THERMO FLUID SCIENCE
ME21004

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Term Project :

Thermodynamic and Fluid Dynamic Analysis of a Domestic Air Conditioning Unit

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Introduction:

An air conditioning system uses principles of thermodynamics to cool a living space. In simple terms, it is a closed system that circulates a substance called a refrigerant, altering the pressure of the refrigerant at different points to promote the transfer of heat.

We will describe the cycle starting indoors, where the refrigerant is a cold, low-pressure mixture of liquid and vapor that enters the evaporator. The indoor fan blows hot air from the living space over the evaporator, which absorbs the heat, cooling the air blown back into the living space. The heat absorbed by the evaporator turns the refrigerant completely into vapor, and is carried outside as the refrigerant travels to the compressor.

The compressor dramatically increases the pressure and the temperature of the vaporized refrigerant and drives it to the condenser. The refrigerant is now hotter than the outside air, and as that air is blown by the outdoor fan over the condenser, the refrigerant cools and condenses into liquid form.

The liquefied refrigerant enters the metering device, which lowers the pressure and the temperature of the refrigerant and sends it back to the evaporator, as the cycle is repeated.

Thermodynamic analysis of energy facilities has two objectives:

Determining a process's thermodynamic efficiency and finding the best strategy for such energy's optimal use.

Two approaches to systems analysis have thus been used to date:

The so-called energetic approach based exclusively on the first law of thermodynamics and the energetic approach supporting the energetic approach by including the second law of thermodynamics as a crucial part of current energy use.

Analysis of the application of the first law cannot be separated from analysis of the second law, especially in systems involving associated work with or exploitation of energy sources at different temperatures. Applying both criteria constitutes a powerful tool for quantitative and qualitative evaluation of energy systems and processes thus enabling potential useful energy to be detected and assessing ways of optimising their use.

This study was aimed at evaluating refrigeration cycle behaviour by vapour compression in a chilled water central air conditioning system by adopting a thermodynamic approach. Irreversibility was determined for the cycle' s main components as well as their influence on the cycle' s total irreversibility. Their variability and impact on operational conditions was assessed. The use of artificial neural networks (for modelling and determining the refrigerant' s thermodynamic properties) and a genetic algorithm (describing the system' s behaviour) were incorporated as innovative tools for making the calculations. These artificial intelligence techniques facilitate calculation and simplify models. They have proved to be as accurate as more complex and rigorous thermodynamic models. In the particular case of this study, it was found that using these artificial intelligence tools outweighed the difficulties of thermodynamic modelling of some elements of the system being analysed with no loss or demerit regarding rigorous thermodynamics, for they are only used in relation to aspects like working substance reproduction properties.

Today, attention to indoor air conditioning is becoming increasingly important. Ventilation systems are used under safe and high-quality conditions with minimal energy dissipation in order to provide the most favorable environmental conditions through the flow of air and prevention of contamination accumulation.

The shape of air flow in the interior is heavily influenced by the air distribution system and the way air enters and exits. In the simplest case, airflow can naturally flow into buildings, halls, tunnels, electricity chambers and other chambers such as computer cases. However, there will not be enough room for the airflow generated by the movement of objects inside these spaces.

Therefore, to improve indoor airflow and design of buildings, it is very important to explore the most efficient ventilation systems. While natural ventilation does not force the electric energy in exchange, mechanical ventilation requires a certain amount of energy to activate the fans and adjust the auto input and other electrical equipment. Obviously, energy efficiency optimization is needed to reduce the demand for electric power and also reduce costs. Optimizing building design and improving ventilation efficiency may help reduce costs and indirectly reduce fossil fuel consumption or other non-renewable resources and also may help control global warming.

Working Process:

Air conditioners transfer heat from the indoors to the outdoors.

Although we may think that air conditioners create cold air, they actually extract heat from the indoor air and send it outside.
When heat is removed from the indoor air, the air is cooled down. It's best to think of the air conditioning process as heat flowing from the indoors to the outdoors.

The Refrigeration Cycle:

An air conditioner works using a thermodynamic cycle called the refrigeration cycle. It does this by changing the pressure and state of the refrigerant to absorb or release heat.

The refrigerant (aka coolant) absorbs heat from inside of your home and then pumps it outside.

Most air conditioners are air-source, split systems. What this means is that there is one unit inside and one unit outside, which is why it is called a split system.

The air-source part refers to the place where the thermal energy is dumped, the outside air. There are other potential places where the heat can be transferred, such as water or ground, known as water-source, or ground-source systems.

The inside unit is normally inside the house somewhere, in the attic, basement, closet or crawl space. The outside unit is normally located on the side or back of the building.
Here are the basic parts of the refrigeration cycle (the same process that your refrigerator used to keep food cold):

Air flows over the indoor coils, which contain extremely cold refrigerant
When air flows over the cold coils, heat from the air gets transferred to the refrigerant inside the coils. After the air flows over the coils, it gets cold, normally

dropping around 20 degrees.
This process follows the 2nd law of thermodynamics, which says that heat naturally (spontaneously) flows from a warmer body to a cooler body.

After the refrigerant absorbs the heat, its state changes from a liquid to a vapor. This warmer refrigerant gas then gets transferred to the compressor (step 2 in the refrigeration cycle).

Warmer, vaporized refrigerant gets compressed (pressurized) to a hot temperature.
Even though the refrigerant has absorbed heat from the indoor air, it is still fairly cool. The still cool, but warmer vaporized gas enters the compressor (located in the outside unit) to increase its pressure and temperature.

We increase the temperature of the refrigerant because it needs to be warmer than the outdoor air. Remember the 2nd law of thermodynamics again—heat flows from warmer to cooler bodies.

If the refrigerant is 120 degrees and the outdoor air is 90 degrees, the outdoor air is cooler, which means the heat from the refrigerant will flow in the direction we want—outside. If the temperature outside is 120 degrees, the compressor will have to work extra hard to increase the temperature of the refrigerant to a higher temperature.

After the refrigerant's temperature is increased above that of the outdoor air's temperature, it then flows into another set of coils, known as the condenser coils (also located outside).

Very hot refrigerant flows into condenser coils where it loses heat to the outdoor air
Since the refrigerant has been compressed (pressurized), it is now hotter than the outdoor air. A condenser fan blows hot outdoor air over the even hotter outdoor condenser coils.

As outdoor air flows over the outdoor coils, heat is removed from the refrigerant and released into the outdoor air. Again, this is due to the 2nd law of thermodynamics.

After the refrigerant loses thermal energy to the outdoor air, it condenses back into a liquid and gets pumped back inside.
The still warm refrigerant from the outdoor unit needs to get cold.

When the refrigerant leaves your outdoor condenser unit, its temperature is still pretty high. The refrigerant's temperature will need to drop significantly before it can absorb more heat from the indoor air.

The metering device, usually a thermostatic expansion valve, is a special device that depressurizes the refrigerant, causing a drop in temperature. It does this by expanding the refrigerant into a larger volume.

The refrigerant needs to be colder than the indoor air in order to absorb heat. Once the refrigerant gets cooled down, it flows back into the evaporator coils where it begins the refrigeration cycle again.
The refrigeration cycle is basically the same for your freezer and refrigerator.

Three Laws of Thermodynamics:

1. First Law- Energy cannot be created or destroyed, but can change form, and location. For instance, burning wood changes the internal energy in the wood into heat and light energy.

2. Second Law- The Second Law is the most understandable and useful in real world applications, and makes heating, air conditioning, and refrigeration possible. Energy must flow from a higher state to a lower state. That is, heat must always flow from the warmer object to a cooler object and not from the cooler object to the warmer object.
The Second Law holds in our everyday visible world, but on the subatomic level the law is constantly violated, but statistically the law holds true. Although beyond the scope of this article, an interested reader will find fascinating theories in quantum mechanics. A search of the "arrow of time" will yield interesting variations of the Second Law.

3. Third Law- As a system approaches Absolute Zero, the entropy of the system approaches a minimum value. Absolute Zero cannot be attained in a real system, it is only a theoretical limit.
Air cycle refrigeration has been used in aircraft air conditioning systems for many years. In this application, an air cycle has the advantage of lower weight relative to vapor compression units and it can make use of existing high-pressure air from the engine compressor.

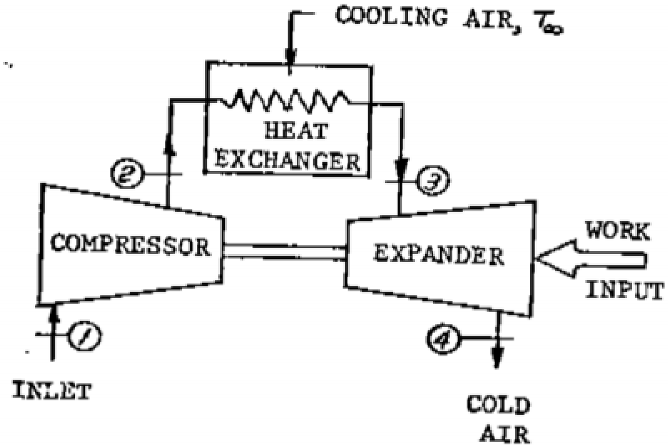


Fig 2.1 : Basic Aircraft AirCycle Unit

Air cycle refrigeration has been used in aircraft air conditioning systems for many-years. (fig 1.1)
In ground-based applications an air cycle unit requires its own compressor. Here, the compressor and expander efficiencies become important factors governing the competitiveness of air cycle systems relative to vapor-compression systems.
Performance with dry air
The basic air cycle unit employing its own compressor is shown in figure 2. For this unit one may define a coefficient of performance (COP) as-

$$\mathbf{COP} = \frac{\textbf{Cooling effect}}{\textbf{work input}} = \frac{\mathbf{h1\text{-}h4}}{\mathbf{Wc\text{-}We}}$$

For a typical unit using turbomachines, $n_c = n_e = 0.85$ is about the maximum possible efficiency and E = 0.95 is the upper limit for a good heat exchanger.

Principle of air conditioning:

Air conditioning operates based on the principles of **phase conversion**, which is the transformation of a material from one state (or phase) of matter to another, such as when a material changes from a liquid to a gas. When a liquid to gas change occurs, the material absorbs heat. Conversely, when the material changes from gas to liquid, it releases heat. An air conditioner is basically a machine that forces phase conversion and uses the resulting heat transfer principles to cool buildings.
Air conditioners are comprised of many components, the primary ones being a fluid compressor, a condenser and an evaporator coil.

Components of air conditioning unit:

In its simplest form, the air conditioning cycle consists of just 4 basic components to complete the circuit:

All air-conditioning systems utilize a specific material to undergo the phase conversion process. This material is called a refrigerant, and is contained within tubing which runs throughout the air-conditioning system.

The refrigerant is pulled into the system's compressor in the form of a warm vapor after leaving the evaporator coil.

The **compressor** increases the density of the incoming refrigerant vapor, causing it to increase in pressure and temperature. This is normally accomplished using a centrifugal system, where a series of spinning blades rapidly forces the vapor to the outside of the compressor chamber, at which point it exits.

This hot, high-pressure vapor then travels to the air conditioner's **condenser** where it moves through a series of coils with thin metal fins attached. A fan blows air over the fins, and heat moves from the refrigerant to the fins and into the air stream. The air that is run over the condenser coils is vented to the building exterior and is released to the atmosphere.

This trip through the condenser causes the vapor to lose a significant amount of heat and it subsequently changes phase from a gas to a high temperature liquid. The liquid refrigerant is then forced through an **expansion valve** which is basically a pinhole that causes the liquid to form a mist. A sudden pressure drops and material expansion when the liquid turns into a mist results in a rapid cooling of the fluid as it throws off heat energy.

This cold mist travels through the **evaporator coil** which is located directly in the air stream of a circulation fan which pulls air from within the building. The fan pushes the air across the cold coils, which pulls heat from the air, causing the air to cool. The transfer of heat to the refrigerant causes it to change back into a warm vapor and it enters the compressor to begin the cycle again.

Working of air conditioning unit:

An air conditioning system uses principles of thermodynamics to cool a living space. In simple terms, it is a closed system that circulates a substance called a refrigerant, altering the pressure of the refrigerant at different points to promote the transfer of heat.

We will describe the cycle starting indoors, where the refrigerant is a cold, low-pressure mixture of liquid and vapor that enters the evaporator. The indoor fan blows hot air from the living space over the evaporator, which absorbs the heat, cooling the air blown back into the living space. The heat absorbed by the evaporator turns the refrigerant completely into vapor, and is carried outside as the refrigerant travels to the compressor.

The compressor dramatically increases the pressure and the temperature of the vaporized refrigerant and drives it to the condenser. The refrigerant is now hotter than the outside air, and as that air is blown by the outdoor fan over the condenser, the refrigerant cools and condenses into liquid form.
The liquefied refrigerant enters the metering device, which lowers the pressure and the temperature of the refrigerant and sends it back to the evaporator, as the cycle is repeated.

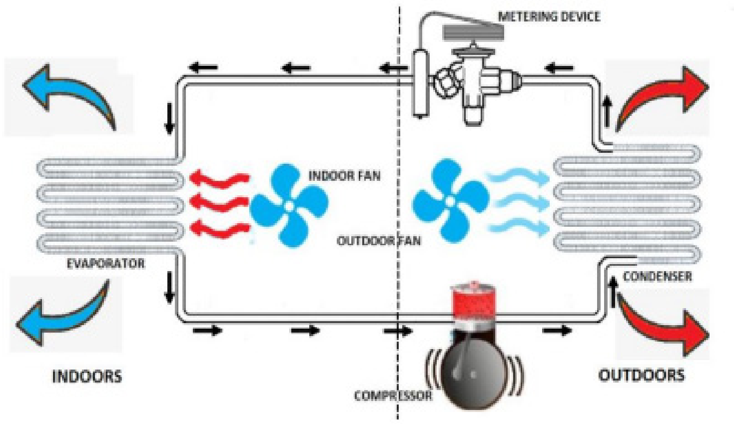


Fig 2.2. : Air Conditioner

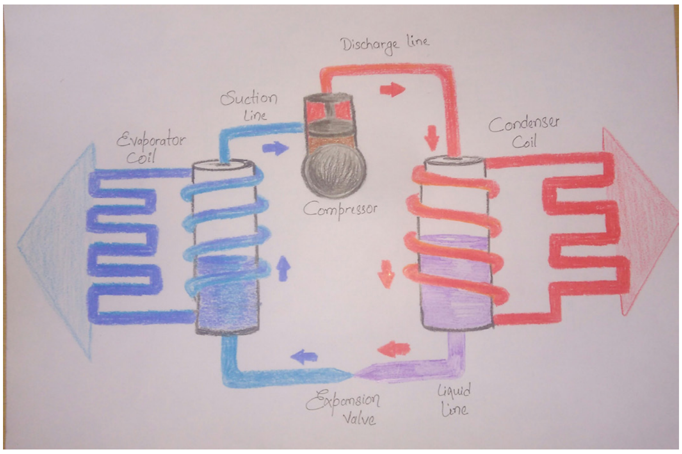


FIG 2.3 : Working of an AC unit

Cycle Analysis:

The Refrigeration cycle:

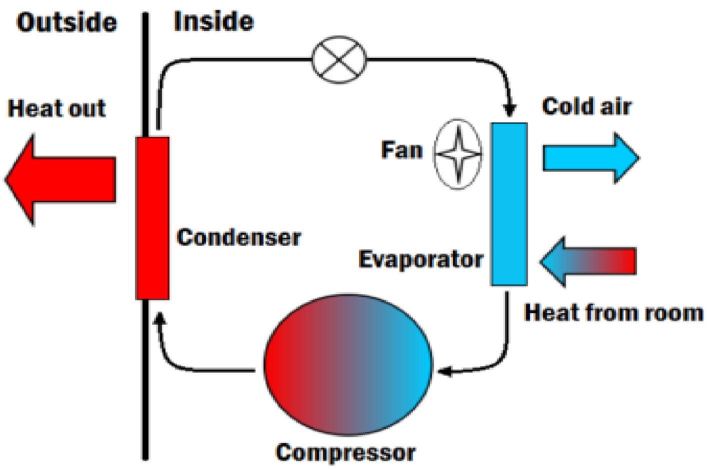


Fig 3.1 : The cycle for an air conditioner must use work supplied by electricity in order to function.

An air conditioner works using a thermodynamic cycle called the refrigeration cycle. It does this by changing the pressure and state of the refrigerant to absorb or release heat. The refrigerant (also known as coolant) absorbs heat from inside of your home and then pumps it outside. Most air conditioners are air-source, split systems. What this means is that there is one unit inside and one unit outside, which is why it is called a split system.
The air-source part refers to the place where the thermal energy is dumped, the outside air. There are other potential places where the heat can be transferred, such as water or ground, known as water-source, or ground-source systems.
The inside unit is normally inside the house somewhere, in the attic, basement, closet or crawl space. The outside unit is normally located on the side or back of the building. Other kinds of air conditioning systems, such as ground source and water-source, follow the refrigeration cycle, but some of the specifics, such as location and parts may differ.

Here are the basic parts of the refrigeration cycle (the same process that your refrigerator used to keep food cold):

- Air flows over the indoor coils, which contain extremely cold refrigerant.
- When air flows over the cold coils, heat from the air gets transferred to the refrigerant inside the coils. After the air flows over the coils, it gets cold, normally dropping around 20 degrees. This process follows the 2nd law of thermodynamics, which says that heat naturally (spontaneously) flows from a warmer body to a cooler body. After the refrigerant absorbs the heat, its state changes from a liquid to a vapor. This warmer refrigerant gas then gets transferred to the compressor (step 2 in the refrigeration cycle).
- Warmer, vaporized refrigerant gets compressed (pressurized) to a hot temperature.

Even though the refrigerant has absorbed heat from the indoor air, it is still fairly cool. The still cool, but warmer vaporized

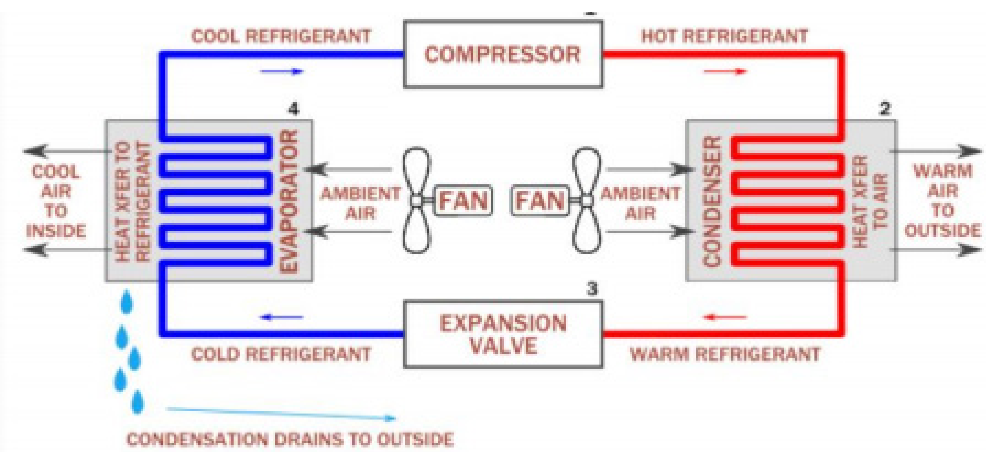


Fig 3.2 : Block Diagram of Air conditioning system

gas enters the compressor (located in the outside unit) to increase its pressure and temperature. We increase the temperature of the refrigerant because it needs to be warmer than the outdoor air. Remember the 2nd law of thermodynamics again—heat flows from warmer to cooler bodies. If the refrigerant is 120 degrees and the outdoor air is 90 degrees, the outdoor air is cooler, which means the heat from the refrigerant will flow in the direction we want—outside. If the temperature outside is 120 degrees, the compressor will have to work extra hard to increase the temperature of the refrigerant to a higher temperature. After the refrigerant's temperature is increased above that of the outdoor air's temperature, it then flows into another set of coils, known as the condenser coils (also located outside).

- Very hot refrigerant flows into condenser coils where it loses heat to the outdoor air.

Since the refrigerant has been compressed (pressurized), it is now hotter than the outdoor air. A condenser fan blows hot outdoor air over the even hotter outdoor condenser coils. As outdoor air flows over the outdoor coils, heat is removed from the refrigerant and released into the outdoor air. Again, this is due to the 2nd law of thermodynamics. After the refrigerant loses thermal energy to the outdoor air, it condenses back into a liquid and gets pumped back inside.

- The still warm refrigerant from the outdoor unit needs to get cold.

When the refrigerant leaves your outdoor condenser unit, its temperature is still pretty high. The refrigerant's temperature will need to drop significantly before it can absorb more heat from the indoor air. The metering device, usually a thermostatic expansion valve, is a special device that depressurizes the refrigerant, causing a drop in temperature. It does this by expanding the refrigerant into a larger volume. The refrigerant needs to be colder than the indoor air in order to absorb heat. Once the refrigerant gets cooled down, it flows back into the evaporator coils where it begins the refrigeration cycle again.

Refer to the block diagram for Air conditioning unit:

Processing of air conditioning unit:

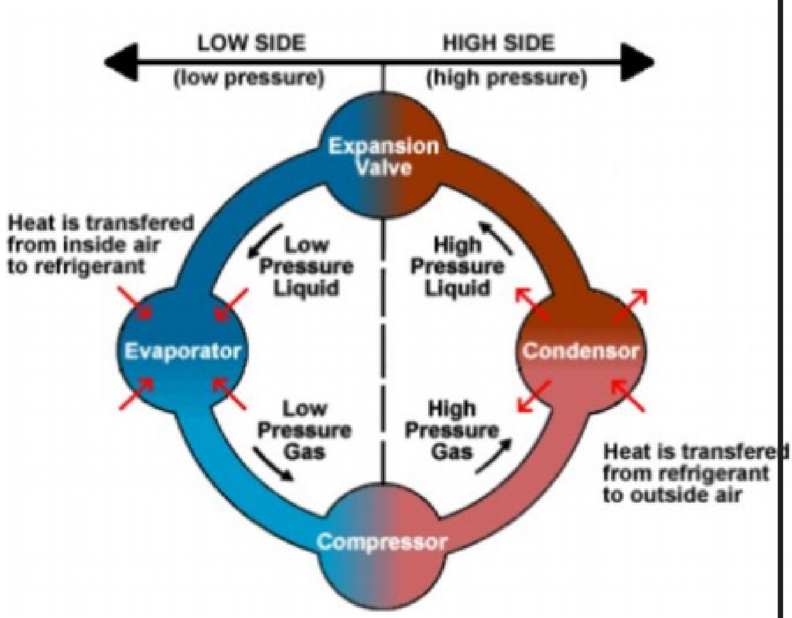


Fig 3.3 : Processing of AC

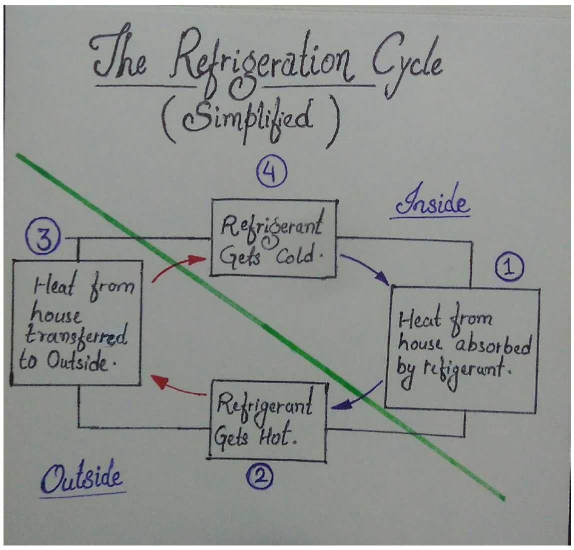


Fig 3.4 : Refrigeration cycle

TYPES OF AIR CONDITIONING UNITS:

1. Room air conditioning unit

ROOM AIR CONDITIONING UNIT

- WINDOW AC UNIT
- SPLIT AC UNIT

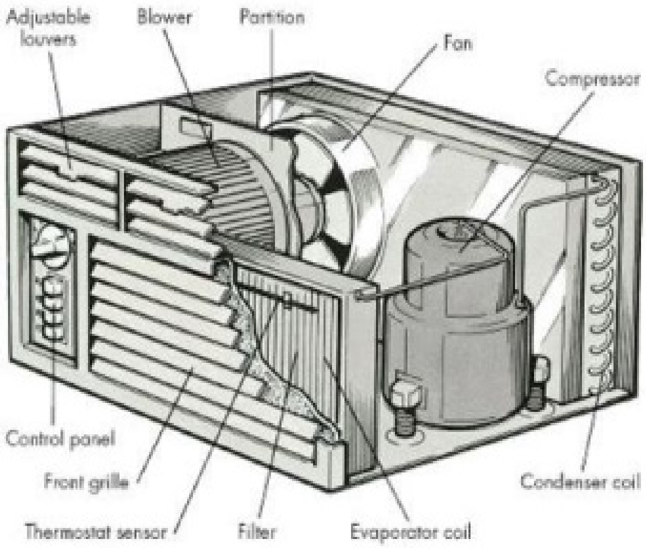


FIG 3.5 : Window AC unit

Window Unit	Split Unit
Noise is on higher side	Minimal Noise
Capacity range is 0.75 ton to 2 ton	Capacity range is 0.8 ton to 2 ton
Ease of installation	Need some efforts in installation
Suitable for small rooms with a window sill	Suitable for any room

Table 3.6 : Comparison between Window unit and Split unit

2. Package air conditioning unit

PACKAGE AIR CONDITIONING UNIT

- WATER COOLED CONDENSER
- AIR COOLED CONDENSER

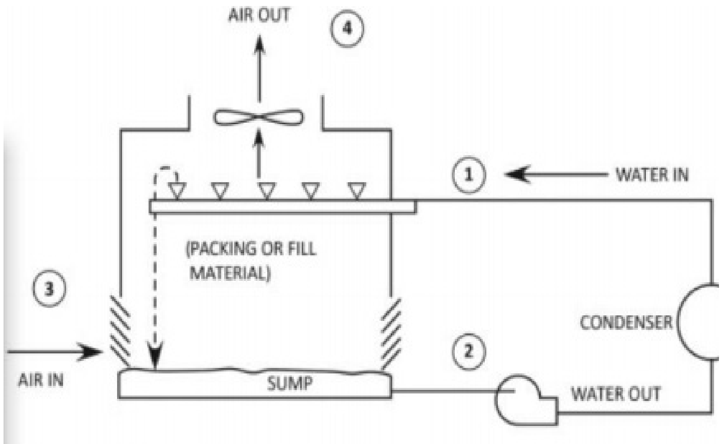


FIG 3.7 : Water Cooled Condenser

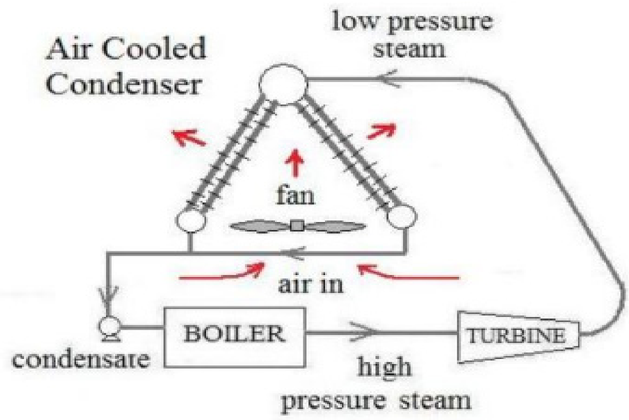
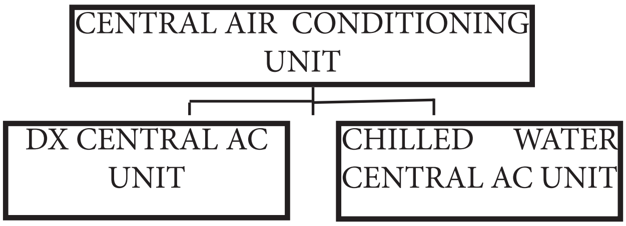


FIG 3.8 : Air Cooled Condenser

3. Central air conditioning unit



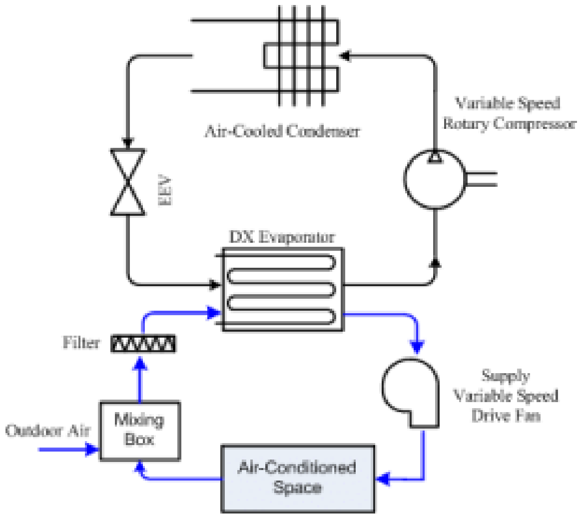


FIG 3.9 : DX Central Air Conditioning Unit

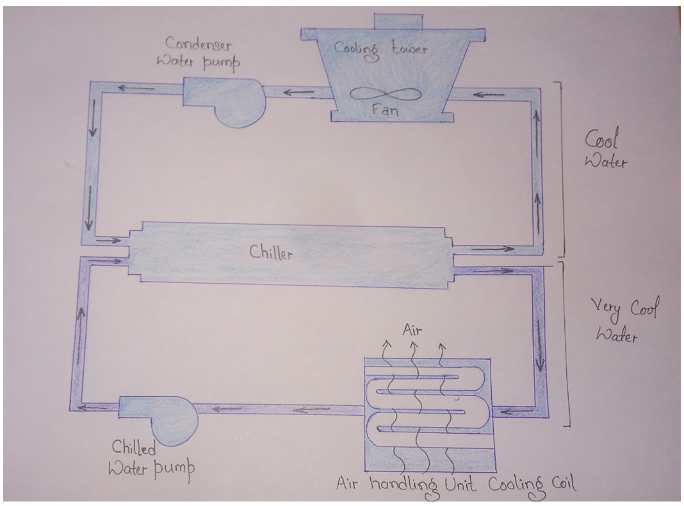


FIG 3.10 : Chilled Water Central AC system with a cooling tower

Mathematical Deduction:

Nomenclature

N	number of hexahedron cells
a	grid spacing
n	number of nodes
ρ	density of fluid
t	time
u	velocity magnitude in x direction
v	velocity magnitude in y direction
w	velocity magnitude in z direction
τ	shear stress
P	pressure
e	internal energy
k	turbulent kinetic energy
ε	rate of dissipation
μ_t	turbulent viscosity
G_k	generation of turbulent kinetic energy due to the mean velocity gradients
G_b	generation of turbulent kinetic energy due to buoyancy
Y_M	contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate
Pr_t	Prandtl number
$C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$	constants used in turbulent model
σ_k	turbulent Prandtl numbers for k
σ_ε	turbulent Prandtl numbers for ε
E	total energy
$(\tau_{ij})_{\text{eff}}$	deviatoric stress tensor
T	temperature
c_p	specific heat capacity at constant pressure
C_{ij}	convection term in Reynolds stress transportation equation
D_{ij}^{T}	turbulent diffusion term in Reynolds stress transportation equation (RSTE)
D_{ij}^{L}	molecular diffusion term in RSTE
P_{ij}	stress production term in RSTE
G_{ij}	buoyancy production term in RSTE
ϕ_{ij}	pressure strain term in RSTE
ε_{ij}	dissipation term in RSTE
F_{ij}	production by system rotation term in RSTE
μ	dynamic viscosity
I	number of iterations

There are three groups of basic equations, which are derived from three basic physics laws of conservation. The mass conservation, momentum conservation and energy conservation results in the continuity equation, Navier– Stokes equation and energy equation, respectively. Since the flow in an air conditioning room is turbulent flow [10], the k–epsilon and the Reynolds stress viscous models have been chosen for investigation. The standard k–epsilon model is a semi-empirical model based on model transport equations for the turbulent kinetic energy (k) and its dissipation rate (e). The transport equation for k is derived from the exact equation, while the transport equation for e is obtained using physical reasoning and bears little resemblance to its mathematically exact counterpart. The turbulent kinetic energy, k, and its rate of dissipation, e, are obtained from the following transport equations:

$$\rho \frac{\mathrm{D}k}{\mathrm{D}t} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + G_k + G_b - \rho\varepsilon - Y_M, \qquad (1)$$

$$\rho \frac{\mathrm{D}\varepsilon}{\mathrm{D}t} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}. \qquad (2)$$

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i}[u_i(\rho E + p)] = \frac{\partial}{\partial x_i}\left[\left(k + \frac{c_p\mu_t}{Pr_t}\right)\frac{\partial T}{\partial x_i} + u_j(\tau_{ij})_{\text{eff}}\right] + S_h.$$

For a single office room, normally a split unit will be used. There are three most suitable blower placement, which have been named as locations I, II and III as shown in Fig. 1(b)–(d), respectively.

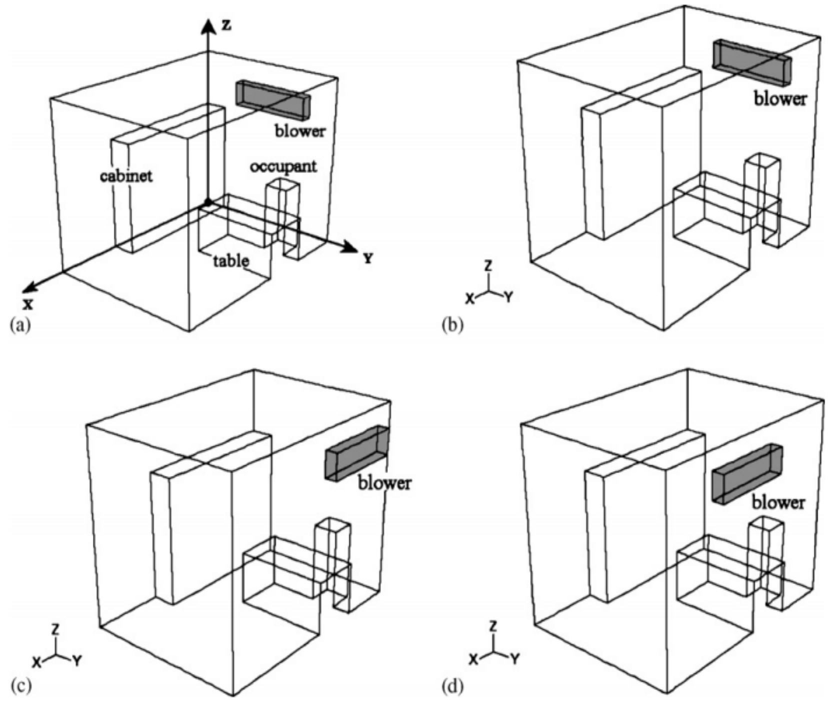


Fig 4.1: The sketch of the room model: (a) coordinate system for the entire room; (b) blower placement in location I; (c) blower placement in location II and (d) blower placement in location III.

The turbulent kinetic energy, k, and its rate of dissipation, e, are obtained from the following transport equations:

$$\rho \frac{Dk}{Dt} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + \frac{1}{2}(P_{ii} + G_{ii}) - \rho\varepsilon(1 + 2M_t^2),$$

$$\rho \frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{\varepsilon 1}\frac{1}{2}[P_{ii} + C_{\varepsilon 3}G_{ii}]\frac{\varepsilon}{k} - C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k}.$$

The convective heat and mass transfer modeling in the Reynolds stress models will be same as k-epsilon model, which is given by the following relation:

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i}[u_i(\rho E + p)] = \frac{\partial}{\partial x_i}\left[\left(k + \frac{c_p \mu_t}{Pr_t}\right)\frac{\partial T}{\partial x_i} + u_j(\tau_{ij})_{\text{eff}}\right] + S_h.$$

To solve these equations, initial and boundary condition must be specified around the boundary of system (domain). Because the equations are highly nonlinear, they are not solvable by explicit, closed-form analytical methods. The numerical finite volume method as used in Fluent has been used for solving the equations.

Mathematical models of the four components:

Nomenclature

A_v	opening percentage of electronic expansion valve
c	constants of hybrid model
f	function
F	frequency of fans (Hz)
K	penalty
H	enthalpy (kJ/kg)
$H_{c,fg}$	enthalpy difference of gas and liquid saturated refrigerant in condenser (kJ/kg)
$H_{c,r,i}$	condenser inlet refrigerant enthalpy (kJ/kg)
$H_{c,r,o}$	condenser outlet refrigerant enthalpy (kJ/kg)
$H_{e,fg}$	enthalpy difference of gas and liquid saturated refrigerant in evaporator (kJ/kg)
$H_{e,r,i}$	evaporator inlet refrigerant enthalpy (kJ/kg)
$H_{e,r,o}$	evaporator outlet refrigerant enthalpy (kJ/kg)
$\dot{m}_{c,air}$	air flow rate of condenser (kg/s)
$\dot{m}_{c,air,nom}$	nominal air flow rate of condenser (kg/s)
$\dot{m}_{e,air}$	air flow rate of evaporator (kg/s)
$\dot{m}_{e,air,nom}$	nominal air flow rate of evaporator (kg/s)
$\dot{m}_r$	refrigerant mass flow rate (kg/s)
$\dot{m}_{r,max}$	maximal refrigerant mass flow rate (kg/s)
$\dot{m}_{r,min}$	minimal refrigerant mass flow rate (kg/s)
n	polytropic exponent
P_c	condenser refrigerant saturated pressure (bar)
$P_{c,max}$	maximal condenser saturated pressure allowed (bar)
$P_{c,min}$	minimal condenser saturated pressure allowed (bar)
P_e	evaporator refrigerant saturated pressure (bar)
$P_{e,max}$	maximal evaporator saturated pressure allowed (bar)
$P_{e,min}$	minimal evaporator saturated pressure allowed (bar)
$\dot{Q}_c$	condenser energy exchange rate (kJ/kg)
$\dot{Q}_e$	evaporator energy exchanger rate (kJ/kg)
$\dot{Q}_{com}$	mechanical work of compressor (kJ/kg)
$\dot{Q}_{req}$	required cooling load (kJ/kg)
$T_{c,air,i}$	condenser inlet air temperature (°C)
$T_{c,max}$	maximal refrigerant saturation temperature in condenser (°C)
$T_{c,min}$	minimum refrigerant saturation temperature in condenser (°C)
$T_{c,r,i}$	condenser inlet refrigerant temperature (°C)
$T_{c,sc}$	condenser subcool temperature (°C)
$T_{c,r,sat}$	condenser refrigerant saturated temperature (°C)
$T_{c,r,i}$	condenser refrigerant inlet temperature (°C)
$T_{c,r,o}$	condenser refrigerant outlet temperature (°C)
$T_{e,r,sat}$	refrigerant saturated temperature in evaporator (°C)
$T_{e,max}$	maximal refrigerant saturation temperature in evaporator (°C)
$T_{e,min}$	minimal refrigerant saturation temperature in evaporator (°C)
$T_{e,sh}$	evaporator superheat temperature (°C)
V_a	volume at bottom dead center (m^3)
V_d	volume when suction valve open (m^3)
$\dot{W}_{c,fan}$	condenser fan power (kW)
$\dot{W}_{c,fan,nom}$	condenser fan power when air flow rate is $m_{c,air,nom}$ (kW)
$\dot{W}_{com}$	electricity power consumption of compressor (kW)
$\dot{W}_{c,fan}$	evaporator fan power (kW)
$\dot{W}_{e,fan,nom}$	evaporator fan power when air flow rate is $m_{e,air,nom}$ (kW)
$\dot{W}_{total}$	total power (kW)
η	enthalpy delivery efficiency
ω	compressor rotation speed (r/s)
ρ	inlet refrigerant density (kg/m^3)

Subscripts

air	feature of air
c	condenser
com	compressor
e	evaporator
ev	expansion valve
i	inlet
o	outlet
m	mass flow rate
q	heat exchange
η	enthalpy delivery efficiency

Evaporator:

Heat transfer properties in evaporator :

$$\dot{Q}_e = \frac{(H_{e,g} - H_{e,r,i})\dot{m}_r + c_{e,1}\dot{m}_r^{c_{e,3}}(T_{e,air,i} - T_{e,r,sat})}{1 + c_{e,2}\left(\dfrac{\dot{m}_r}{\dot{m}_{e,air}}\right)^{c_{e,3}}}$$

where $c_{e,1}$, $c_{e,2}$ and $c_{e,3}$ are constants obtained by fitting experiment data, $H_{e,g}$, $H_{e,r,i}$, $\dot{m}_r$, $\dot{m}_{e,air}$, $T_{e,air,i}$, $T_{e,r,sat}$ and $\dot{Q}_e$ are the enthalpy of saturated gas phase refrigerant in evaporator, refrigerant enthalpy of evaporator inlet, mass flow rates of refrigerant, air outside evaporator, temperature of inlet air and saturated refrigerant of evaporator, heat exchanging rate of evaporator, respectively (see Appendix B for the calculations of $H_{e,g}$, $H_{e,r,i}$ and $T_{e,r,sat}$).

Energy balance equation

$$\dot{Q}_e = \dot{m}_r(H_{e,r,o} - H_{e,r,i})$$

Where He,r,o is refrigerant enthalpy at evaporator.

Condenser:

Representation of condenser by hybrid model

$$\dot{Q}_c = \frac{c_{c,1}\dot{m}_r^{c_{c,4}}(T_{c,r,sat} - T_{c,air,i}) + c_{c,2}\dot{m}_r(T_{c,r,i} - T_{c,r,sat}) + H_{c,fg}\dot{m}_r}{1 + c_{c,3}\left(\frac{\dot{m}_r}{\dot{m}_{c,air}}\right)^{c_{c,4}}}$$

where $c_{c,1}$, $c_{c,2}$, $c_{c,3}$ and $c_{c,4}$ are constants calculated by fitting experiment data, $H_{c,fg}$ is enthalpy difference between saturated liquid and gas phase refrigerant in condenser, $\dot{m}_{c,air}$ is the mass flow rate of air outside condenser. $T_{c,r,sat}$, $T_{c,r,i}$, $T_{c,air,i}$ are temperature of saturated refrigerant, inlet refrigerant and inlet air of condenser, $\dot{Q}_c$ is the heat transferring rate of condenser (see Appendix B for the calculations of $H_{c,fg}$ and $T_{c,r,sat}$).

Energy balance equation

$$\dot{Q}_c = \dot{m}_r(H_{c,r,i} - H_{c,r,o})$$

where $H_{c,r,i}$ and $H_{c,r,o}$ are enthalpy of inlet and outlet refrigerant (see Appendix B for the calculations of $H_{c,r,i}$, and $H_{c,r,o}$).

Compressor :

In a compressor, the mass flow rate and the refrigerant energy change during compression stroke can be expressed:

$$\dot{m}_r = \left(c_{com,m,1} - c_{com,m,2}\left(\frac{P_c}{P_e}\right)^{c_{com,m,3}}\right)\omega$$

and

$$\dot{Q}_{com} = \frac{n}{n-1}(V_a - V_d)P_e\left[\left(\frac{P_c}{P_e}\right)^{\frac{n-1}{n}} - 1\right]\omega\dot{m}_r$$

where $c_{com,m,1}$, $c_{com,m,2}$ and $c_{com,m,3}$ are constants determined by curve fitting, P_c, P_e, ω, n, V_a, V_d, and $\dot{Q}_{com}$ are condensing temperature, evaporating pressure, compressor rotation speed, polytropic exponent, volume at bottom dead center, volume when suction valve open and mechanical work input to refrigerant by compressor respectively. Since the parameters n, V_a and V_d are constants for a given compressor and at a specified working environment, Eq. (6) can be further simplified to a hybrid model form:

$$\dot{Q}_{com} = c_{com,q,1}\omega\dot{m}_r P_e\left(\left(\frac{P_c}{P_e}\right)^{c_{com,q,2}} - 1\right) \quad (7)$$

where $c_{com,q,1} = n/n - 1(V_a - V_d)$ and $c_{com,q,2} = n - 1/n$.

Expansion Valve:

The mass flow rate of expansion value is determined by value opening percentage, pressure difference and inlet refrigerant density. Its mass flow rate is given by

$$\dot{m}_r = (c_{ev,1} + c_{ev,2}A_v)\sqrt{\rho(P_c - P_e)}$$

where $c_{ev,1}$ and $c_{ev,2}$ are constants, A_v and ρ are opening percentage of electronic expansion valve and density of inlet refrigerant respectively (see Appendix B for the calculation of ρ). Since the expansion process is isenthalpic, it is assumed that refrigerant enthalpy is constant which implies $Q_{ev} = 0$.

Energy balance of overall cycle:- Finally, the corresponding energy balance equation for the overall system is given as

$$\dot{Q}_c = \dot{Q}_{com} + \dot{Q}_e$$

Optimization problem formulation:

The objective of global optimization for vapor compression refrigeration cycle is to satisfy cooling load requirement of cold reservoir with minimal energy consumption. Mathematically, it can be formulated as:

$$\text{Min } \dot{W}_{total} = \dot{W}_{com} + \dot{W}_{c,fan} + \dot{W}_{e,fan}$$
$$\text{Subject to } \dot{Q}_e = \dot{Q}_{req}$$

where $\dot{W}_{total}$, $\dot{W}_{com}$, $\dot{W}_{c,fan}$, $\dot{W}_{e,fan}$ and $\dot{Q}_{req}$ are total power consumption, power consumption of compressor, condenser fan power consumption, evaporator fan power consumption and required cooling load respectively. The power consumption models of the compressor, condenser fan and evaporator fan are formulated according to their working principles.

Power consumption of compressor:

Using a hybrid model to describe the delivery coefficient of compressor, ncom

$$\eta_{com} = c_{com,\eta,1} + c_{com,\eta,2}(P_c/P_e)^{c_{com,\eta,3}}$$

The power consumption of compressor is given as

$$\dot{W}_{com} = \frac{\dot{Q}_{com}}{\eta_{com}}$$

where $c_{com,\eta,1}$, $c_{com,\eta,2}$ and $c_{com,\eta,3}$ are constants calculated by catalog or experiment data.

Power consumptions of condenser fan and evaporator fan:

The power consumptions of fans are influenced by two parameters; mass flow rates of fluids and the pressure difference between the inlets and outlets and can be described:

$$\dot{W}_{c,fan} = \dot{W}_{c,fan,nom}\left(c_{c,fan,0} + c_{c,fan,1}\left(\frac{\dot{m}_{c,air}}{\dot{m}_{c,air,nom}}\right) + c_{c,fan,2}\left(\frac{\dot{m}_{c,air}}{\dot{m}_{c,air,nom}}\right)^2 + c_{c,fan,3}\left(\frac{\dot{m}_{c,air}}{\dot{m}_{c,air,nom}}\right)^3\right)$$

$$\dot{W}_{e,fan} = \dot{W}_{e,fan,nom}\left(c_{e,fan,0} + c_{e,fan,1}\left(\frac{\dot{m}_{e,air}}{\dot{m}_{e,air,nom}}\right) + c_{e,fan,2}\left(\frac{\dot{m}_{e,air}}{\dot{m}_{e,air,nom}}\right)^2 + c_{e,fan,3}\left(\frac{\dot{m}_{e,air}}{\dot{m}_{e,air,nom}}\right)^3\right)$$

vhere $c_{c,fan,0}$ to $c_{c,fan,3}$ and $c_{e,fan,0}$ to $c_{e,fan,3}$ are coefficients deternined by catalog or experiment data, $\dot{W}_{c,fan}$, $\dot{W}_{e,fan}$, $\dot{W}_{c,fan,nom}$, $\dot{V}_{e,fan,nom}$, $\dot{m}_{c,air,nom}$ and $\dot{m}_{e,air,nom}$ are measured power consumpions of condenser fan, measured power consumption of evapoator fan, nominal power consumption of condenser fan, nominal ower consumption of evaporator fan, nominal mass flow rate of ondenser fan and mass flow rate of evaporator fan respectively.

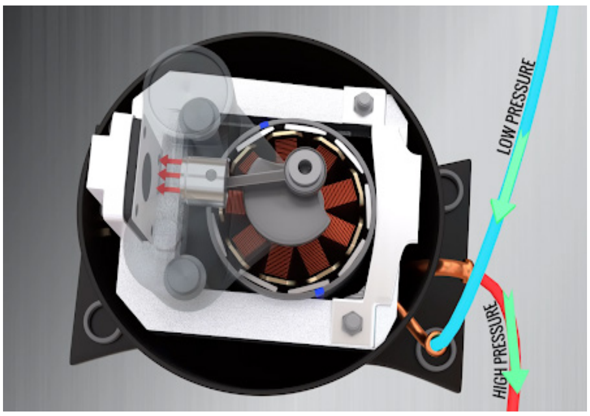


Fig 4.2: A compressor

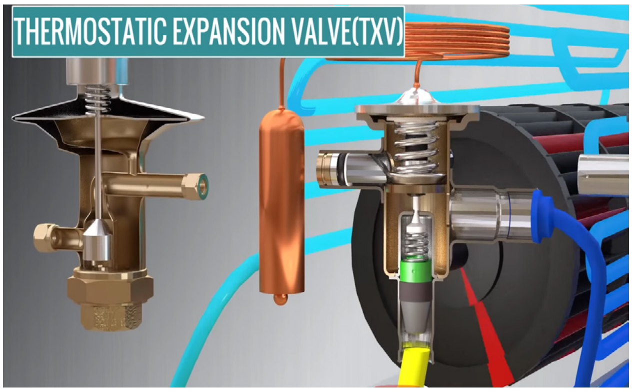


Fig 4.3: Expansion Valve:

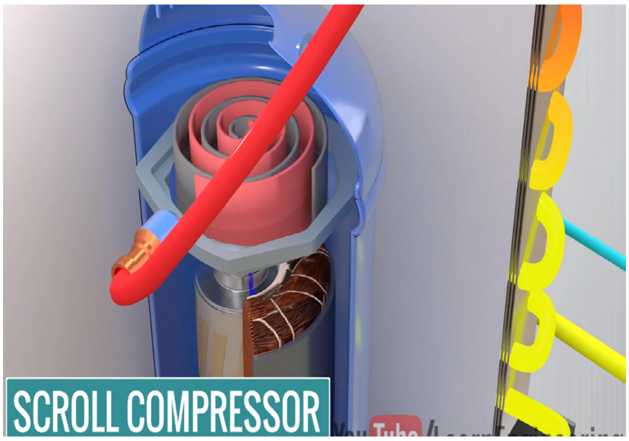


Fig 4.4: A scroll compressor

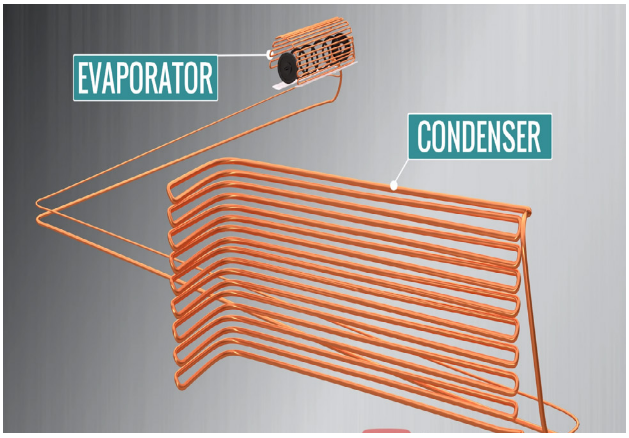
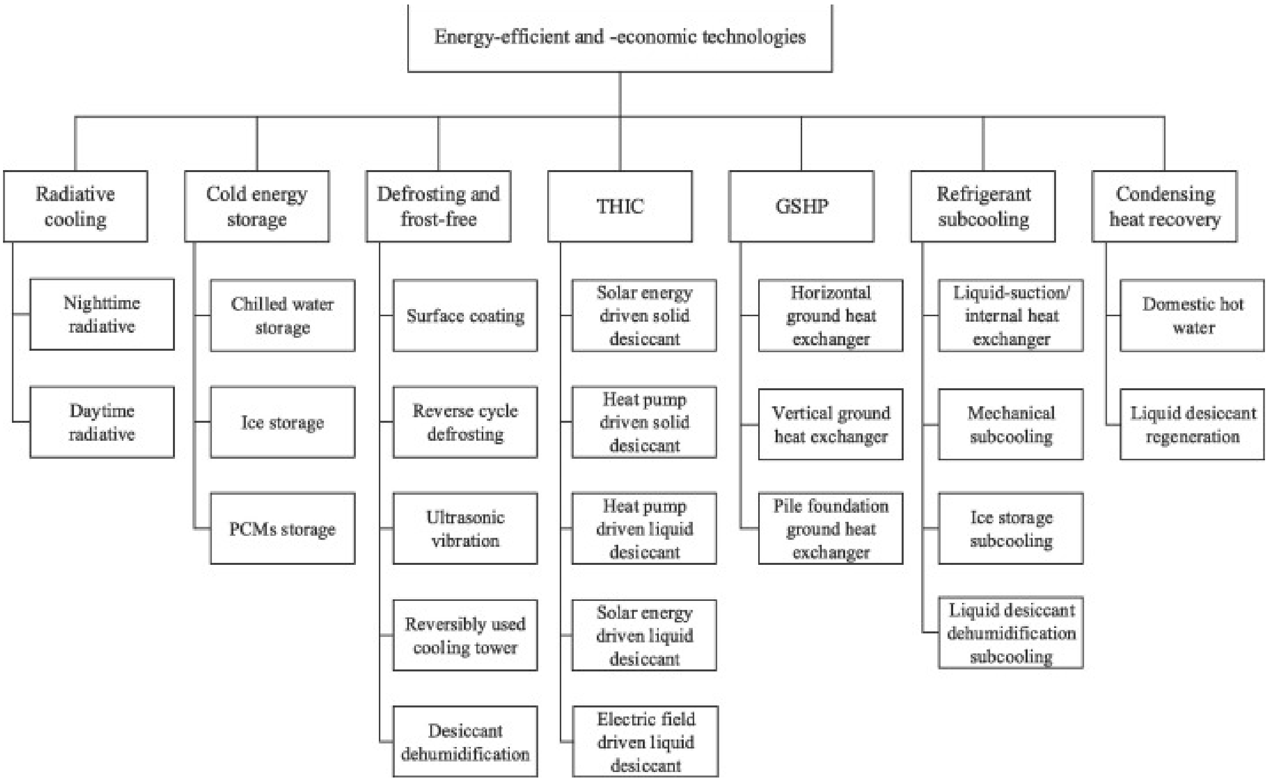


Fig 4.5: Evaporator and Condenser

Improvements:

Energy-efficient and economic technologies for air conditioning with vapor compression refrigeration:



Up to now, Vapor Compression Refrigeration System (VCRS) is the most popular and widely used refrigeration system, which has a market share of 80%. Therefore, it is critical to improve the efficiency of the VCRS for decreasing the energy consumption of refrigeration. As a matter of fact, relevant technologies have been investigated since early last century and some of them have been widely applied in the VCRS. These technologies include **radiative cooling, cold energy storage, defrosting and frost-free, temperature and humidity independent control (THIC), ground source heat pump (GSHP), refrigerant subcooling, and condensing heat recovery.**

(VCRS) are widely used to provide cooling or freezing for domestic/office buildings, supermarkets, data centres, etc., which expend 15% of globally electricity and contribute to 10% of greenhouse gas emissions globally. It is reported that cooling demand is expected to grow tenfold by 2050. Therefore, it is critical to improve the efficiency of the VCRS.

Radiative cooling could produce a cold source **8 °C lower than the surroundings, which reduces the electricity consumption** of the VCRS by 21%; cold energy storage is used to shift the peak cooling load, and as a result, the electricity consumption and operation cost of the VCRS could be reduced by 12% and 32%, respectively; frosting is a big issue of the VCRS especially for freezing applications, and more than 60% of electricity consumption for defrosting could be saved with the advanced defrosting and frost-free technologies; THIC deals with the building sensible load and latent load separately, which not only increases the COP of the VCRS by 35%, but also improves the building thermal comfort; GSHP uses the ground as a low-temperature cooling source for condensing the refrigerant in the VCRS in summer, which decreases the condensing temperature by 5 °C and correspondingly increases the COP of the VCRS by 14%; refrigerant subcooling and condensing heat recovery can increase the refrigerating capacity and achieve multi-functions of the VCRS, respectively.

Radiative Cooling:

Radiative cooling is a free cooling technology taking advantage of the Earth's transparent window. Nighttime radiative cooling has been widely investigated since 1918. However, the materials in the early stage can only provide cooling at night. The reason is that the radiative materials also absorb the solar light in the daytime which counteracts the cooling effect. To make it use in daytime, a good method is to reserve the cold energy at night while release it in the daytime.

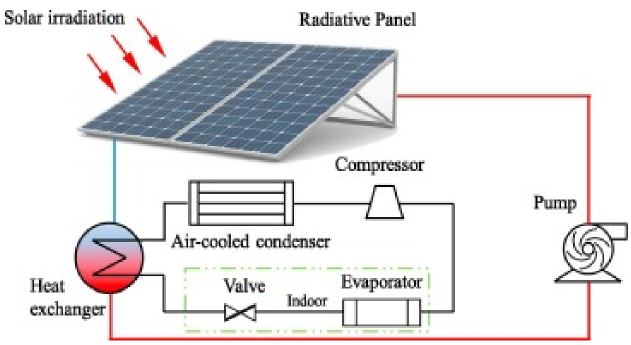


Fig 5.1: A radiative-cooled vapor compression refrigeration system

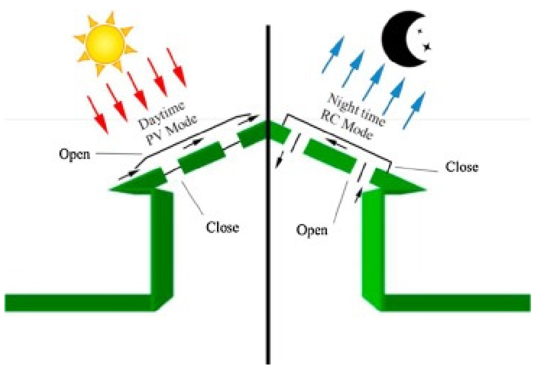


Fig 5.2: Schematic of the building integrated photovoltaic-radiative cooling system

The total electricity production and cooling energy gain of the system were **96.96% higher than those of radiative cooling** the building integrated photovoltaic system.

Absorption Cooling System

Absorption refrigeration technology was introduced to address some serious issues such as the **energy crisis, increased fuel prices, and environmental problems** associated with the conventional compression refrigeration systems. It has attracted an increasing deal of interest thanks to such advantages as utilization of low-grade heat sources and environment-friendly working fluid pairs. Nevertheless, this technology suffers from two major obstacles including the usually too large size of the cooling unit and the low coefficient of performance (COP), preventing the absorption systems from being commercially successful. Numerous research works have been done to develop strategies in order to improve the COP of the absorption systems, so as to make the absorption refrigeration technology more competitive with the conventional compression refrigeration systems. In this paper, it is intended to conduct a literature review on various technologies implemented to improve the COP of absorption refrigeration systems. Among effective and promising workarounds for increasing the COP of absorption refrigeration systems, this work refers to cycle design improvement, heat recovery method, development of new working pairs, adding sub-components, and improvement of operating conditions.
According to Henning, absorption refrigeration systems are responsible for almost 60% of all installed thermally driven refrigeration systems in Europe.

The following list presents several advantages of absorption refrigeration systems:

i. Absorption refrigeration systems can be thermally **driven by low-grade heat sources** (e.g., engine exhaust) and renewable sources of energy (e.g., solar energy). This makes the system very effective in the reduction of CO2 emission and very promising in saving energy.

ii. Absorption refrigeration systems work based on **environment-friendly refrigerants** such as water, minimizing their impact on the ozone layer and global warming;
iii. Absorption refrigeration systems **operate quietly** as those have almost no high-speed moving parts. This also makes their maintenance **cheap and easy**;
iv. Absorption refrigeration systems offer **heat recovery** from virtually any system;
v. With an absorption refrigeration system, there is **no cycling loss** during on-off operation during which the conventional VCRSs are known to produce lots of waste heat; and
vi. Absorption refrigeration systems are **very durable** with expected lifetimes of 20–30 years.

Improvement of absorption structures and mechanism:

- Operating fluid pairs:

An appropriate pair of absorbent (sorbent) and absorbate (refrigerant) is of great importance in the absorption cooling machine as the efficiency is considerably influenced by the thermodynamic properties of the solution. The followings shall be considered when choosing an appropriate working fluid pair in an absorption cooling system :

i. Large latent heats of concentration and vaporization for the refrigerant inside the absorbent;

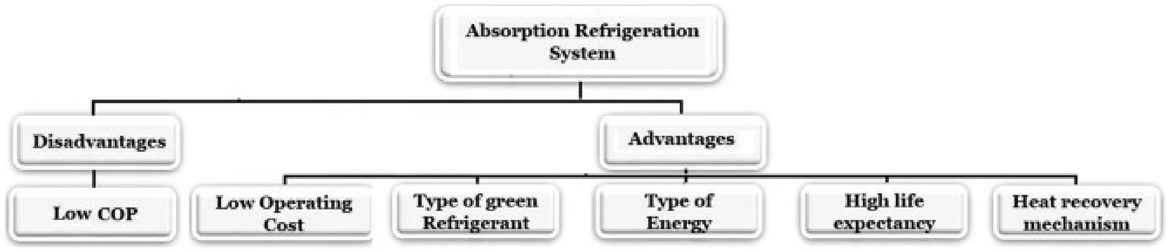


Fig 5.3: Main advantages and disadvantages of absorption refrigeration technology.

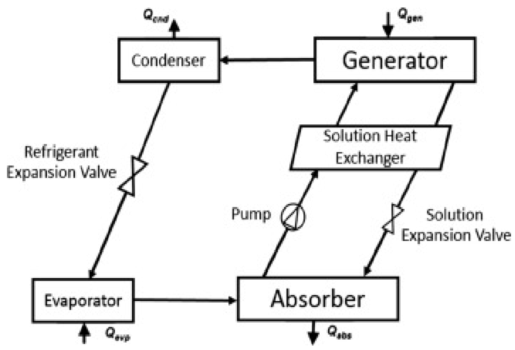


Fig 5.4: Schematic of single-effect absorption refrigeration system.

ii. Favorable thermodynamic properties such as viscosity, diffusive coefficient, and conductivity; and
iii. Chemical stability, environment-friendliness, and cost-effectiveness.

H2O-NH3 and LiBr-H2O mixtures represent the most common pair due to their significant thermodynamic properties.
The NH3-H2O system is frequently used for residential and light commercial refrigeration applications where lower temperatures are needed, while the LiBr-H2O system is widely employed for large commercial cooling applications where intermediate temperatures are required.

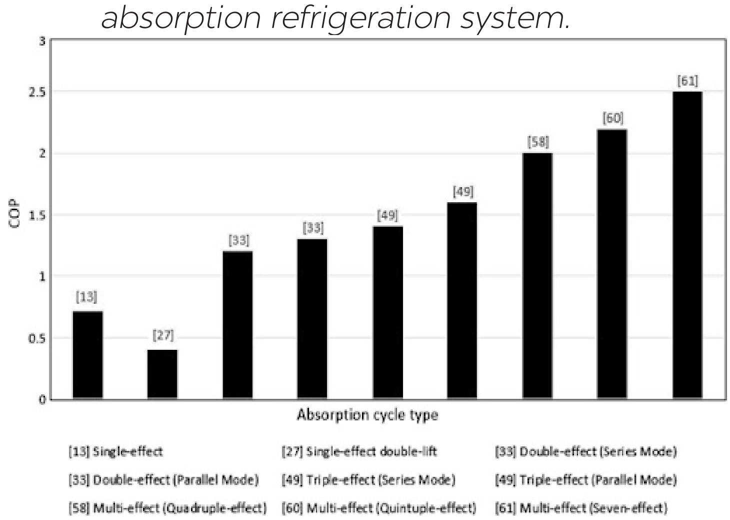


Fig 5.5: COP comparison for different cycle design configurations.

Refrigerant:

A refrigerant is a fluid that is used in air conditioners and refrigerators, to take heat from the contents of a refrigerator or the room (in the case of ACs) and throw the heat out in the atmosphere. A refrigerant undergoes phase changes from a liquid to gas (on absorbing heat) and back to liquid (when a compressor compresses it). The choice of ideal refrigerant is made based on its **favorable thermodynamic properties, non-corrosive nature, and safety (non-toxic and non-flammable).** Although many fluids can be used to act as a refrigerant, but in 20th century, CFCs became the most popular refrigerants.

Old and Modern refrigerants

The most common refrigerant in the past was a **CFC, most commonly called as Freon.** Freon was a brand name for a refrigerant "R-12" by DuPont. In the 1990s and 2000s, the CFCs were replaced with HCFCs (hydrochlorofluorocarbon) and the most common HCFC is "R-22".

50-60% of Air Conditioners in India still (in 2016) use HCFCs. However, **HCFCs are just marginally better than CFCs as they contain chlorine, which is harmful** for the environment. As per Indian Government's plan, HCFCs will be phased out from India by the year 2030.

To remove chlorine from the refrigerant, manufacturers created another set of refrigerants called **HFCs (or Hydro Fluro Carbons)**. Although they also have the potential for global warming, but still they are better than HCFCs as they do not deplete the ozone layer. **The most common HFC used in air conditioners is R-410A.** This refrigerant is better than R-22 in terms of "Ozone Depletion" potential and energy efficiency, but it still causes global warming. A few more HFCs that are commonly used are: **R-32 in Air Conditioners and R-134A in refrigerators.** About 20-30% of the air conditioners in India still (in 2016) use HFCs. **R-32 is better than R-410A in terms of global warming potential**, but then it is still an HFC. As per latest news, India plans to phase out HFCs as well in next few years, and the timeline for it is still under consideration.

The most environment-friendly refrigerants that are available in Indian market currently are "R-290" and "R-600A". They are HC or Hydrocarbons, and their chemical names are **"Propane" for R-290 and "Iso-Butane" for R-600A.** They are completely **halogen free, have no ozone depletion potential and are lowest in terms of global warming potential**. They also have high-energy efficiency but are highly flammable as they are hydrocarbons. But they are the greenest refrigerants in the market. In fact, most refrigerators in the Indian market are now on R-600A and there are no reported incidents of any accidents due to the same. So we can comfortably believe that they are safe.

If you are someone who cares about energy efficiency and global warming, go for an Air Conditioner with R-290 or a Refrigerator with R-600A. The more you opt for it, the more the manufacturers will start using them in their appliances. Hopefully, with stringent standards and better advancements in technology, we will be able to see better refrigerants in future.

Refriger-ant	**Global Warming Potential**	**Ozone Depletion-Potential**
R-22	1810	Medium
R-410A	2088	Zero
R-32	675	Zero
R-32	1430	Zero
R-134A	3	Zero
R-290	3	Zero

Fig 6.1: GWP and ODP comparisons for different refrigerants

Discussion and Conclusion:

Air-conditioning is the process used to create and maintain certain temperature, relative humidity, and air purity conditions in indoor spaces. This process is typically applied to maintain a level of personal comfort. It's also used in industrial applications to ensure the correct operation of equipment or machinery that need to operate in specific environmental conditions or alternatively to be able to carry out certain industrial processes, such as welding, which produce considerable amounts of heat that need to be disposed of in some manner.

An air-conditioning system must be effective regardless of outside climatic conditions and involves control over four fundamental variables: air temperature, humidity, movement, and quality.

Air-conditioning is based on the mechanism: a fluid, generally water or air, is cooled by evaporation of another fluid, called the refrigerant. The refrigerant circuit, comprising the compressor, evaporator, condenser, and expansion valve, is an integral part of the system.

An air conditioning cycle works using a thermodynamic cycle called the refrigeration cycle.

We have discussed and analysed the thermodynamic and fluid mechanical working of the air conditioner. And the principle of air conditioning, i.e matter state conversion.

Three laws of thermodynamics are discussed. The air conditioning unit operates on the principle of phase conversion. The main process underlying air-conditioning is the exchange of heat and water vapor between the indoor and outdoor environments and the people inside the air-conditioned space.

An air conditioning unit works using a thermodynamic cycle called the refrigeration cycle. There are three types of air conditioning units- Room ac unit, Package ac unit, Central ac unit.

Mathematical Deductions were carried out. Mathematical models of the four components have been studied.

We have also carried out discussions about the components involved inside the air conditioner that help convert the coolant from one state to another.

We have also discussed in brief the energy efficient technologies involved in air conditioning.

Also, discussion on energy-efficient and economic technologies for ac unit with vapor compression refrigeration has done. Improvements are suggested. Leading refrigerants supporting environment sustainable nature are discussed.

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