

Lesson

3

Applications Of Refrigeration & Air Conditioning

Objectives of the lesson:

The objectives of this lesson are to introduce the student to:

i. Applications of refrigeration in:

- a) Food processing, preservation and distribution (*Section 3.2*)
- b) Chemical and process industries (*Section 3.3*)
- c) Special Applications such as cold treatment of metals, medical, construction, ice skating etc. (*Section 3.4*)
- d) Comfort air-conditioning (*Section 3.5*)

ii. Applications of air conditioning, namely:

- a) Industrial, such as in textiles, printing, manufacturing, photographic, computer rooms, power plants, vehicular etc. (*Section 3.5.1*)
- b) Comfort – commercial, residential etc. (*Section 3.5.2*)

At the end of the lesson, the student should be able to:

- a) List various applications of refrigeration and air conditioning
- b) List typical conditions required for various food products, processes etc.
- c) State pertinent issues such as energy efficiency, Indoor Air Quality etc.

3.1. Introduction

As mentioned in Lesson 1, refrigeration deals with cooling of bodies or fluids to temperatures lower than those of surroundings. This involves absorption of heat at a lower temperature and rejection to higher temperature of the surroundings. In olden days,

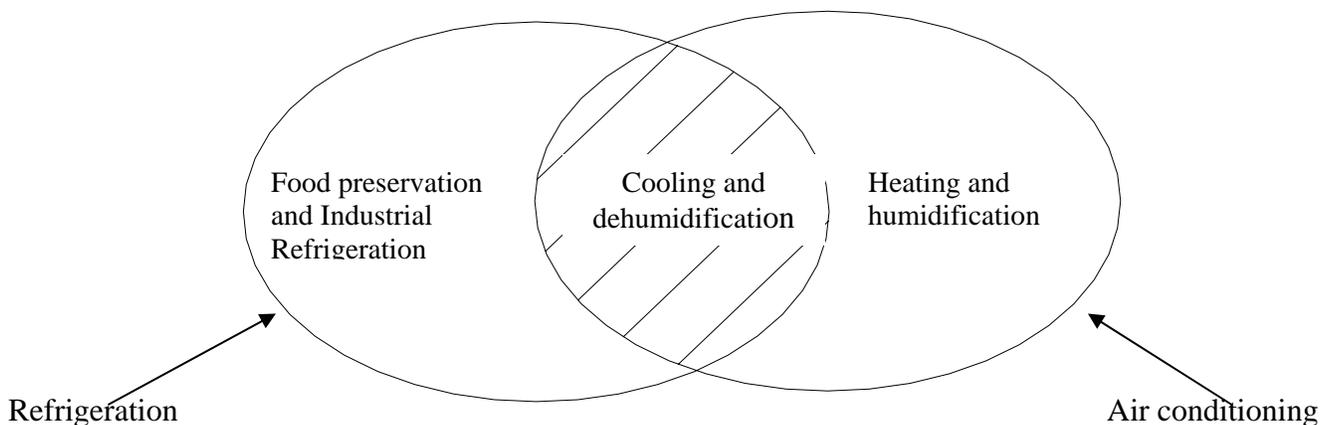


Fig.3.1. Relation between refrigeration and air conditioning

the main purpose of refrigeration was to produce ice, which was used for cooling beverages, food preservation and refrigerated transport etc. Now-a-days refrigeration and air conditioning find so many applications that they have become very essential for mankind, and without refrigeration and air conditioning the basic fabric of the society will be adversely affected. Refrigeration and air conditioning are generally treated in a single subject due to the fact that one of the most important applications of refrigeration is in cooling and dehumidification as required for [summer air conditioning](#). Of course, refrigeration is required for many applications other than air conditioning, and air conditioning also involves processes other than cooling and dehumidification. Figure 3.1 shows the relation between refrigeration and air conditioning in a pictorial form.

The temperature range of interest in refrigeration extends down to about -100°C . At lower temperatures [cryogenic systems](#) are more economical. Now-a-days refrigeration has become an essential part of food chain- from post harvest heat removal to processing, distribution and storage. Refrigeration has become essential for many chemical and processing industries to improve the standard, quality, precision and efficiency of many manufacturing processes. Ever-new applications of refrigeration arise all the time. Some special applications require small capacities but are technically intriguing and challenging.

As mentioned before, air-conditioning is one of the major applications of refrigeration. Air-conditioning has made the living conditions more comfortable, hygienic and healthy in offices, work places and homes. As mentioned in Lesson 1, air-conditioning involves control of temperature, humidity, cleanliness of air and its distribution to meet the comfort requirements of human beings and/or some industrial requirements. Air-conditioning involves cooling and dehumidification in summer months; this is essentially done by refrigeration. It also involves heating and humidification in cold climates, which is conventionally done by a boiler unless a [heat pump](#) is used.

The major applications of refrigeration can be grouped into following four major equally important areas.

1. Food processing, preservation and distribution
2. Chemical and process industries
3. Special Applications
4. Comfort air-conditioning

3.2. Application of refrigeration in Food processing, preservation and distribution

3.2.1. Storage of Raw Fruits and Vegetables: It is well-known that some bacteria are responsible for degradation of food, and enzymatic processing cause ripening of the fruits and vegetables. The growth of bacteria and the rate of enzymatic processes are reduced at low temperature. This helps in reducing the spoilage and improving the shelf life of the food. Table 3.1 shows useful storage life of some plant and animal tissues at various

temperatures. It can be seen that the storage temperature affects the useful storage life significantly. In general the storage life of most of the food products depends upon water activity, which essentially depends upon the presence of water in liquid form in the food product and its temperature. Hence, it is possible to preserve various food products for much longer periods under frozen conditions.

Food Product	Average useful storage life (days)		
	0°C	22°C	38°C
Meat	6-10	1	< 1
Fish	2-7	1	< 1
Poultry	5-18	1	< 1
Dry meats and fish	> 1000	> 350 & < 1000	> 100 & < 350
Fruits	2 - 180	1 - 20	1 - 7
Dry fruits	> 1000	> 350 & < 1000	> 100 & < 350
Leafy vegetables	3 - 20	1 - 7	1 - 3
Root crops	90 - 300	7 - 50	2 - 20
Dry seeds	> 1000	> 350 & < 1000	> 100 & < 350

Table 3.1. Effect of storage temperature on useful storage life of food products

In case of fruits and vegetables, the use of refrigeration starts right after harvesting to remove the post-harvest heat, transport in refrigerated transport to the cold storage or the processing plant. A part of it may be stored in [cold storage](#) to maintain its sensory qualities and a part may be distributed to retail shops, where again refrigeration is used for short time storage. Depending upon the size, the required capacity of refrigeration plants for cold storages can be very high. Ammonia is one of the common refrigerants used in cold storages. Figure 3.2 shows the photograph of ammonia based refrigerant plant for a cold storage. Figure 3.3 shows the photograph of a typical cold storage. [Household refrigerator](#) is the user end of cold chain for short time storage.



Fig.3.2. Ammonia based refrigeration plant for a large cold storage



Fig.3.3. Photograph of a typical cold storage

The cold chain has proved to be very effective in reducing spoilage of food and in food preservation. It is estimated that in India, the post-harvest loss due to inadequate cold storage facilities is high as 30 percent of the total output. The quality of remaining 70 percent is also affected by inadequate cold chain facilities. This shows the importance of proper refrigeration facilities in view of the growing food needs of the ever-growing population. Refrigeration helps in retaining the sensory, nutritional and eating qualities of the food. The excess crop of fruits and vegetables can be stored for use during peak demands and off-season; and transported to remote locations by refrigerated transport. In India, storage of potatoes and apples in large scale and some other fruits and vegetables in small scale and frozen storage of peas, beans, cabbage, carrots etc. has improved the standard of living. In general, the shelf life of most of the fruits and vegetables increases by storage at temperatures between 0 to 10°C. Table 3.2 shows the typical storage conditions for some fruits and vegetables as recommended by [ASHRAE](#). Nuts, dried fruits and pulses that are prone to bacterial deterioration can also be stored for long periods by this method. The above mentioned fruits, vegetables etc, can be stored in raw state. Some highly perishable items require initial processing before storage. The fast and busy modern day life demands ready-to-eat frozen or refrigerated food packages to eliminate the preparation and cooking time. These items are becoming very popular and these require refrigeration plants.

3.2.2. Fish: Icing of fish according to ASHRAE Handbook on Applications, started way back in 1938. In India, iced fish is still transported by rail and road, and retail stores store it for short periods by this method. Freezing of fish aboard the ship right after catch results in better quality than freezing it after the ship docks. In some ships, it is frozen along with seawater since it takes months before the ships return to dock. Long-term preservation of fish requires cleaning, processing and freezing.

	Storage Temperature, °C	Relative Humidity, %	Maximum, recommended storage time	Storage time in cold storages for vegetables in tropical countries
Apples	0 – 4	90 – 95	2 - 6 months	-
Beetroot	0	95 – 99	4 – 6 months	
Cabbage	0	95 – 99	5 – 6 months	2 months
Carrots	0	98 – 100	5 – 9 months	2 months
Cauliflower	0	95	3 – 4 weeks	1 week
Cucumber	10 - 13	90 – 95	10 – 14 days	
Eggplant	8 - 12	90 – 95	7 days	
Lettuce	0	95 – 100	2 – 3 weeks	
Melons	7 - 10	90 - 95	2 weeks	
Mushrooms	0 - 4	95	2 - 5	1 day
Onions	0	65 - 70	6 – 8 months	
Oranges	0 - 4	85 - 90	3 – 4 months	
Peas, Green	0	95 - 98	1 – 2 weeks	
Pears	0	90 - 95	2 – 5 months	
Potatoes	4 - 16	90 - 95	2 – 8 months	
Pumpkin	10 - 13	70 – 75	6 – 8 months	
Spinach	0	95	1 – 2 weeks	1 week
Tomatoes	13 - 21	85 - 90	1 – 2 weeks	1 week

Table 3.2. Recommended storage conditions for fruits and vegetables

3.2.3. *Meat and poultry*: These items also require refrigeration right after slaughter during processing, packaging. Short-term storage is done at 0°C. Long-term storage requires freezing and storage at -25°C.

3.2.4. *Dairy Products*: The important dairy products are milk, butter, buttermilk and ice cream. To maintain good quality, the milk is cooled in bulk milk coolers immediately after being taken from cow. Bulk milk cooler is a large refrigerated tank that cools it between 10 to 15°C. Then it is transported to dairy farms, where it is pasteurized. Pasteurization involves heating it to 73°C and holding it at this temperature for 20 seconds. Thereafter, it is cooled to 3 to 4°C. The dairies have to have a very large cooling capacity, since a large quantity of milk has to be immediately cooled after arrival. During the lean period, the refrigeration plants of dairies are used to produce ice that is used during peak periods to provide cooling by melting. This reduces the required peak capacity of the refrigeration plant.

Ice cream manufacture requires pasteurization, thorough mixing, emulsification and stabilization and subsequently cooling to 4 to 5°C. Then it is cooled to temperature of about – 5 °C in a freezer where it stiffens but still remains in liquid state. It is packaged and hardened at –30 to –25°C until it becomes solid; and then it is stored at same temperature.

Buttermilk, curd and cottage cheese are stored at 4 to 10°C for increase of shelf life. Use of refrigeration during manufacture of these items also increases their shelf life. There are many varieties of cheese available these days. Adding cheese starter like lactic acid and several substances to the milk makes all of these. The whey is separated and solid part is cured for a long time at about 10°C to make good quality cheese.

3.2.5. *Beverages*: Production of beer, wine and concentrated fruit juices require refrigeration. The taste of many drinks can be improved by serving them cold or by adding ice to them. This has been one of the favourite past time of aristocracy in all the countries. Natural or man-made ice for this purpose has been made available since a very long time. Fruit juice concentrates have been very popular because of low cost, good taste and nutritional qualities. Juices can be preserved for a longer period of time than the fruits. Also, fruit juice concentrates when frozen can be more easily shipped and transported by road. Orange and other citrus juices, apple juice, grape juice and pineapple juice are very popular. To preserve the taste and flavor of juice, the water is driven out of it by boiling it at low temperature under reduced pressure. The concentrate is frozen and transported at -20°C.

Brewing and wine making requires fermentation reaction at controlled temperature, for example lager-type of beer requires 8 to 12°C while wine requires 27-30°C. Fermentation is an exothermic process; hence heat has to be rejected at controlled temperature.

3.2.6. *Candy*: Use of chocolate in candy or its coating with chocolate requires setting at 5-10°C otherwise it becomes sticky. Further, it is recommended that it be stored at low temperature for best taste.

3.2.7. *Processing and distribution of frozen food*: Many vegetables, meat, fish and poultry are frozen to sustain the taste, which nearly duplicates that of the fresh product. Freezing retains the sensory qualities of colour, texture and taste apart from nutritional qualities. The refrigeration systems for frozen food applications are very liberally designed, since the food items are frozen in shortest period of time. The sharp freezing with temperature often below -30°C, is done so that the ice crystals formed during freezing do not get sufficient time to grow and remain small and do not pierce the cell boundaries and damage them. Ready-to-eat frozen foods, packed dinners and bakery items are also frozen by this method and stored at temperatures of -25 to -20 °C for distribution to retail stores during peak demands or off-season demands.

Vegetables in this list are beans, corn, peas, carrots, cauliflower and many others. Most of these are blanched before freezing. There are various processes of freezing. *Blast freezers* give a blast of high velocity air at -30°C on the food container. In *contact freezing*, the food is placed between metal plates and metal surfaces that are cooled to -30°C or lower. *Immersion freezing* involves immersion of food in low temperature brine. *Individual quick freezing (IQF)* is done by chilled air at very high velocities like 5-10 m/s that keeps the small vegetable particles or shrimp pieces floating in air without clumping, so that maximum area is available for heat transfer to individual particles. The

frozen particles can be easily packaged and transported. The refrigeration capacities in all the freezers are very large since freezing of large quantities is done in a very short time. Liquid nitrogen and carbon dioxide are also used for freezing.

Of late supermarket refrigeration is gaining popularity all over the world. At present this constitutes the largest sector of refrigeration in developed countries. In a typical supermarket a large variety of products are stored and displayed for sale. Since a wide variety of products are stored, the required storage conditions vary widely. Refrigeration at temperatures greater than 0°C and less than 0°C is required, as both frozen and fresh food products are normally stored in the same supermarket. Figure 3.4 shows the photograph of a section of a typical supermarket. Refrigeration systems used for supermarkets have to be highly reliable due to the considerable value of the highly perishable products. To ensure proper refrigeration of all the stored products, a large of refrigerant tubing is used, leading to large refrigerant inventory.



Fig.3.4. Section of a supermarket with refrigerated display cases

Q. Food products can be preserved for a longer time at low temperatures because:

- a) At low temperatures the bacterial activity is reduced
- b) Enzymatic activity is reduced at low temperatures
- c) Quality of food products improves at low temperatures
- d) All of the above

Ans.: a) and b)

Q. The cold chain is extremely useful as it:

- a) Makes seasonal products available throughout the year
- b) Reduces food spoilage
- c) Balances the prices
- d) All of the above

Ans.: d)

Q. The useful storage life of food products depends on:

- a) Storage temperature
- b) Moisture content in the storage
- c) Condition of food products at the time of storage
- d) All of the above

Ans.: d)

Q. Cold storages can be used for storing:

- a) Live products such as fruits, vegetables only
- b) Dead products such as meat, fish only
- c) Both live and dead products
- d) None of the above

Ans.: c)

Q. Fast freezing of products is done to:

- a) Reduce the cell damage due to ice crystal growth
- b) Reduce energy consumption of refrigeration systems
- c) Reduce bacterial activity
- d) All of the above

Ans.: a)

Q. Products involving fermentation reactions require refrigeration because:

- a) Fermentation process is exothermic
- b) Fermentation process is endothermic
- c) Fermentation has to be done at controlled temperatures
- d) All of the above

Ans.: a) and c)

Q. Supermarket refrigeration requires:

- a) Provision for storing a wide variety of products requiring different conditions
- b) Reliable refrigeration systems due to the high value of the perishable products
- c) Large refrigerant inventory due to long refrigerant tubing
- d) All of the above

Ans.: d)

3.3. Applications of refrigeration in chemical and process industries

The industries like petroleum refineries, petrochemical plants and paper pulp industries etc. require very large cooling capacities. The requirement of each industry-process wise and equipment-wise is different hence refrigeration system has to be customized and optimized for individual application. The main applications of refrigeration in chemical and process industries involve the following categories.

3.3.1. Separation of gases: In petrochemical plant, temperatures as low as -150°C with refrigeration capacities as high as 10,000 [Tons of Refrigeration](#) (TR) are used for separation of gases by fractional distillation. Some gases condense readily at lower temperatures from the mixtures of hydrocarbon. Propane is used as refrigerant in many of these plants.

3.3.2. Condensation of Gases: some gases that are produced synthetically, are condensed to liquid state by cooling, so that these can be easily stored and transported in liquid state. For example, in synthetic ammonia plant, ammonia is condensed at -10 to 10°C before filling in the cylinders, storage and shipment. This low temperature requires refrigeration.

3.3.3. Dehumidification of Air: Low humidity air is required in many pharmaceutical industries. It is also required for air liquefaction plants. This is also required to prevent static electricity and prevents short circuits in places where high voltages are used. The air is cooled below its dew point temperature, so that some water vapour condenses out and the air gets dehumidified.

3.3.4. Solidification of Solute: One of the processes of separation of a substance or pollutant or impurity from liquid mixture is by its solidification at low temperature. Lubricating oil is dewaxed in petroleum industry by cooling it below -25°C . Wax solidifies at about -25°C .

3.3.5. Storage as liquid at low pressure: Liquid occupies less space than gases. Most of the refrigerants are stored at high pressure. This pressure is usually their saturation pressure at atmospheric temperature. For some gases, saturation pressure at room temperature is very high hence these are stored at relatively low pressure and low temperature. For example natural gas is stored at 0.7 bar gauge pressure and -130°C . Heat gain by the cylinder walls leads to boiling of some gas, which is compressed, cooled and expanded back to 0.7 bar gauge.

3.3.6. Removal of Heat of Reaction: In many chemical reactions, efficiency is better if the reaction occurs below room temperature. This requires refrigeration. If these reactions are exothermic in nature, then more refrigeration capacities are required. Production of viscose rayon, cellular acetate and synthetic rubber are some of the examples. Fermentation is also one of the examples of this.

3.3.7. *Cooling for preservation:* Many compounds decompose at room temperature or these evaporate at a very fast rate. Certain drugs, explosives and natural rubber can be stored for long periods at lower temperatures.

3.3.8. *Recovery of Solvents:* In many chemical processes solvents are used, which usually evaporate after reaction. These can be recovered by condensation at low temperature by refrigeration system. Some of the examples are acetone in film manufacture and carbon tetrachloride in textile production.

3.4. Special applications of refrigeration

In this category we consider applications other than chemical uses. These are in manufacturing processes, applications in medicine, construction units etc.

3.4.1. *Cold Treatment of Metals:* The dimensions of precision parts and gauge blocks can be stabilized by soaking the product at temperature around -90°C . The hardness and wear resistance of carburized steel can be increased by this process. Keeping the cutting tool at -100°C for 15 minutes can also increase the life of cutting tool. In deep drawing process the ductility of metal increases at low temperature. Mercury patterns frozen by refrigeration can be used for precision casting.

3.4.2. *Medical:* Blood plasma and antibiotics are manufactured by freeze-drying process where water is made to sublime at low pressure and low temperature. This does not affect the tissues of blood. Centrifuges refrigerated at -10°C , are used in the manufacture of drugs. Localized refrigeration by liquid nitrogen can be used as anesthesia also.

3.4.3. *Ice Skating Rinks:* Due to the advent of artificial refrigeration, sports like ice hockey and skating do not have to depend upon freezing weather. These can be played in indoor stadium where water is frozen into ice on the floor. Refrigerant or brine carrying pipes are embedded below the floor, which cools and freezes the water to ice over the floor.

3.4.4. *Construction:* Setting of concrete is an exothermic process. If the heat of setting is not removed the concrete will expand and produce cracks in the structure. Concrete may be cooled by cooling sand, gravel and water before mixing them or by passing chilled water through the pipes embedded in the concrete. Another application is to freeze the wet soil by refrigeration to facilitate its excavation.

3.4.5. *Desalination of Water:* In some countries fresh water is scarce and seawater is desalinated to obtain fresh water. Solar energy is used in some cases for desalination. An alternative is to freeze the seawater. The ice thus formed will be relatively free of salt. The ice can be separated and thawed to obtain fresh water.

3.4.6. *Ice Manufacture:* This was the classical application of refrigeration. Ice was manufactured in plants by dipping water containers in chilled brine and it used to take about 36 hours to freeze all the water in cans into ice. The ice thus formed was stored in

ice warehouses. Now that small freezers and [icemakers](#) are available. Hotels and restaurants make their own ice, in a hygienic manner. Household refrigerators also have the facility to make ice in small quantities. The use of ice warehouses is dwindling because of this reason. Coastal areas still have ice plants where it is used for transport of iced fish.

Refrigeration systems are also required in remote and rural areas for a wide variety of applications such as storage of milk, vegetables, fruits, foodgrains etc., and also for storage of vaccines etc. in health centers. One typical problem with many of the rural and remote areas is the continuous availability of electricity. Since space is not constraint, and most of these areas in tropical countries are blessed with alternate energy sources such as solar energy, biomass etc., it is preferable to use these clean and renewable energy sources in these areas. Thermal energy driven absorption systems have been used in some instances. Vapour compression systems that run on photovoltaic (PV) cells have also been developed for small applications. Figure 3.5 shows the schematic of solar PV cell driven vapour compression refrigeration system for vaccine storage.

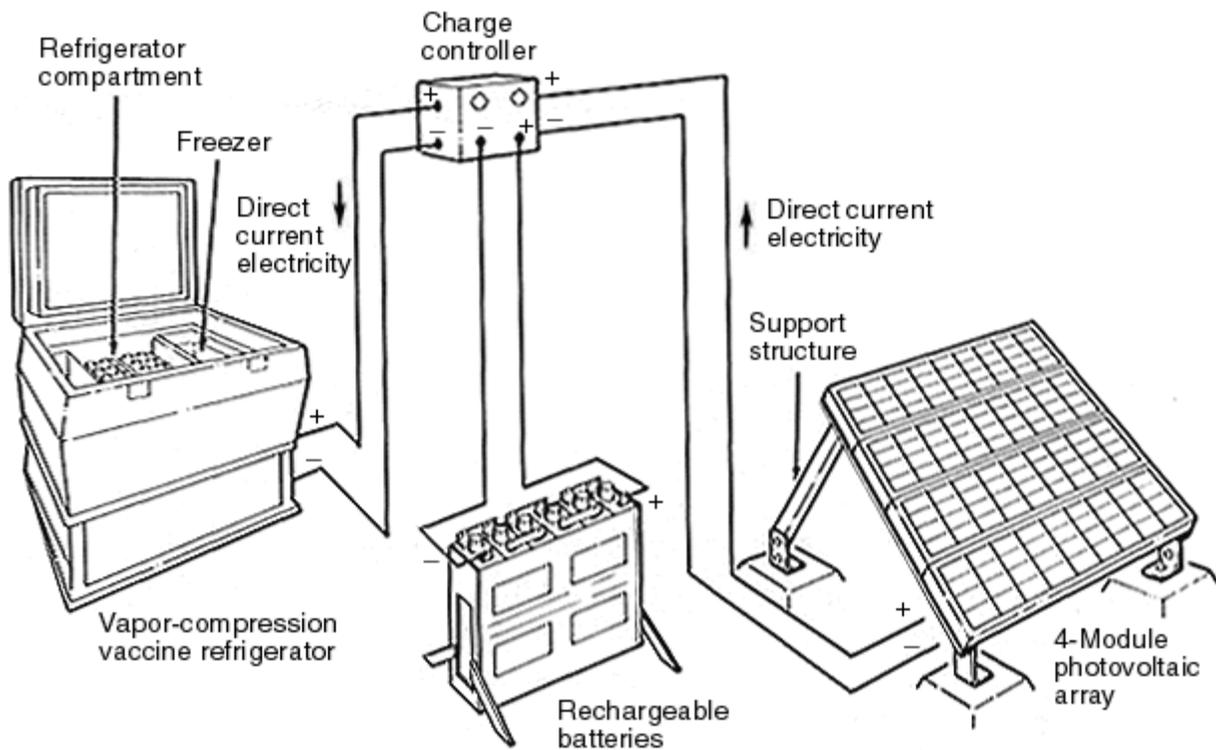


Fig.3.5. Solar energy driven refrigeration system for vaccine storage

Q. Refrigeration is required in petrochemical industries to:

- a) Separate gases by fractional distillation
- b) Provide safe environment
- c) Carry out chemical reactions
- d) All of the above

Ans.: a)

Q. Cold treatment of metals is carried out to:

- a) To stabilize precision parts
- b) To improve hardness and wear resistance
- c) To improve ductility
- d) To improve life of cutting tools
- e) All of the above

Ans.: e)

Q. Refrigeration is used in construction of dams etc to:

- a) Avoid crack development during setting of concrete
- b) Avoid water evaporation
- c) Reduce cost of construction
- d) All of the above

Ans.: a)

Q. Refrigeration is required in remote and rural areas to:

- a) Store fresh and farm produce
- b) Store vaccines in primary health centres
- c) Store milk before it is transported to dairy plants
- d) All of the above

Ans.: d)

Q. Compared to urban areas, in rural areas:

- a) Continuous availability of grid electricity is not ensured
- b) Space is not a constraint
- c) Refrigeration is not really required
- d) Refrigeration systems cannot be maintained properly

Ans.: a) and b)

3.5 Application of air conditioning:

Air-conditioning is required for improving processes and materials apart from comfort air-conditioning required for comfort of persons. The life and efficiency of electronic devices increases at lower temperatures. Computer and microprocessor-based equipment also require air-conditioning for their efficient operation. Modern electronic equipment with Very Large Scale Integrated (VLSI) chips dissipates relatively large quantities of energy in a small volume. As a result, unless suitable cooling is provided, the chip temperature can become extremely high. As the computing power of computers increases, more and more cooling will be required in a small volume. Some supercomputers required liquid nitrogen for cooling.

Air-conditioning applications can be divided into two categories, namely, industrial and comfort air-conditioning.

3.5.1. Industrial Air-conditioning: The main purpose of industrial air conditioning systems is to provide conducive conditions so that the required processes can be carried out and required products can be produced. Of course, the industrial air conditioning systems must also provide at least a partial measure of comfort to the people working in the industries. The applications are very diverse, involving cooling of laboratories down to -40°C for engine testing to cooling of farm animals. The following are the applications to name a few.

Laboratories: This may involve precision measurement to performance testing of materials, equipment and processes at controlled temperature and relative humidity. Laboratories carrying out research in electronics and biotechnology areas require very clean atmosphere. Many laboratories using high voltage like in LASERS require very low humidity to avoid the sparking.

Printing: Some colour printing presses have one press for each colour. The paper passes from one press to another press. The ink of one colour must get dried before it reaches the second press, so that the colours do not smudge. And the paper should not shrink, so that the picture does not get distorted. This requires control over temperature as well humidity. Improper humidity may cause static electricity, curling and buckling of paper.

Manufacture of Precision Parts: If the metal parts are maintained at uniform temperature during manufacturing process, these will neither expand nor shrink, maintaining close tolerances. A lower relative humidity will prevent rust formation also. A speck of dust in a switch or relay can cause total or partial malfunction in spacecraft. The manufacture of VLSI chips, microprocessors, computers, aircraft parts, Micro-Electro Mechanical Systems (MEMS), nanomaterial fabrication and many areas of modern progress require a very clean atmosphere and proper control over humidity. Any impurity in the atmosphere will spoil the VLSI chips. The concept of Clean rooms has been introduced for such industries. In fact, all precision industries that use microprocessors require these clean rooms.

Textile Industry: The yarn in the textile industry is spun and it moves over spools at very high speeds in modern machines. It is very sensitive to humidity. The generation of static electricity should be avoided. Its flexibility and strength should not change. If it breaks during the process, the plant will have to be stopped and yarn repaired before restarting the plant.

Pharmaceutical Industries: In these industries to obtain sterile atmosphere, the airborne bacteria and dust must be removed in the air-conditioning system by filters. These industries require clean rooms. If capsules are made or used in the plant, then air has to be dry otherwise the gelatin of capsules will become sticky.

Photographic Material: The raw material used for filmmaking has to be maintained at low temperature, since it deteriorates at high temperature and humidity. The film also has to be stored at low temperature. The room where film is developed requires 100% replacement by fresh air of the air polluted by chemicals.

Farm Animals: The yield of Jersey cows decreases drastically during summer months. Low temperature results in more efficient digestion of food and increase in weight of cow and the milk yield. Animal barns have to be ventilated in any case since their number density is usually very large. In many countries evaporative cooling is used for creating comfort conditions in animal houses.

Computer Rooms: These require control of temperature, humidity and cleanliness. The temperature of around 25 °C and relative humidity of 50% is maintained in these rooms. The dust spoils the CD drives and printers etc.; hence the rooms have to be kept clean also by using micro filters in the air-conditioning system.

Power Plants: Most of the modern power plants are microprocessor controlled. In the earlier designs, the control rooms were very large and were provided with natural ventilation. These days the control rooms are very compact, hence these require air-conditioning for persons and the microprocessors.

Vehicular Air-conditioning: Bus, tram, truck, car, recreational vehicle, crane cabin, aircraft and ships all require air-conditioning. In bus, tram, aircraft and ship, the occupancy density is very high and the metabolic heat and water vapour generated by persons has to be rejected. The cooling load in these is very high and rapidly changes that provides a challenge for their design.

3.5.2. Comfort Air-Conditioning: Energy of food is converted into chemical energy for functioning of brain, lungs, heart and other organs and this energy is ultimately rejected to the surroundings. Also the internal organs require a temperature close to 35°C for their efficient operation, and regulatory mechanisms of human body maintain this temperature by rejecting appropriate amount of heat. Human beings do not feel comfortable if some extra effort is required by the body to reject this energy. The air temperature, humidity and velocity at which human body does not have to take any extra action, is called [comfort condition](#). Comfort condition is also sometimes called as neutral condition.

The residences, offices, shopping centers, stores, large buildings, theatres, auditorium etc. all have slightly different requirements and require different design. The required cooling capacities also vary widely depending upon the application. The factory assembled room air conditioners are very widely used for small residences, offices etc. These units are available as window type or split type. The capacity of these systems vary from a fraction of a ton (TR) to about 2 TR. These systems use a vapour compression refrigeration system with a sealed compressor and forced convection type evaporators and condensers. Figure 3.6 shows the schematic of a widow type room air conditioner. In this type all the components are housed in a single outer casing. In a split type air conditioner, the compressor and condenser with fan (commonly known as condensing unit) are housed in a separate casing and is kept away from the indoor unit consisting of the evaporator, blower, filter etc. The outdoor and indoor units are connected by refrigerant piping. For medium sized buildings factory assembled package units are

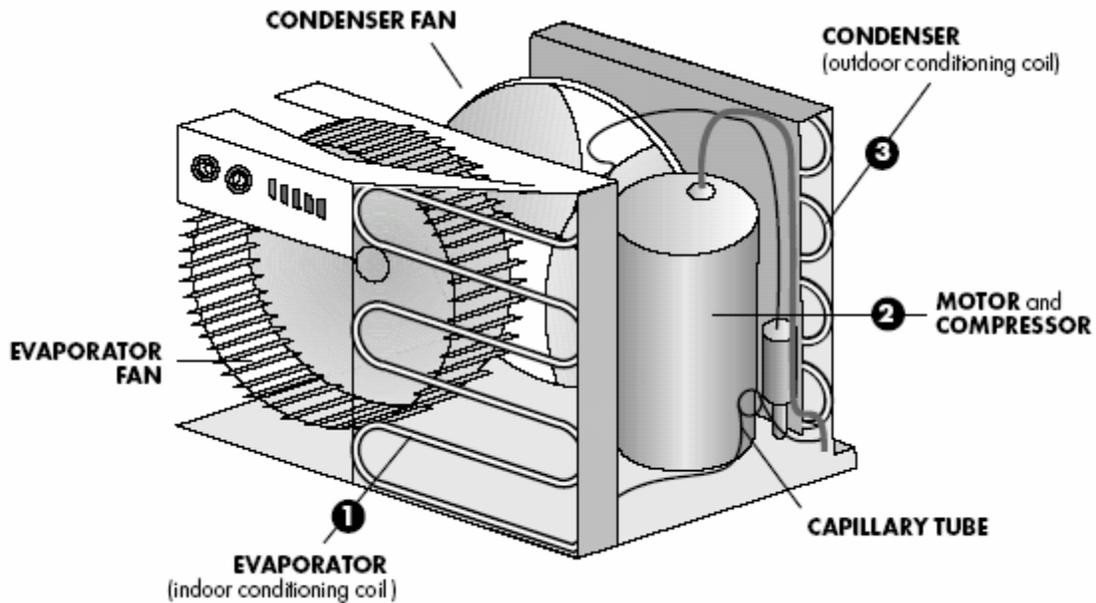


Fig.3.6. Schematic of window type room air conditioner

available, while for very large buildings a central air conditioning system is used.

Hospitals require sterile atmosphere so that bacteria emitted by one patient does not affect the other persons. This is specially so for the operation theatres and intensive care units. In these places no part of the room air is re-circulated after conditioning by A/C system. In other places up to 90% of the cold room air is re-circulated and 10% outdoor fresh air is taken to meet the ventilation requirement of persons. In hospitals all the room air is thrown out and 100% fresh air is taken into the A/C system. Since, outdoor air may be at 45°C compared to 25°C of the room air, the air-conditioning load becomes very large. The humidity load also increases on this account. Operation theaters require special attention in prevention of spores, viruses, bacteria and contaminants given

off by various devices and materials. Special quality construction and filters are used for this purpose.

Restaurants, theatres and other places of amusement require air-conditioning for the comfort of patrons. All places where, a large number of people assemble should have sufficient supply of fresh air to dilute CO₂ and body odours emitted by persons. In addition, people dissipate large quantities of heat that has to be removed by air-conditioning for the comfort of persons. These places have wide variation in air-conditioning load throughout the day. These have large number of persons, which add a lot of water vapour by respiration and perspiration. The food cooked and consumed also adds water vapour. This vapour has to be removed by air-conditioning plant. Hence, these buildings have large latent heat loads. Infiltration of warm outdoor is also large since the large number of persons enter and leave the building leading to entry of outdoor air with every door opening. Ventilation requirement is also very large.

Air-conditioning in stores and supermarkets attracts more customers, induces longer period of stay and thereby increases the sales. Supermarkets have frozen food section, refrigerated food section, dairy and brewage section, all of them requiring different temperatures. The refrigeration system has to cater to different temperatures, apart from air-conditioning. These places also have a wide variation in daily loads depending upon busy and lean hours, and holidays.

Large commercial buildings are a world of their own; they have their own shopping center, recreation center, gymnasium swimming pool etc. Offices have very high density of persons during office hours and no occupancy during off time. These buildings require integrated concept with optimum utilization of resources and services. These have security aspects, fire protection, emergency services, optimum utilization of energy all built-in. Modern buildings of this type are called intelligent buildings where air-conditioning requires large amount of energy and hence is the major focus.

Since persons have to spend a major part of their time within the building, without much exposure to outdoors, the concept of Indoor Air Quality (IAQ) has become very important. There are a large number of pollutants that are emitted by the materials used in the construction of buildings and brought into the buildings. IAQ addresses to these issues and gives recommendation for their reduction to safe limits. Sick building syndrome is very common in poorly designed air conditioned buildings due to inadequate ventilation and use of improper materials. The sick building syndrome is characterized by the feeling of nausea, headache, eye and throat irritation and the general feeling of being uncomfortable with the indoor environment. In developed countries this is leading to litigation also.

In the earlier systems little attention was paid to energy conservation, since fuels were abundant and inexpensive. The energy crisis in early seventies, lead to a review of basic principles and increased interest in energy optimization. The concept of low initial cost with no regard to operating cost has become obsolete now. Approaches, concepts and thermodynamic cycles, which were considered impractical at one time, are receiving

serious considerations now. Earlier, the index of performance used to be [first law efficiency](#), now in addition to that; the [second law efficiency](#) is considered so that the available energy utilized and wasted can be clearly seen. Concepts of hybrid cycles, heat recovery systems, alternate refrigerants and mixtures of refrigerants are being proposed to optimize energy use. Large-scale applications of air-conditioning in vast office and industrial complexes and increased awareness of comfort and indoor air quality have lead to challenges in system design and simulations. Developments in electronics, controls and computers have made refrigeration and air-conditioning a high-technology industry.

Q. Air conditioning involves:

- a) Control of temperature
- b) Control of humidity
- c) Control of air motion
- d) Control of air purity
- e) All of the above

Ans.: e)

Q. The purpose of industrial air conditioning is to:

- a) Provide suitable conditions for products and processes
- b) Provide at least a partial measure of comfort to workers
- c) Reduce energy consumption
- d) All of the above

Ans.: a) and b)

Q. Air conditioning is required in the manufacture of precision parts to:

- a) Achieve close tolerances
- b) Prevent rust formation
- c) Provide clean environment
- d) All of the above

Ans.: d)

Q. Modern electronic equipment require cooling due to:

- a) Dissipation of relatively large amount of heat in small volumes
- b) To prevent erratic behaviour
- c) To improve life
- d) All of the above

Ans.: d)

Q. Human beings need air conditioning as:

- a) They continuously dissipate heat due to metabolic activity
- b) Body regulatory mechanisms need stable internal temperatures
- c) Efficiency improves under controlled conditions
- d) All of the above

Ans.: d)

Q. Small residences and offices use:

- a) Window air conditioners
- b) Split air conditioners
- c) Central air conditioning
- d) All of the above

Ans.: a) and b)

3.6. Conclusions:

The scope of refrigeration is very wide and applications are very diverse and literally thousands of scientists and engineers have contributed towards its development. The accomplishments of these unnamed persons are summarized in the ASHRAE Handbooks. The principles presented in this text follow the information provided in these handbooks.

Q. What do you understand by a cold chain for food products?

Ans.: Proper food preservation requires the maintenance of a cold chain beginning from the place of harvest and ending at the place of consumption. A typical cold chain consists of facilities for pre-treatment at the place of harvest, refrigeration/freezing at food processing plant, refrigeration during transit, storage in refrigerated warehouses (cold storages), refrigerated displays at the market, and finally storage in the domestic freezer/refrigerator. It is very important that suitable conditions be provided for the perishable products through out the chain.

Q. Explain the importance of cold storages

Ans.: Preservation of perishable products using cold storages equalizes the prices throughout the year and makes these products available round the year. Without them, the prices would be very low at the time of harvest and very high during the off-season. With storage facilities, it would also be possible to make the products available in areas where they are not grown.

Q. What are the important issues to be considered in the design of refrigeration systems?

Ans.: Refrigeration systems are used in a wide variety of applications. Each application has specific requirements of temperature, moisture content, capacity, operating duration, availability of resources etc. Hence, refrigeration system design must be done for each application based on the specific requirements. Since refrigeration systems are cost and energy intensive, it is important to design the systems to achieve low initial and running costs. Reliability of the systems is also very important as the failure of the refrigeration systems to perform may lead huge financial losses. Of late, issues related to environment have attracted great attention, hence the refrigeration systems should be as far as possible environment friendly.

Q. What is the relation between refrigeration and air conditioning?

Ans. Air conditioning involves control of temperature and moisture content. One of the most common requirement of air conditioning systems is cooling and dehumidification of air. Refrigeration systems are required for cooling and dehumidification. Refrigeration systems can also be used for heating of air by utilizing the heat rejected at the condenser, i.e., by running them as heat pumps.

Q. What is meant by IAQ and what does it involve?

Ans.: IAQ stands for Indoor Air Quality and it refers to the ways and means of reducing and maintaining the pollutants inside the occupied space within tolerable levels. IAQ involves specifying suitable levels of fresh air supply (ventilation), suitable air filters, use of proper materials of construction, furniture, carpets, draperies etc.