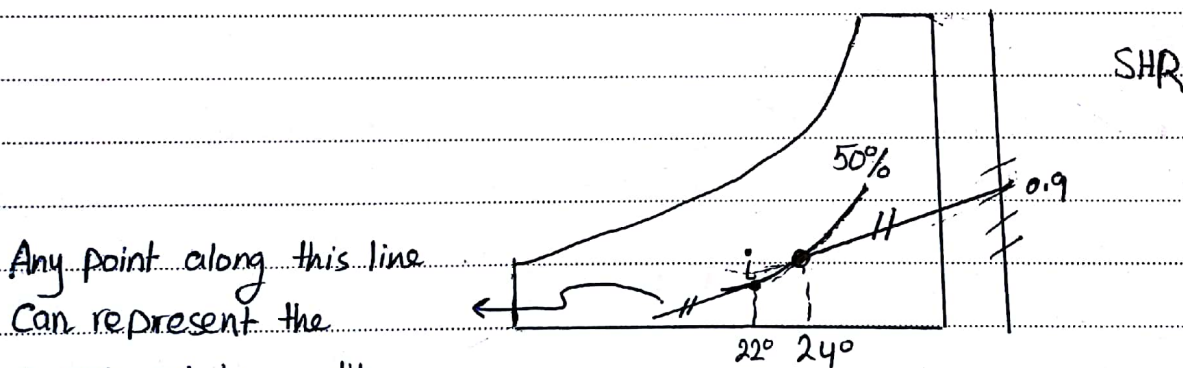


② Determine the location of the inside design condition point on the psychrometric Chart

③ Open your book page 66, and notice that @  $T = 24^\circ\text{C}$ ,  $RH = 50\%$ , there is a small circle. This circle is called alignment circle. Draw a line that connects between the alignment circle and the SHR Value



④ Draw a parallel line starting from the inside condition point



because the temperature at any point along this line is less than  $T_{\text{inside}}$

∴ The supply air can provide cooling

In addition, the humidity ratio at any point along this line is less than the humidity ratio of the inside condition space

∴ The supply air can provide dehumidification

- As the supply state point gets closer to the inside condition state along this line, more mass flow rate is required.

- Since  $T_{\text{supply}}$  is given, find the state of supply air along



the parallel line. Now you can find  $h_{\text{supply}} = 33 \text{ KJ/kg dry air}$

(5) Find  $\dot{m}_{\text{air}}$  as follows

$$\dot{Q}_{\text{space}} = \dot{m}_{\text{air}} (h_{\text{inside}} - h_{\text{supply}})$$

$$300 = \dot{m}_{\text{air}} (43 - 33) \Rightarrow \dot{m}_{\text{air}} = 30 \text{ kg/s}$$

$$\therefore \dot{Q}_{\text{cc}} = \dot{m}_{\text{air}} (h_{\text{mixing}} - h_{\text{supply}}) = 30 (56 - 33) = 780 \text{ KW}$$

$$\dot{Q}_{\text{cc}} = \dot{Q}_{\text{space}} + \dot{Q}_{\text{ventilation}}$$