

## Industrial Refrigeration

S.No.	Board of Study	Course Code	Course Title	Scheme of Examination					
				Theory			Practical		Total Marks
				ES E	C T	T A	ESE	T A	
1	Mechanical Engineering	2037683(037)	Industrial Refrigeration	70	20	30	-	-	120
1	Mechanical Engineering	2037693(037)	Industrial Refrigeration(Lab)	-	-	-	30	50	80

Unit Number	Unit Titles	Total Marks
I	Food Preservation systems	14
II	Commercial Structures refrigeration	14
III	Low Temperature Refrigeration	14
IV	Ice Production and Industrial Applications	14
V	Transport Air Conditioning	14
		<b>70</b>

### Unit 1.0 Food Preservation systems

Refrigeration system for food preservation, Factors contributing to food spoilage, causes of food spoilage, methods of food preservation, Methods of food preservation like heat processing, dehydration, chemical preservation, oils and spices, canning and pasteurization, freezing.

Freezing for preservation of food- slow or sharp freezing, Quick freezing, Immersion freezing, Indirect contact freezing, Air blast freezing.

Milk chilling plant, Cold storage and commercial cabinets for different applications like reach in refrigerators, walk in cooler, display cases, refrigerated vehicles.

### Unit 2.0 Commercial Structures refrigeration

Commercial HVAC SYSTEM - Air-conditioning for thermal and humidity comfort, Ventilation, Space pressurization and its working, Type of HVAC systems – single split system ,multi split system ,VRF AND VRV SYSTEM, Air conditioning - Refrigerant-based, Non- refrigerant: System Capacity Sizing, Ventilating-Mechanical ventilation, natural ventilation, hvac – economizers “free cooling” Air-conditioning of houses, offices, hotels , restaurants, departmental stores and shopping complex. Air-conditioning of theatres and auditoriums, Air-conditioning of hospitals and medical establishment Energy code items related to hvac equipment andm Controls

### Unit 3.0 Low Temperature Refrigeration

Meaning and definition of cryogenics, Importance of cryogenics studies Properties of engineering materials at cryogenic temperatures, mechanical properties ,thermal properties, electric & magnetic properties, Super conducting materials ,thermo electric materials, composite materials, Properties of cryogenic fluids. Applications of cryogenic systems: Super conductive devices such as bearings, motors, magnets, space technology, cryogenics in biology and medicine, food preservation and industrial applications.

### Unit-4.0 Ice production and Industrial Applications

Introduction, principles of ice production, different methods of ice manufacturing Treatment of water for making ice,

Brines, freezing tanks, ice cans, quality of ice. Types and design of industrial icemakers- Block ice made in plants, Shell ice, Flake ice, Tube ice, Plate ice and Slush, slurry or binary ice. Production of dry ice. Ice-cream manufacturing, refrigeration for breweries, selection of refrigerant for breweries. Air conditioning in textile and photographic industries  
Refrigeration in the chemical industry

#### Unit 5.0 Transport Air Conditioning

Introduction, automobile air conditioning. Refrigeration systems for transport refrigeration Railway air- conditioning, Marine air conditioning, Aircraft air conditioning Application of refrigeration in pharmaceutical & medical needs like storage and containment during transportation.

### Unit 1.0 Food Preservation systems

#### Refrigeration and Freezing for Food Preservation

Because food is so important to survival, food preservation is one of the oldest technologies used by human beings. There are many different preservation techniques commonly used today, including:

- Refrigeration and freezing : Canning : Irradiation : Dehydration : Freeze-drying : Salting : Pickling : Pasteurizing : Fermentation : Carbonation : Cheese-making : Chemical preservation

A bag of frozen vegetables will last many months without spoiling.

The basic idea behind all forms of food preservation is either:

- To slow down or completely stop the activity of disease-causing bacteria
- To kill the bacteria altogether

In certain cases, a preservation technique may also destroy enzymes naturally found in a food that cause it to spoil or discolor quickly. An enzyme is a special protein that acts as a catalyst for a chemical reaction, and enzymes are fairly fragile. By increasing the temperature of food to about 150 degrees Fahrenheit (66 degrees Celsius), enzymes are destroyed.

A food that is sterile contains no bacteria. Unless sterilized and sealed, all food contains bacteria. For example, bacteria naturally living in milk will spoil the milk in two or three hours if the milk is left out on the kitchen counter at room temperature. By putting the milk in the refrigerator you don't eliminate the bacteria already there, but you do slow down the bacteria enough that the milk will stay fresh for a week or two.

#### Refrigeration and Freezing

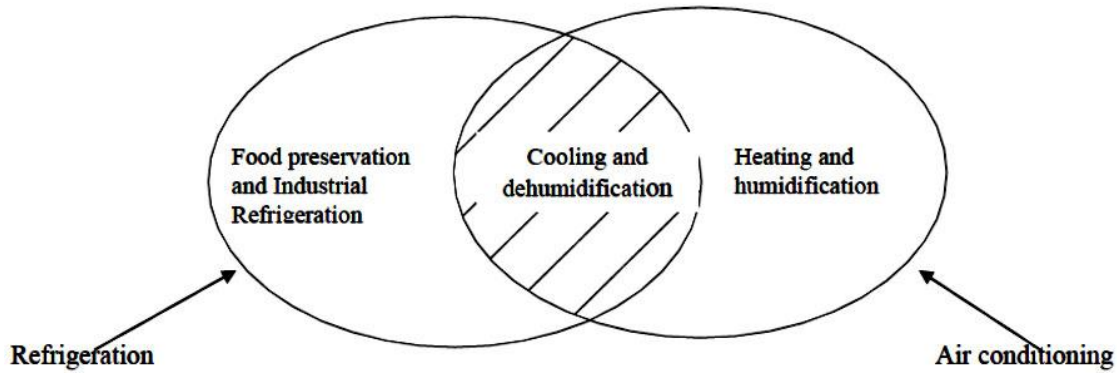
Refrigeration and freezing are probably the most popular forms of food preservation in use today. In the case of refrigeration, the idea is to **slow bacterial action** to a crawl so that it takes food much longer (perhaps a week or two, rather than half a day) to spoil. In the case of freezing, the idea is to **stop bacterial action** altogether. Frozen bacteria are completely inactive.

Refrigeration and freezing are used on almost all foods: meats, fruits, vegetables, beverages, etc. In general, refrigeration has no effect on a food's taste or texture. Freezing has no effect on the taste or texture of most

meats, has minimal effects on vegetables, but often completely changes fruits (which become mushy). Refrigeration's minimal effects account for its wide popularity.

**1.1 Refrigeration system for food preservation**

# Applications of Refrigeration & Air Conditioning



*Fig.3.1. Relation between refrigeration and air conditioning*

**Refrigeration**

**1.1.**

**Introduction**

Refrigeration manages cooling of bodies or liquids to temperatures lower than those of surroundings. This includes retention of heat at a lower temperature and dismissal to higher temperature of the surroundings. In long time past days, the fundamental motivation behind refrigeration was to deliver ice, which was utilized for cooling refreshments, nourishment reservation and refrigerated transport and so on. Presently refrigeration and air conditioning discover such a large number of uses that they have ended up exceptionally vital for humanity, and without refrigeration and ventilating the essential fabric of the general public will be unfavorably influenced.

Refrigeration and ventilation are by and large treated in a solitary subject because of the way that a standout among the most critical uses of refrigeration is in cooling and dehumidification as needed for summer ventilating. Obviously, refrigeration is needed for some applications other than cooling, and ventilating additionally includes forms other than cooling and dehumidification.

The temperature scope of enthusiasm for refrigeration reaches out down to about -1000C. At lower temperatures cryogenic frameworks are more prudent. Now a-days refrigeration has turned into a key part of natural way of life from post harvest heat evacuation to handling, appropriation and capacity. Refrigeration has ended up fundamental for some substance and preparing businesses to enhance the standard, quality, accuracy and effectiveness of numerous assembling techniques. Ever-new utilizations of refrigeration emerge constant.

Some extraordinary applications oblige little limits yet are actually captivating and testing. As said some time recently, cooling is one of the significant utilization of refrigeration. Ventilating has made the living conditions more agreeable, hygienic and sound in work places, working environments and homes. Air Conditioning includes control of temperature, mugginess, cleanliness of air and its appropriation to meet the solace prerequisites of people and/or some mechanical necessities. Air Conditioning includes cooling and dehumidification in summer months; this is basically done by refrigeration. It additionally includes heating and humidification in cool atmospheres, which is routinely done by an evaporator unless a heat pump is utilized.

The significant applications of refrigeration can be gathered into taking after four noteworthy similarly essential ranges.

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

## **1.2. Application of refrigeration in Food processing, preservation and distribution**

### **1.2.1. Storage of Raw Fruits and Vegetables:**

It is remarkable that some microscopic organisms are in charge of corruption of sustenance, and enzymatic preparing reason maturing of the leafy foods. The development of microbes and the rate of enzymatic techniques are diminished at low temperature. These aides in decreasing the waste and enhancing the time span of usability of the nourishment. Table 3.1 shows helpful capacity life of some plant and creature tissues at different temperatures. It can be seen that the stockpiling temperature influences the valuable stockpiling life fundamentally. When all is said in done the stockpiling existence of the vast majority of the sustenance items relies on water action, which basically relies on the vicinity of water in fluid structure in the nourishment item and its temperature. Subsequently, it is conceivable to protect different sustenance items for any longer periods under solidified conditions.

### **1.2 Factors contributing to food spoilage, causes of food spoilage, methods of food reservation**

## Introduction



*Spoiled food (Source: mademags)*

If food items are kept for a long period of time and not stored properly, they get spoil such food items are bad for [health](#). When food items kept for a long time gets spoil as germs start growing on it. Once the food is spoiled, it cannot be eaten and has to be thrown away. Spoilage is a process in which food items deteriorate to the point in which it is not edible to [human](#).

## Causes of Spoilage

The food and [water](#) may be infected by germs. Flies carry germs. When they sit on our food, they pass on these germs to our food. There are various factors which are responsible for food spoilage such as bacteria, mould, yeast, moisture, [light](#), [temperature](#), and [chemical reaction](#).

### 1. Bacteria

They are the most abundant [microorganisms](#) found on the [earth](#). They are tiny in size and vary in [shape](#). Some bacteria are useful also. They help to convert milk into curd.



*Bacteria growth (Source: femininetouchblog)*

### 2. Protozoa

They are single-celled [microorganisms](#) that cause [disease](#) like food poisoning etc.

### 3. Fungi

They are found in damp and warm places and grow on the dead and rotting matter.



*Fungi (Source: sciencedaily)*

### 4. Temperature

Temperature is one of the major factors which is responsible for food spoilage.

## Signs of food spoilage

Signs of food spoilage include an appearance different from the fresh food, such as a change in color, a change in texture, an unpleasant odor or taste.

### *Activity I*

- Aim: To study the growth of fungus.
- [Materials](#): Piece of bread
- [Method](#): Take a piece of bread. Make it moist and keep it in a warm corner of the room for 3-4 days. Observe it after 3-4 days.
- Observation: Presence of greenish patch growing on the bread.



(Source: i2-prod.mirror)

## Food Preservation

Food is valuable. Preserving food can help to avoid wasting of food. Food preservation involves preventing the food from being spoilt. Preservation of food is the process by which food is stored by special methods. Cooked or uncooked food can be preserved in different ways to be used later. Some methods of preservation are:

### 1. Freezing

Food kept in a refrigerator remains fresh for some days. Germs do not grow easily in cool places. We preserve food items, like milk fruit, vegetables and cooked food by keeping them in a refrigerator.



*Method of freezing (Source: skinnycentral)*

### *Activity II*

- Aim: To understand the principle of food preservation.
- Materials: Two apples, fridge
- Method: Take two apples. Keep one apple in the fridge and one outside for 2-3 days. Record your observation.
- Observation: The apple inside the fridge is fresh while the one outside will start decaying.



*(Source: food.onehowto)*

### 2. Boiling

By this method, we can preserve food for a short period of time. Germs in milk are killed by pasteurization. It is done by boiling milk for sometimes and then cooling it quickly.

### 3. Salting

We can add salt to preserve pickles and fish.

### 4. Sweetening

Excess sugar in food also acts as a preservative. We store food for a long time in the form of jams, jellies, and murabbas by adding sugar.

## 5. Dehydration

In this method, the food items are dried in sun to stop the growth of bacteria in them. Certain foods, like [raw mangoes](#), fishes, potato chips and papads are preserved by this method.



(Source: amazonaws)

## 6. Canning

In this method, air is removed from food and put in airtight cans so that germs do not grow on them. Food items like vegetables, seafood, dairy [products](#) etc. Are preserved through this method.



canning

## Advantages and Disadvantages

- **Advantages of food preservation:** Germs do not grow easily in preserved food and make it safe to eat. Preservation enables us to enjoy seasonal fruits like strawberries and mangoes even during the offseason.
- **Disadvantages of food preservation:** Excess salt and sugar are used in the preservation of food which is not good for health. Some methods of food preservation may lead to loss of [nutrients](#).

### 1.3 Methods of food preservation like heat processing, dehydration, chemical preservation, oils and spices, canning and pasteurization, freezing.

## What are the different methods of Food Preservation?



Different Methods of Food Preservation

**Food preservation** is known “as the science which deals with the process of prevention of decay or spoilage of food thus allowing it to be stored in a fit condition for future use”. Preservation ensures that the quality, edibility and the nutritive value of the food remains intact. Preservation involves preventing the growth of bacteria, fungi and other microorganisms as well as retarding oxidation of fats to reduce rancidity. The process also ensures that there is no discolouration or aging. Preservation also involves sealing to prevent re-entry of microbes. Basically food preservation ensures that food remains in a state where it is

- not contaminated by pathogenic organisms or chemicals
- does not lose optimum qualities of colour, texture, flavor and nutritive value

**Drying** is the oldest method of food preservation. This method reduces water activity which prevents bacterial growth. Drying reduces weight so foods can be carried easily. Sun and wind are both used for drying as well as modern applications like Bed dryers, Fluidized bed dryers, Freeze Drying, Shelf dryers, Spray drying and Commercial food dehydrators and Household oven. Meat and fruits like apples, apricots and grapes are some examples of drying with this method.

**Freezing** is keeping prepared food stuffs in cold storages. Potatoes can be stored in dark rooms but potato preparations need to be frozen.

**Smoking** is the process that cooks, flavours and preserves food exposing it to the smoke from burning wood. Smoke is antimicrobial and antioxidant and most often meats and fish are smoked. Various methods of smoking are used like Hot smoking, Cold smoking, Smoke roasting and Smoke baking. Smoking as a preservative enhances the risk of cancer.

**Vacuum packing creates** a vacuum by making bags and bottles airtight. Since there is no oxygen in the created vacuum bacteria die. Usually used for dry fruit.

**Salting and Pickling:** Salting also known as curing removes moisture from foods like meat. Pickling means preserving food in brine (salt solution) or marinating in vinegar (acetic acid) and in Asia, oil is used to preserve foods. Salt kills and inhibits growth of microorganisms at 20% of concentration. There are various

methods of pickling like chemical pickling and fermentation pickling. In commercial pickles sodium benzoate or EDTA is added to increase shelf life.

**Sugar** is used in syrup form to preserve fruits or in crystallized form if the material to be preserved is cooked in the sugar till crystallization takes place like candied peel and ginger. Another use is for glazed fruit that gets superficial coating of sugar syrup. Sugar is also used with alcohol to preserve luxury foods like fruit in brandy.

**Lye** also known as Sodium hydroxide turns food alkaline and prevents bacterial growth.

**Canning and bottling** means sealing cooked food in sterile bottles and cans. The container is boiled and this kills or weakens bacteria. Foods are cooked for various lengths of time. Once the can or bottle is opened the food is again at risk of spoilage.

**Jellying** is preserving food by cooking in a material that solidifies to form a gel. Fruits are generally preserved as jelly, marmalade or fruit preserves and the jellying agent is pectin that is naturally found in fruit. Sugar is also added.

**Potting** is a traditional British way of preserving meat by placing it in a pot and sealing it with a layer of fat.

**Jugging** is preserving meat by stewing it in an earthenware jug or casserole. Brine or wine is used to stew meat in and sometimes the animal's blood.

**Burial in the ground** preserves food as there is lack of light and oxygen and it has cool temperatures, pH level, or desiccants in the soil. Used to preserve cabbages and root vegetables.

**Pulsed Electric Field Processing** is a new method of preservation that uses brief pulses as strong electric field to process cells. This is still at an experimental stage.

**Modified atmosphere** preserves food by operating on the atmosphere around it. Salad crops that are difficult to preserve are packaged in sealed bags with an atmosphere modified to reduce the oxygen concentration and increase the carbon dioxide concentration.

**Controlled use of organism** is used on cheese, wine and beer as they are preserved for a longer time. This method uses benign organisms to preserve food by introducing them to food where they make an environment which is not suitable for harmful pathogens to grow.

**High pressure food preservation** is a method that presses foods inside a vessel by exerting 70,000 pounds per square inch or more of pressure. This disables microorganisms and prevents spoilage but food retains its appearance, texture and flavour.

**Modified Atmosphere Packaging** extends the shelf life of fresh food products. The atmospheric air inside a package is substituted with a protective gas mix which ensures that the product will stay fresh for as long as possible.

Besides these there is Pasteurisation and Irradiation are also used.

**Various food preservation techniques to increase shelf-life of the products\***

Method	Effect on microbial growth or survival
Refrigeration	Low temperature to retard growth
Freezing	Freezing Low temperature and reduction of water activity to prevent microbial growth, slowing of oxidation reactions
Drying, curing and conserving	Reduction in water activity sufficient to delay or prevent microbial growth
Vacuum and oxygen free modified atmosphere packaging	Low oxygen tension inhibits strict aerobes and delays growth of facultative anaerobes
Carbon dioxide enriched and or modified atmosphere packaging	Specific inhibition of some micro-organisms

Method	Effect on microbial growth or survival
Addition of weak acids; e.g. sodium lactate	Reduction of the intracellular pH of micro-organisms
Lactic fermentation	Reduction of pH value in situ by microbial action and sometimes additional inhibition by the lactic and acetic acids formed and by other microbial products. (e.g. ethanol, bacteriocins)
Sugar preservation	Cooking in high sucrose concentration creating too high osmotic pressure for most microbial survival.
Ethanol preservation	Steeping or cooking in Ethanol produces toxic inhibition of microbes. Can be combined with sugar preservation
Emulsification	Compartmentalisation and nutrient limitation within the aqueous droplets in water-in-oil emulsion foods

### What Is Food Preservation?

Food preservation refers to a variety of techniques used to prevent food from spoiling. Methods of food preservation include:

- [Canning](#)
- Pickling
- Drying
- Freeze drying
- Fermentation
- Curing
- Freezing

Maintaining nutritional value, texture, and flavor are key aspects in food preservation.

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### **Why Preserve Food at Home?**

If you want to enjoy market produce all year round, preserving food at home can be a healthy and cost efficient option. Enjoy the bounty of summer deep into the winter season with [berry jam](#), pickled peppers, and brandied cherries using our preservation methods below.

### **11 Types of Food Preservation Techniques**

1. **Cool Temperature Storage.** Cold food storage is the simplest food preservation method. It occurs in refrigerators and cool, dark places such as: root cellars, unheated basements, and pantries. Cooling preserves food by slowing down the growth of microorganisms that cause the food to spoil. Before the refrigerator was invented, cooling for food storage was common in root cellars and iceboxes. Ideal foods for root cellar storage are: potatoes, yams, onions, garlic, apples, cabbage, turnips, beets, carrots.
2. **Food Drying.** Drying foods inhibits the growth of bacteria, yeasts, and mold through the removal of moisture content. Dehydration has been practiced since ancient times with prehistoric peoples sun-drying seeds. Electric food dehydrators, ovens, and freeze-drying are now speeding up the process that was traditionally done by sun and air. Foods that dehydrate well are fruits, vegetables, legumes, spices, meat, and fish.
3. **Canning: Water Bath.** In the 1800s, a French cook named Nicolas Appert, known as the “father of canning” invented the packing, heating, and sealing technique that we still use today for food products. The process involves placing foods in canning jars and heating them to a high temperature to destroy the microorganisms that cause food to spoil. During the heating process, air is pushed out of the jar, and as the cans cool, a vacuum seal forms. Canning in a bath of boiling water is ideal for high-acid foods, like fruits and fruit juice, pickled vegetables, salsa, [chutneys](#), vinegars, and condiments. Water bath canning requires extended cooking time at a low temperature to destroys the mold, yeast, and enzymes that cause spoilage while making a vacuum seal for long-term storage.
4. **Canning: Pressure Canning.** The second primary type of home canning, pressure canning uses high temperatures (240°F) and special equipment to preserve low-acid foods, like vegetables, dairy, meat and seafood, legumes, and soups.
5. **Freezing.** Freezing foods uses little specialized equipment, while preserving fresh flavors and textures. Freezing slows the growth of microorganisms and enzymes that can cause food spoilage. For the best results, freeze room-temperature foods, remove all the air from the freezer bag, and consume within 6 months of freezing. Sealing frozen produce in vacuum-sealed bags prevents ice crystals from forming and can extend the shelf life of food.
6. **Freeze-drying.** Freeze-drying is a low-temperature dehydration process that involves freezing food and removing the ice by sublimation—turning ice into vapor. This method can be done in a freezer (takes several weeks), on dry ice, or using a modern freeze-dryer unit, which can take less than 24 hours.
7. **Fermentation.** Fermentation is a chemical reaction in which microorganisms, such as bacteria or yeast, convert carbohydrates to alcohol or organic acids under anaerobic conditions. This process

creates some of our favorite funky foods like cheese, yogurt, kombucha, [sauerkraut](#), [kimchi](#), and sourdough bread.

8. **Preserving in Salt and Sugar.** Before industrial refrigeration, most foods were cured using sugar, salt, or a mixture of both. Salt and sugar reduce the water content and inhibits microbial growth in meats, fruits, and vegetables aiding in preservation. Common sugar-preserved foods are jams and [jellies](#), while salt cod, salt pork, corned beef, and bacon are common foods preserved with salt.
9. **Alcohol.** Fruit has a long history of getting preserved in alcohol. During the eighteenth century in Europe, fruits like peaches, cherries, and apricots were submerged in brandy and served as dessert after a meal. Alcohol draws water out of food, similar to salt and sugar, inhibiting microbial growth. This method is great for making extracts and infused alcohols, like cordials and rumtopf, a German method of preserving summer fruit in alcohol.
10. **Vinegar Pickling.** Vinegar pickling creates a high acid environment that kills off microbes and causes food to change in flavor and texture. [Vinegar](#), salt, and sugar are heated and added to fruit or vegetables to make pickles of cucumber, okra, apples, beets, peppers, carrots, onions, cauliflower, green beans, and plums.
11. **Olive Oil Preserving.** [Extra-virgin olive oil](#) is a natural preservative that prevents spoilage by isolating food from air, providing a seal that can slow down oxidation and molding. It is used for preserving fresh herbs, vegetables, and fish. It's important to keep food safety in mind when storing vegetables such as [garlic](#), mushrooms, chili peppers, or herbs in oil—these low-acid foods can be a source of bacteria and should be stored in the refrigerator as a precaution.

### **Preserving By Dehydration: How to Make Dehydrated Fruit:**

Wash and dry fruit. Peel the fruit if the peel isn't edible. Slice the fruit into ½-inch cubes, removing any seeds, and coat with fresh lemon juice. Spread fruit slices in one layer onto dehydrator racks or parchment paper-lined baking sheets. Set a dehydrator to 135°F and dehydrate for 6 to 8 hours until dried and crisp. Alternatively, in a 200°F oven: bake fruit slices for 2 to 3 hours, flipping halfway through, until the chips are crisp. Store all dried fruit in an airtight container in a cool and dark place.

### **Preserving With Yeast: How to Ferment Vegetables:**

Place 2 cloves of garlic in the bottom of a clean glass quart-sized jar. Layer 3 cups of cut vegetables (such as cauliflower, carrots, cabbage, or green beans) into the jar, leaving 1 to 2 inches of headspace. Add any seasonings into the jar, such as caraway seeds or peppercorns. Dissolve 2 tablespoons of salt in 1 quart filtered water and pour over the vegetables until the tops are covered. Tightly seal the container and ferment at room temperature (60 to 70 degrees is ideal) for about 5 days, tasting to desired flavor. Burp the jar daily to release excess pressure. Once they are finished, move to the refrigerator for storage.

### **Preserving in Alcohol: How to Make Homemade Vanilla Extract**

Cut 5 whole vanilla beans in half lengthwise. Place the beans in an 8-ounce jar and cover with 1 cup of vodka. Screw on the lid and shake to combine. Place in a cool, dark place for at least 2 months. The longer the vanilla sits, the stronger the flavor will be.

### **Preserving in Salt: How to Cure Fish With Salt and Sugar**

Rinse and dry one 2-pound piece of salmon (or other fatty fish like tuna, mackerel, trout, or cod). In a medium bowl, combine ½ cup of sugar with ½ cup kosher salt, and rub over the entire fish; sprinkle with ½ cup fresh dill leaves. Wrap tightly with several layers of plastic wrap, place in a shallow glass dish, and

weigh down with a heavy pan. Place in the refrigerator and cure for 2 to 3 days, turning over after 24 hours. Cured fish can be stored in the refrigerator for up to 3 days.

### **Preserving in Vinegar: How to Quick Pickle Vegetables**

Whisk together ½ cup rice vinegar, 1 tablespoon of sugar, and 2 teaspoons of salt in a bowl. Add 1 cup of thinly sliced vegetables (such as red onion, carrots, or cucumbers), and let sit at room temperature for 30 minutes.

### **Preserving in Oil: How to Preserve Sun-Dried Tomatoes in Olive Oil**

Rehydrate ½ cup sun-dried tomatoes by simmering them in a large pot with 2 cups of hot water and 2 cups of red wine vinegar until they are plump, about 5 to 10 minutes. Remove from heat and let sit another 5 minutes, then drain and dry with paper towels. Transfer the tomatoes to a glass jar, add 1 teaspoon dried oregano and a pinch of chili flake, then fill the jar with olive oil, making sure the tomatoes are completely covered in oil. Store in the refrigerator for up to 3 months

## **1.4 Freezing for preservation of food- slow or sharp freezing, Quick freezing, Immersion freezing, Indirect contact freezing, Air blast freezing.**

### **Food Freezing System: Direct and Indirect | Food Technology | Biotechnology**

There are a number of freezing methods and equipment were developed for speed, quality, or for specific types of food. The conditions surrounding the product during freezing are maintained by an enclosure and a refrigeration system.

Freezing systems can be classified in two groups: 1. Direct Contact Systems 2. Indirect Contact Systems.

#### *1. Direct Contact Systems:*

In direct contact system there is a direct contact between the food product and medium used for reduction of product temperature is used.

#### **The most important types of direct freezing systems are:**

- i. Air blast freezing system.
- ii. Fluidized-bed freezing system.
- iii. Immersion freezer.

#### *2. Indirect Contact Systems:*

There are numerous systems used to freeze food products without direct contact between the product and the medium used for the product temperature. Most frozen food are the result of using indirect contact types of freezing systems, where food is separated from the refrigerant by some barrier.

#### **The important types of indirect freezing systems are:**

##### **I. Plate Freezers:**

It is an indirect freezing system in which the food product does not have any direct contact with the medium used for the product temperature. The basic system of plate freezers consists of flat hollow plates, refrigeration coil these plates to cool the surface in contact with the food products. The plates are made up of aluminum or mild steel.

Aluminum plates are formed from a number of hollow, extruded sections, butt-welded together along their length. The sections are connected at each end to header, allowing ammonia to flow to and fro, each section

of the plate. The food products are placed between stacked parallel plates and then pressure applied to the overall stacks to minimize the thermal contact resistance between the plates and product.

The product should be in planar geometry, so unpackaged meat and fish products are suited for this method. Other irregularly shaped products including vegetables such as cauliflower, spinach, broccoli and shrimp can be frozen using this method by packaging the product in brick shaped container prior to freezing. The refrigerated temperature of this method is around  $-30^{\circ}\text{C}$  and it takes less than 24 hours to freeze cartons of chilled and boned meat to below  $-10^{\circ}\text{C}$ . There are two types of plate freezer; horizontal plate freezers and vertical plate freezers.

#### **a. Horizontal Plate Freezers:**

A horizontal plate freezer consists of a set of parallel, refrigerated plates within an insulated enclosure. The stack of plates is placed inside a steel frame and each plate connected to the adjacent plate allowing the plates to be moved apart to form a gap for cartons to be placed between two adjacent plates.

Hydraulic rams are used to move the plate and to apply the pressure on the cartons between the plates during freezing. The freezers are operated either batch or continuous modes. In the batch mode, the spacing in the plates is expanded to allow the product to be loaded on the large tray.

Once the products loaded, the plates are hydraulically closed between the refrigerated plate and the food product. Once the freezing process is over, the plates are opened and the product is removed. In the continuous mode the plates are moved through the enclosed system as the product freezes and then the product between the plates removed one at a time.

#### **b. Vertical Plate Freezers:**

It is primarily used to freeze unpacked food such as fish. Here the food product is placed directly between the plates and then pressure is applied to assure proper thermal contact. Once the process has been completed, the plates can be opened to remove the product.

#### **Advantages of Plate Freezing Methods:**

**The main advantages of plate freezing method are mentioned below:**

- (i) Faster temperature reduction and freezing time particularly suited to hot offal and hot boned meat.
- (ii) Better stowage density in container.
- (iii) Lower refrigeration capacity requirements due to the absence of high capacity fans in the freezer.
- (iv) High quality of the products.
- (v) Speed of freezing is high.
- (vi) Significant reductions in energy, packaging and resource consumption.

#### **Disadvantages of Plate freezing Methods:**

**Main disadvantages of plate freezing methods are:**

- (i) Higher capital cost.
- (ii) A larger charge of refrigerant is required.
- (iii) All cartons should be the same height to simplify loading.

## **II. Air Blast Freezers:**

Air blast freezers are used for both direct and indirect freezing applications. In this method, the product is exposed to a low temperature and high velocity air stream. Air blast freezers typically are operated at temperatures of  $-30$  to  $-45^{\circ}\text{C}$  with the air velocities of 10-15 m/sec.

Air-blast freezers have package that acts as the barrier, for product with unusual shapes, short freezing times are possible by maintaining high air velocities, low air temperature, good contact between the package and the product surface. This process can be continuous or batch, most systems are continuous.

In this method a refrigeration system first cools an air stream to a minimum of  $-40^{\circ}\text{C}$ . The air flows through an enclosed system in which the food product is moved through the system on a conveyor belt. The configuration of the conveyor belt system can vary depending on the food products.

In the simplest design of conveyor belt is that the product is conveyed along a straight belt through on tunnel freezer. But in some other design includes multi-tiered and spiral conveyor belts which are used to minimize the space requirements of the system. The most important factor of the air blast freezer is to ensure uniform air flow over the product.

The direction of the air flow is also an important factor. The best method is parallel air flow (the air flows parallel to the product in the same direction). The other methods of the air flows are counter flow (air flows in the opposite direction to product) and cross flow (air flows perpendicular to the product).

The counter flow methods are effective methods than the other two. The batch air blast freezers are usually consists of a well-insulated container with an air cooler and fans. The product is loaded on a movable belt with stacked trays and the belt is moved into the freezing container. Maintaining uniform air flow is very important, so suitable facilities are required to ensure uniform airflow over all the trays for proper freezing.

### **III. Immersion Freezers:**

This is another important method for freezing which uses direct contact systems. Here the freezing is done with the help of refrigerant. In this method the refrigerant is come in contact with unpackaged food. So this refrigerant must be non-toxic, pure, clean, free from foreign taste, odour, color or bleaching agents and so on.

**The refrigerants are used for the immersion freezing are classified in to two classes:**

1. Low freezing point liquids – These are chilled by indirect contact with another refrigerant.
2. Cryogenic liquids – Compressed liquefied nitrogen which gives their cooling effect to their own evaporation.

#### **Immersion Freezing with Low Freezing Point Liquids:**

The low freezing point liquids that have been used for the non-packaged food includes solutions of sugars, sodium chloride and glycerol. These must be used at sufficient concentration to remain at  $-18^{\circ}\text{C}$  or lower to be effective. In the case of NaCl brine, this requires a concentration of 21%.

NaCl brine cannot be used with unpackaged food that should not become salty, especially fish and fish products. The disadvantage of NaCl brine is that the possible accumulation of the salt brine on the surface of the product. Sugar solutions have been used to freeze fruits at  $-18^{\circ}\text{C}$  and glycerol – water mixtures have been used to freeze fruits.

#### **Immersion Freezing with Cryogenic Liquids:**

Cryogenic liquids are liquefied gases of low boiling point such as liquid nitrogen and liquid carbon dioxide with boiling point  $-196^{\circ}\text{C}$  and  $-79^{\circ}\text{C}$  respectively. Today liquid nitrogen is the most commonly used cryogenic liquid in immersion freezing of food.

#### **Advantages of Liquid Nitrogen:**

- (i) It undergoes slow boiling at  $-196^{\circ}\text{C}$ , which provide a great driving force for heat transfer.
- (ii) Liquid nitrogen contacts all portion of irregularly shaped food, thus minimizing resistance to heat transfer.
- (iii) Since the cold temperature results from evaporation of liquid nitrogen, there is no need for a primary refrigerant to cool this medium.
- (iv) Liquid nitrogen is nontoxic and inert to food constituent. By displacing air from the food it can minimize oxidative changes during freezing and through packaged storage.
- (v) The speed of liquid nitrogen freezing produces frozen food with a quality unattainable by non-cryogenic freezing methods. Some products such as mushroom cannot be frozen by other methods without excessive tissue damage. But such kinds of products can be effectively frozen by means of liquid nitrogen.

#### **Disadvantages of Liquid Nitrogen:**

Cost is high.

#### **Advantages of Direct Immersion Freezing Methods:**

There is intimate contact between the food or package and refrigerant, so resistance to heat transfer is minimized. This is important with irregularly shaped food pieces to be frozen very rapidly such as loose shrimp, mushrooms and other food.

Although loose food pieces can be frozen individually by immersion freezing and air blast freezing, immersion freezing minimizing their contact with air during freezing, which can be desirable for food sensitive to oxidation. The speed of immersion freezing with cryogenic liquids produces quality unattainable by any other freezing method.

### **1.5 Milk chilling plant, Cold storage and commercial cabinets for different applications like reach in refrigerators,**

#### **Importance of Glycol Milk Cooling Systems**

Glycol cooling systems are an integral part of the milk chilling plant process. In the dairy farming industry, these systems are used for cooling milk after pasteurization by capturing and releasing heat. Glycol chillers work fast, keeping temperature and bacteria growth under control 24/7.

In addition, glycol chillers are also less expensive to install, easier to maintain, and are more reliable than conventional refrigeration systems often used in the industry.

#### **What Temperature Should Milk Be Kept?**

Dairy farms are encouraged to cool milk from the initial temperature of 98°F down to 37-38°F. Under no circumstances should the milk ever rise above 45°F. For this reason, it can be extremely beneficial for dairy farmers to utilize dairy bulk milk coolers.

#### **Components of a Dairy Milk Cooling System**

Basic cooling systems consist of an air-cooled condenser unit, refrigeration compressor, and refrigerated bulk tank. Your unit can be configured as an [air-cooled chiller system](#) or a [water-cooled chiller unit](#) depending on standard outdoor temperatures in your region and available space. Additional components are often added to these systems to lower the milk's temperature before it reaches the milk chiller tank.

- Refrigeration Heat Recovery (RHR) - An RHR unit makes a cooling system more effective by gathering heat that would otherwise be wasted into the air, and then using it for water heating purposes.
- Well Water Precoolers - Heat exchangers use well water to chill the milk before it reaches the bulk milk cooling tank. Using a well water precooler can save a dairy farmer up to 60% in milk chiller costs when properly sized.
- Scroll Compressors - Scroll type compressors have been utilized in the dairy farm industry with impressive results for over 15 years. While they are slightly more expensive than traditional reciprocating compressors, they are 15-20% more efficient and even have fewer moving parts.

#### **Benefits of Bulk Milk Chilling Units from Cold Shot Chillers**

Years of working closely with dairy farm professionals has allowed our team to fully understand the importance of the milk chilling process. Here's what our Cold Shot Chillers have to offer:

- **Reduced Refrigerant Loss** - Our chillers work to decrease the loss of refrigerant to the environment, making our units more productive and efficient.
- **Low Energy Output** - Our economical solutions reduce energy output, providing you with lower operational costs and increased profitability.
- **On-demand chilling** - Extend the shelf life of your milk with lower cooling time and no need for storage tanks.
- **Redundancy Options** - We offer a variety of available redundancy options that will keep your milk chilled and operations running smoothly.
- **Easy to Maintain** - spend less time on maintenance with the help of easy-to-clean plate & frame heat exchangers.

### Cold Storage Rooms

A cold storage unit incorporates a refrigeration system that maintains the desired room environment for the commodities to be stored. We are very adept in offering a wide range of Modern Cold Rooms and Commercial Cold Storage. The Cold Rooms that we provide are widely are fully computerized and with modern technology intended to preserve the freshness in food use of for meeting the storage as well as cooling needs arising in the food processing enterprises. We procure our complete range that is crafted at par with global quality standards.

### Industries And Applications of Cold Storage

1. Post-Harvest Storage of Products
2. Retail Food Industry
3. Pharmaceuticals and Healthcare Industry
4. Brewery and Winery Industries
5. Chemical and Processing Industries
6. The Hospitality Industry

### 5 Benefits of a Cold Storage Room



A **cold storage room** is a great place to store [fruits and vegetables](#), as well as other products, as they prolong the life and help prevent spoilage of foods. **Cold Rooms** are a great idea as they will keep items much cooler than regular room temperature. This makes **cold storage rooms** and **cooler rooms refrigeration** a great choice for storing perishable items. There are several benefits that these units provide, they are also beneficial for both personal and business use.

## A Wide Range of Benefits

### 1. A Range of Uses

[Cold storage rooms](#) are temperature adjustable, they can be used for different functions by adjusting the temperature to change from a drying room to help control the moisture content of the products being stored to a blast freezer. These units are airtight, they will also help to protect your products from extreme temperature and weather changes that will happen outside of the unit. Another great thing about these containers having an adjustable temperature range is that they can be used as a dehumidifier to help to dry out and control the moisture content when dry storage is needed. The temperatures inside most of these units can be adjusted from a low of negative thirty degrees Celsius to a plus thirty degrees Celsius. Simply set the unit to the preferred temperature and the cool storage unit will take care of the rest.



### 2. Customisable sizes and settings

**Cooler rooms refrigeration** technology has developed to the point where many different sizes and types are available for your particular need. These custom units can be fitted with the correct refrigerant system to meet the particular needs you may have. You may not need a unit that is constantly working at a freezing temperature to keep your products frozen. If this is the case a refrigeration unit is available to keep your products dry and cool. Not only can you select different refrigeration types, these units can be constructed to any shape, as well as the particular size you may need. Portable units and permanent stationary units are available in many sizes.

### 3. Freeing up space

Having enough space and storage is a constant challenge we all face at home and at work. Depending on the type of business you have, a [cold storage room](#) is an added challenge we face. Inside coolers can take

up space that can otherwise be used for other purposes such as food preparation and cooking. Not only do these inside coolers take up a lot of space they can also raise the temperature of the rooms they are located in because of the extra heat that is produced while they are in operation. The fans and compressors of these units develop heat while they are in operation. This extra heat is eliminated from the room if a cold storage unit is used outside of the building. Not only can the elevated room temperature be a factor, the noise level can also be affected. The noise of the constant running can be eliminated from the room when an outside **cold storage room** is used.

#### 4. Backup Capabilities and Accessibility

Not only will a **cold storage room** provide an extra storage area they can also be used for added protection of your products. When you have the threat of losing electricity, the contents of the coolers and refrigerators can be moved into the cold storage area. The airtight construction of a [cold storage room](#) will allow the temperature of the area to remain at a lower and a constant temperature for a longer period of time. This will allow you to store more products for longer in the event of an electrical outage. [Cold storage rooms](#) can also be set up to meet the storage needs you require. By adding wire shelving racks any storage task can be accomplished. Free-standing storage racks can be used so they can be moved in and out as the storage needs change. Wire racks are great to use because fresh air can constantly surround the products that are stored on the wire rack.

#### 5. Saving Money



We all have to throw away food and other products that spoil because we do not store them adequately. Cooler rooms refrigeration will help you to save money by keeping the spoils to a minimum. A cold storage room can keep fruits and vegetables at the correct temperature while controlling the moisture level to help extend the life of the fresh produce longer until it can be used. This will help to minimise waste and save money. Fruits left at room temperature can spoil quickly. If you grow your own fruits and vegetable a cold storage room can keep your harvest fresher and longer. Cold storage rooms will also benefit you if you purchase your fruits and vegetables in bulk. Furthermore, they can be used to extend the life of other bulk materials such as flour, sugar and other cooking ingredients. Canned goods can be kept longer and protected from spoilage as well by keeping them from coming in contact with direct lighting.

**walk in cooler, display cases, refrigerated vehicles.**

## Walk-in refrigeration

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Regulations set the energy efficiency minimum



Walk-in freezer and walk-in cooler components are subject to Canada's *Energy Efficiency Regulations*, which set a minimum performance standard for their energy efficiency. Find details in the [Guide to the Regulations](#).

### How a typical system works

Walk-in refrigerators and freezers are very large, insulated, enclosed spaces used to store and/or display refrigerated or frozen food or other perishable goods. They are used primarily in the food service and food sales industry. Where commercial refrigerators and freezers used in supermarkets and food processing and packaging can be much larger and are typically supplied by central refrigeration systems.

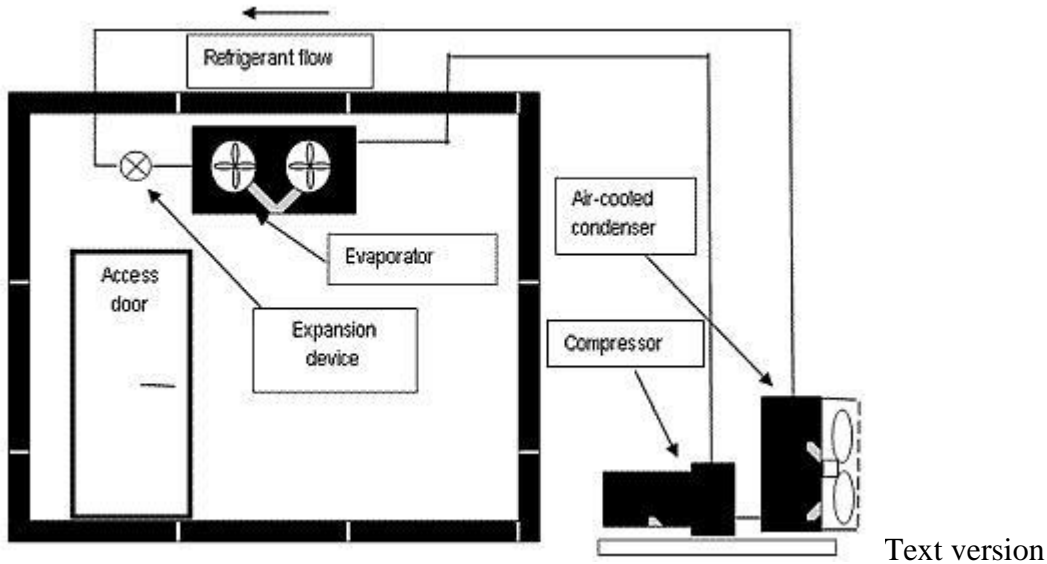
Walk-in refrigerators operate above 0°C and at or below 13°C, and walk-in freezers operate at or below 0°C. The room is cooled by a packed unitary or split refrigeration system consisting of:

- an evaporator fan coil (usually mounted on the room's ceiling)
- a compressor (usually mounted outside the room)
- a water- or air-cooled condensing coil

Refrigerant continuously circulates from the compressor to the condenser, into the expansion device, through the evaporator and back to the compressor.

The refrigerant absorbs heat from the room and expels that heat through evaporation and condensation within the closed refrigeration system. The heat may be expelled into the building, outdoors, or into cooling water.

### Diagram of a typical walk-in refrigerator or freezer



### Know what you need

To choose the most efficient refrigerator or freezer, consider:

- the temperature the unit must maintain
- the functions the unit must perform (refrigeration, freezing or both)
- the configuration of doors required for access and/or display
- the speed at which cooling or freezing must occur (for health reasons)

### Opting for increased efficiency

There are many options that reduce energy transfer and, therefore, energy use:

#### *Insulation*

- better insulation in walls, ceiling and floor
- better gaskets and sealing materials for doors
- improved materials, geometries, and manufacturing techniques in panel interface systems for better overall insulating capacity of the envelope

#### *Lighting*

- high efficiency lighting (LEDs) and electronic lighting ballasts
- fiber optic lighting gathered from rooftop collectors
- occupancy sensors turn inside lights on only when a person is present

### *In-and-out*

- vestibule entryways and revolving doors
- automatic door opening and closing systems
- air curtains, especially recirculating models, and even strip curtains
- automatic evaporator fan shut-off whenever the walk-in door is opened

### *Controls and monitors*

- refrigeration system override for off-peak hours
- air and water infiltration sensors to monitor condition of insulation
- evaporator fan control to run at variable speed, or cycle on and off, during periods when the compressor is off

### *Efficient technologies*

- higher efficiency compressors
- higher efficiency evaporator and condenser fan blades
- improved evaporator and condenser coils
- higher efficiency fan motors, e.g. three-phase, ECMs and PSCs

## **WHAT ARE THE DIFFERENT TYPES OF COMMERCIAL REFRIGERATION EQUIPMENT?**

There is a wide variety of commercial refrigeration systems that we recommend:

- Reach-in vertical cases and refrigerators
- Plug-in enclosed vending machines
- Semi-vertical display cabinets
- Horizontal cases
- Deli cases
- Drop-in coolers
- Draft beer systems
- Undercounter refrigerators
- Back bar coolers
- Refrigerated display cases

- Prep table

All of these various types of commercial refrigeration equipment have different functions. Let's dive into the three main examples below.

## COOLERS

Coolers keep items, such as food and beverages, below the average room temperature yet above freezing. Such equipment prevents spoilage by keeping perishable items cool.

## FREEZERS

Freezers keep perishable items completely frozen, preventing them from spoiling. Ice cream, microwavable food, and certain other types of goods should remain frozen.

## COMBINATION COOLERS AND FREEZERS

Combination commercial refrigeration units can allow for both chilling and freezing perishable items.

### Display case refrigerator

Refrigerated display cases allow you to draw attention to food products while also maintain a food safe temperature. They are perfect for bakeries, delis, and seafood counters looking to put their products close to the checkout without exposing those foods to unsafe temperature drops. Store your baked goods, fresh sushi, or deli meats in a refrigerated display case while still providing customers visual access to choose which product they would like to purchase.

We offer a wide selection of refrigerated display cases to fit your daily needs. If you operate a bakery, you may choose from refrigerated bakery cases that are fully enclosed to showcase cakes and tarts or partially enclosed cases that provide a section to store chilled beverages. For a deli, we carry refrigerated deli cases that maintain the perfect temperature for meats and cheeses without drying out your product. Additionally, you can find refrigerated sushi cases to draw attention to extravagant sushi rolls to boost your sales.

## **Unit 2.0 Commercial Structuresrefrigeration**

### 3 Common Types of Commercial HVAC Systems

## 3 Common Types of Commercial HVAC Systems



A heating, ventilation, and air conditioning (HVAC) system is a must-have system for any residential, industrial, or commercial building. The system keeps the indoor environment conducive for occupants by controlling the humidity, temperature, air quality of the building.

Getting quality HVAC systems is crucial, considering that it is responsible for about [40% of the total energy](#) consumed in commercial buildings.

If you need to replace your commercial air conditioning system, you should understand the different types of HVAC systems available.

### Common Types of HVAC systems

There are three major types of commercial air conditioning systems available on the market.

#### 1. Split HVAC System

The split HVAC system gets its name from the way it's set up as well as its components. The system comprises of the following parts:

- An indoor unit, such as an air handler
- An outdoor unit, which is the condenser
- A programmable or non-programmable thermostat
- A humidity control or filtration system
- Ductwork, which moves conditioned air from the system to the building

There are two types of split commercial air conditioners:

- Single-split

- Multi-split

### Single-Split System

The single-split is an affordable commercial air conditioning system that is suitable for small spaces such as cafes, server rooms, shops, and offices. The compact system is easy to install, and this is why it's preferred for new buildings or renovated commercial spaces.

#### Advantages

- Cheaper to install and, therefore, ideal for small commercial spaces
- Each of the units is self-contained. Therefore, if one breaks down, the others will still be working.
- Energy-efficient. Each indoor unit can be used to deliver air conditioning only to the room that needs it.
- The best solution for a single room that requires an additional HVAC system

#### Disadvantages

- It occupies a lot of space as it has an outdoor unit for each internal unit

### Multi-Split System

With multi-split systems, you can connect several indoor units to one external unit. These systems are usually installed in larger spaces such as retail shops, doctors' units, and restaurants.

A multi-split system has a lot of pipework and needs to be properly installed. Get a professional to do the job as installation mistakes can reduce your [HVAC efficiency by 30%](#).

#### Advantages

- Takes up less space. One outdoor unit can be used with several indoor units.
- It preserves the external appearance of your building
- The installation doesn't require your building to have ductwork

#### Disadvantages

- The installation cost is higher
- The installation can take longer as there is more pipework to be done

## 2. VRV or VRF System

The Variable Refrigerant Volume (VRV) or Variable Refrigerant Flow (VRF) system uses a refrigerant as its heating and cooling element. This is the best system for use in medium or large commercial spaces since it has a single condenser that can be used for more than one evaporator.

Each of the system's internal units uses Electronic Expansion Valve (EEV) to control the refrigerant supply, ensuring it is in line with the demand from the building space.

There are two types of VRV system:

- **Heat pump systems**, which are used for either cooling or heat pumping. These are large multi-splits units that are more efficient for open spaces.
- **Heat recovery systems**, which can cool and heat buildings simultaneously. The systems save energy and are ideal for use in commercial spaces comprising of several rooms.

### **Advantages**

- Ideal for medium and large commercial spaces
- Easy to install in buildings under expansion
- Quick installation without inconveniencing occupants of the building

### **Disadvantages**

- Expensive to install
- If the unit breaks down, the whole HVAC system will be affected

## 3. **CAV and VAV Systems**

A Constant Air Volume (CAV) and a Variable Air Volume (VAV) system are two different HVAC systems that function nearly the same way.

### **CAV System**

The CAV system uses a compressor, such as Danfoss or Copeland, that operates at full capacity until the temperature required in the building is achieved.

The system is ideal for commercial spaces where temperatures remain constant for a long time, for example, manufacturing and warehouse facilities.

### **Advantages**

- Suitable for spaces that have constant ventilation requirements

### **Disadvantages**

- Produces fixed air volume, which results in high energy costs in spaces that don't require the highest airflow
- Are poor at controlling humidity

## VAV System

The Variable Air Volume system is suitable for spaces with varying heating and cooling needs. The system compressor or fan speed varies depending on the temperature of the room. The compressor also regulates the refrigerant flow to maintain consistent temperatures. This makes the system energy-efficient.

### Advantages

- Saves energy costs
- Suitable for buildings with variable ventilation loads
- Superior control of humidity and temperature

### Disadvantages

- Expensive to set up
- The system takes up a lot of space since a fan room must be located in the building

The ideal HVAC system for your building will depend on the air conditioning needs. The right commercial air conditioner will provide value for your money

## 2.1 Commercial HVAC SYSTEM - Air-conditioning for thermal and humidity comfort, Ventilation, Space pressurization and its working

### Heating, Ventilation and Air-Conditioning Systems, Part of Indoor Air Quality Design Tools for Schools

The main purposes of a Heating, Ventilation and Air-Conditioning (HVAC) system are to help maintain good indoor air quality through adequate ventilation with filtration and provide thermal comfort. HVAC systems are among the largest energy consumers in schools. The choice and design of the HVAC system can also affect many other high performance goals, including water consumption (water cooled air conditioning equipment) and acoustics.

The following actions detail how engineers can design a quality system that is cost-competitive with traditional ventilation designs, while successfully providing an appropriate quantity and quality of outdoor air, lower energy costs and easier maintenance.

#### Codes and Standards

The national consensus standard for outside air ventilation is ASHRAE Standard 62.1-2010, Ventilation for Acceptable Indoor Air Quality and its published Addenda. This standard is often incorporated into state and local building codes and specifies the amounts of outside air that must be provided by natural or mechanical ventilation systems to various areas of the school, including classrooms, gymnasiums, kitchens and other special use areas.

*Many state codes also specify minimum energy efficiency requirements, ventilation controls, pipe and duct insulation and sealing and system sizing, among other factors. In addition, some states and localities have established ventilation and/or other indoor air quality related requirements that must also be followed.*

- Design in accordance with ASHRAE standards Design systems to provide outdoor air ventilation in accord with ASHRAE Standard 62.1-2007 and thermal comfort in accord with ASHRAE Standard 55–1992 (with 1995 Addenda) Thermal Environmental Conditions for Human Occupancy.
- Ensure familiarity with and adherence to, all state and local building codes and standards.

[Standards are available at ASHRAE](#) [EXIT](#) [EPA WEBSITE](#)

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#### Potential for Natural Ventilation and Operable Windows

In some parts of the country, where temperature and humidity levels permit, natural ventilation through operable windows can be an effective and energy-efficient way to supplement HVAC systems to provide outside air ventilation, cooling and thermal comfort when conditions permit (e.g., temperature, humidity, outdoor air pollution levels, precipitation). Windows that open and close can enhance occupants' sense of well-being and feeling of control over their environment. They can also provide supplemental exhaust ventilation during renovation activities that may introduce pollutants into the space.

However, sealed buildings with appropriately designed and operated HVAC systems can often provide better indoor air quality than a building with operable windows. Uncontrolled ventilation with outdoor air can allow outdoor air contaminants to bypass filters, potentially disrupt the balance of the mechanical ventilation equipment and permit the introduction of excess moisture if access is not controlled.

Strategies using natural ventilation include wind driven cross-ventilation and stack ventilation that employs the difference in air densities to provide air movement across a space. Both types of natural ventilation require careful engineering to ensure convective flows. The proper sizing and placement of openings is critical and the flow of air from entry to exit must not be obstructed (e.g., by closed perimeter rooms).

- **Designers should consider the use of natural ventilation and operable windows to supplement mechanical ventilation.** Consider outdoor sources of pollutants (including building exhausts and vehicle traffic) and noise when determining if and where to provide operable windows.
  - **If operable windows will be used to supplement the HVAC system, ensure that:**
    - openings for outdoor air are located between 3-6 feet from the floor (head height);
    - the windows are adjustable and can close tightly and securely;
    - the windows are placed to take maximum advantage of wind direction, with openings on opposite sides of the building to maximize cross-ventilation.
- 

#### Selection of HVAC Equipment

In most parts of the country, climatic conditions require that outdoor air must be heated and cooled to provide acceptable thermal comfort for building occupants, requiring the addition of HVAC systems. The selection of equipment for heating, cooling and ventilating the school building is a complex design decision that must balance a great many factors, including:

- heating and cooling needs
- energy efficiency
- humidity control
- potential for natural ventilation

- adherence to codes and standards
- outdoor air quantity and quality
- indoor air quality
- cost

**Where feasible, use central HVAC air handling units (AHUs) that serve multiple rooms in lieu of unit ventilators or individual heat pumps.** Although there are many different types of air handling units, for general IAQ implications in schools, air handling units can be divided into two groups: unit ventilators and individual heat pump units that serve a single room without ducts; and central air handling units that serve several rooms via duct work.

Unit ventilators and heat pumps have the advantage of reduced floor space requirements and they do not recirculate air between rooms. However, it is more difficult to assure proper maintenance of multiple units over time and they present additional opportunities for moisture problems through the wall penetration and from drain pan and discharge problems. Central air handling units have a number of advantages as compared to unit ventilators and heat pumps serving individual rooms. They are:

- Quieter and therefore more likely to be turned on or left on by teachers and staff;
- Less drafty due to multiple supplies and a return that is away from occupants;
- Better at controlling humidity and condensed moisture drainage;
- Easier to maintain due to reduced number of components and few units to access;
- More space around units and can be accessed without interfering with class activities;
- Space for higher efficiency air filters and more surface area;
- Made of heavier duty components;
- Less likely to have quantity of outdoor air supply inadvertently reduced.

Specify the following features for all air handling units:

**Double-sloped drain pan and drain trap depth**

- Double-sloped drain pan - A double-sloped pan prevents water from standing and stagnating in the pan.
- Non-corroding drain pan - Made from stainless steel or plastic. Prevents corrosion that would cause water to leak inside the AHU.
- Easy access doors - All access doors are hinged and use quick release latches that do not require tools to open. Easy access to filters, drain pans and cooling coils is imperative.
- Double wall cabinet - The inner wall protects the insulation from moisture and mechanical damage, increases sound dampening and is easier to clean.
- Tightly sealed cabinet - Small yet continuous air leaks in and out of the AHU cabinet can affect IAQ and energy. The greatest pressure differentials driving leaks occur at the AHU.
- Double wall doors with gaskets - Double wall doors provide better thermal and acoustic insulation and will remain flatter, allowing a better seal against door frame gaskets
- Minimum 2 inch thick filter slots - For better protection of the indoor environment, as well as the equipment and ducts, the filters slots should be able to accommodate 2 in. or thicker filters.
- Extended surface area filter bank - To reduce the frequency of filter maintenance and the cost of fan energy, the bank is designed to allow more filter area, such as the deep V approach or bags.

- Air filter assemblies (racks & housings) designed for minimum leakage - The filter bank should have gaskets and sealants at all points where air could easily bypass the air filters, such as between the filter rack and the access door. Use properly gasketed manufacturer supplied filter rack spacers.
  - Air filter monitor - A differential pressure gauge to indicate the static pressure drop across the filter bank. This feature could easily be installed as an option in the field.
  - Corrosion resistant dampers & links - **All moving parts such as pivot pins, damper actuators and linkages are able to withstand weather and moisture-induced corrosion for the full life of the system**
- 

## Energy Recovery Ventilation

Consider specifying energy recovery ventilation equipment.

Indoor air can be 2 to 5 times more polluted than outdoor air; therefore, most HVAC system designers understand that increased amounts of outdoor air supply is generally better for IAQ. Yet there are concerns over the implications that this added amount of outdoor air supply has on the first cost and operating cost of the HVAC system, as well as moisture control for the school (too wet or too dry).

As a result, school designers often try to reduce the amount of outdoor air equal to — or even below — 15 cubic feet per minute (cfm) of outside air per person, the minimum for school classrooms, as established by the American Society of Heating, Refrigerating and Air -conditioning Engineers (ASHRAE) . In many parts of the country these concerns can easily be addressed by application of basic engineering principles and off-the-shelf HVAC equipment.

First cost, energy costs and moisture control do not have to be at odds with good IAQ. Energy recovery ventilation equipment can make the negative implications of 15 cfm per person of outdoor air behave like 5 cfm, while retaining the IAQ advantage of 15 cfm. This approach has been proven in many schools in various regions east of the Rockies, where advanced HVAC systems cost roughly the same as conventional systems, yet provide significant operating cost savings and IAQ advantages.

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## Location of Outdoor Air Intakes and Exhaust

### Sloped Intake Plenum and Accessible Intake Screen

- **Proper location of outdoor air intakes can minimize the blockage of airflow and intake of contaminated air.** The bottom of air intakes should be at least 8 inches above horizontal surfaces (generally the ground or the roof) to prevent blockage from leaves or snow. In northern locations, more separation may be needed due to greater snow depths or drifting snow.
- **Intakes should not be placed within 25 feet of any potential sources of air contaminants, including sewer vents, exhaust air from the school, loading docks, bus loading areas, garbage receptacles, boiler or generator exhausts and mist from cooling towers.** If the source is large or contains strong contaminants, or if there is a dominant wind direction in the area, the minimum separation distance may need to be increased. Air admittance valves, an inexpensive and code-approved one-way air valve, can be added to sewer vents to eliminate the potential for release of gases into the surrounding air.

- **Grilles protecting air intakes should be bird- and rodent-proofed to prevent perching, roosting and nesting.** Waste from birds and other pests (e.g., rats) can disrupt proper operation of the HVAC system, promote microbial growth and cause human disease. The use of outdoor air intake grilles with vertical louvers, as opposed to horizontal louvers, will reduce the potential for roosting.
  - **Intake Screens must be accessible for inspection and cleaning.** In existing schools, an insufficient amount of ventilation air is often the result of clogged intake screens that are inaccessible for inspection and cleaning. Screens hidden by an intake grille should be designed with a grille that is easily opened, such as a hinged grille with two quick-release latches, or in the worst case, a grille with four one-quarter turn fasteners. All screens should be easily removable for cleaning.
  - **Consider adding a section of sloped intake plenum that causes moisture to flow to the outside or to a drain if intake grilles are not designed to completely eliminate the intake of rain or snow.**
- 

### Outdoor Air Quantity

Classrooms and other school spaces must be ventilated to remove odors and other pollutants.

- The national consensus standard for outside air ventilation is ASHRAE Standard 62.1-2001, If outside air is provided through a mechanical system, then at least 15 cubic feet per minute (cfm) of outside air must be provided for each occupant. A typical classroom with 30 people requires a minimum of 15 x 30 or 450 cfm of outside air.

In spaces where the number of occupants is highly variable such as gyms, auditoriums and multipurpose spaces, demand controlled ventilation (DCV) systems can be used to vary the quantity of outside air ventilation in these spaces in response to the number of occupants. One technique for doing this is to install carbon dioxide (CO<sub>2</sub>) sensors that measure concentrations and vary the volume of outside air accordingly.

If an auditorium fills up for school assembly, then CO<sub>2</sub> concentrations will increase, a signal will be provided to the HVAC system and outside air volumes will be increased accordingly. When the spaces served by an air handler have highly variable occupancy, this type of control can both save energy and help control moisture (and mold) by reducing the quantity of humid outside air when it is not needed for ventilation. CO<sub>2</sub> and other sensors must be periodically calibrated and maintained.

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### Air Filtration

In addition to "atmospheric dust," airborne particulates can include pollen, mold (fungal) spores, animal dander, insect proteins, pesticides, lead and infectious bacteria and viruses. Designers can integrate features into the ventilation system that will provide benefits for the school occupants as well as the efficiency and longevity of the HVAC system. In addition, these features can reduce the need for expensive cleaning of the duct work and air handling units.

### Filter Efficiency

- **Air filters should have a dust-spot rating between 35% and 80% or a Minimum Efficiency Rating Value (MERV) of between 8 and 13.** The higher the rating, the better the protection for the equipment and the occupants. It has been estimated that a 30% increase in static pressure across a

coil results in a \$200 per 10,000 cfm of air movement (at 7 cents per KWH). This does not include the added cost of cleaning dirty heating or cooling oils, drain pans, or air ducts. Designers should consider specifying a low efficiency (~10%) pre-filter upstream of the main filters. The pre-filters are generally easy and inexpensive to change and will capture a significant amount of the particulate mass in the air thereby extending the useful life of the more expensive main filters.

- See ASHRAE Standard 52.2-1999 Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Pressure Drop
- **Design more filter surface area into ventilation systems.** This has two advantages: the number of filter changes each year is reduced, thereby reducing the cost of labor to properly maintain the filters; and static pressure loss is lower, which saves money by reducing the amount of power needed to operate fans and blowers. Since different filter media are approximately proportional in their efficiency/pressure drop ratio, the most effective method for reducing pressure drop is to design more filter surface area into the filter system. This can be done by the specification of a filter with larger amounts of surface area, such as a pleated filter or bag filter. The next method is to increase the number and/or size of the filters in the airstream, for example, by mounting the filter slots in a "V" pattern, rather than a filter rack that is simply flat and perpendicular to the airstream.

#### Monitoring Pressure

- **Consider installing a simple pressure differential gauge across all filter banks.** This will prevent school facilities personnel from having to guess whether the filter is ready for replacement. A gauge with a range of zero to 1.0 in. w.g. can save money and the environment by preventing premature disposal of filters that still have useful life and can prevent health and maintenance problems caused by overloaded filters that have blown out. The gauge should be easily visible from a standing position in an easily accessed location near the air handling unit.

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#### Air Cleaning for Gaseous Contaminants

The most effective means of reducing exposure of occupants to gases and VOCs is to manage and control potential pollution [sources](#). Filters are available to remove gases and volatile organic contaminants from ventilation air; however, because of cost and maintenance requirements, these systems are not generally used in normal occupancy buildings or schools. In specially designed HVAC systems, permanganate oxidizers and activated charcoal may be used for gaseous removal filters.

Some manufacturers offer "partial bypass" carbon filters and carbon impregnated filters to reduce volatile organics in the ventilation air of office environments. Gaseous filters must be regularly maintained (replaced or regenerated) in order for the system to continue to operate effectively.

- See also "[Residential Air Cleaners \(2nd Edition\): A Summary of Available Information.](#)"

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#### Ventilation Controls

Although a typical HVAC system has many controls, the control of outdoor air quantity that enters the building can have a significant impact on IAQ, yet typically is not part of standard practice. Demand controlled ventilation is addressed as a method of humidity control, but is not otherwise discussed here because its primary use is to reduce the supply of outdoor air below the recommended minimum for the purposes of saving energy, not for improving IAQ.

- See more about Humidity Control

### Volume Monitoring and Control

Supplying acceptable quantities of outdoor air to occupied spaces is a critical component of good indoor air quality. Yet nearly all school ventilation systems cannot indicate whether outdoor air is even being supplied to the school, much less gauge the quantity of that air. Virtually all existing school ventilation systems rely upon a fixed damper to regulate the amount of outdoor air.

Yet wind, stack effect, unbalanced supply and return fans and constantly changing variable air volume (VAV) systems can cause significant under- or over-ventilation, which can affect IAQ and energy costs. Combinations of these effects can even cause the intake system to actually exhaust air.

- **Specify the addition of a measuring station that actively controls the amount of outdoor airflow by modulating the outdoor air damper and the return (recirculation) damper, if needed to overcome wind and stack effects.** These measuring stations are designed to work in limited duct space and with low air velocities. This is an easy task, as some manufacturers offer their airflow measuring stations in separate packages with dampers and actuators and others are built into the AHU at the factory.
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### Moisture and Humidity Control

Uncontrolled moisture indoors can cause major damage to the building structure, as well as to furnishings and to finish materials like floors, walls and ceilings. Uncontrolled moisture can trigger mold growth which not only damages the school facility, but can lead to health and performance problems for students and staff.

Primary causes of indoor moisture problems in new schools include:

- Use of building materials that were repeatedly or deeply wetted before the building was fully enclosed
- Poor control of rain and snow, resulting in roof and flashing leaks
- Wet or damp construction cavities
- Moisture-laden outdoor air entering the building
- Condensation on cool surfaces

Controlling moisture entry into buildings and preventing condensation are critical in protecting buildings from mold and other moisture-related problems, including damage to building components.

- Visit the [Moisture Control page](#) for more moisture information.
- 

### Air Distribution and Duct Insulation

Dirt and moisture should not be present in duct systems and must be controlled to prevent mold growth. However, it is not always possible to assure that ducts remain dirt and moisture free. In many existing schools, sheet metal ducts, as well as those constructed of or lined with insulation products, are often contaminated with mold because dirt and moisture found their way into the system.

Duct board and duct liner are widely used in duct systems because of their excellent acoustic, thermal and condensation control properties. If the HVAC system is properly designed, fabricated, installed, operated

and maintained, these duct systems pose no greater risk of mold growth than duct systems made of sheet metal or any other materials.

However, the very properties that make duct board and duct liner superior insulators (e.g., a fibrous structure with large surface area that creates insulating air pockets), also makes them capable of trapping and retaining moisture if they do get wet (though the fibers themselves do not absorb moisture).

While there is an ongoing debate about the wisdom of using insulation materials in duct systems that might retain moisture longer, all sides agree that extraordinary attention to preventing moisture contamination of the duct work should be the primary strategy for preventing mold growth. See ANSI/ASHRAE Addenda 62t and 62w, Addenda to ANSI/ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality.

As a secondary strategy, designers should consider methods of reducing the potential for future problems to occur due to unforeseen moisture contamination by investigating insulation products now on the market that minimize the potential for moisture to penetrate the insulation material. These include foil vapor retarders, tightly bonded non-woven vapor retarders, butt or shiplap edges and other techniques that have been developed by insulation manufacturers to address concerns about moisture.

- **Pay special attention to preventing moisture from entering duct work.** Preventing [moisture](#) from entering duct work is critical to preventing [mold](#) problems in all types of ducts. Moisture in ducts is usually due to penetration of precipitation through inlet louvers, excess moisture in outdoor air, or condensation droplets from cooling coils that are not properly drained or ducts that are not properly sealed. Under certain circumstances, when exceeding recommended maximum cooling coil face velocity, water droplets can escape cooling coils and be carried into the air stream, saturating any dirt or dust downstream. Because dust and dirt serve as a food source for mold and are usually present in all but brand new duct systems, mold will grow on any duct surface that remains wet.
- **If specifying duct board or internal duct lining for thermal and/or acoustical control, be sure to consider the potential for uncontrolled moisture to enter the duct over the life of the system.** Select products that will minimize the potential for moisture retention in the event of unforeseen contamination of the duct system, such as those with properties that reduce the potential for moisture to penetrate the air stream surface. Ensure that all duct systems are properly fabricated and installed.
- **Degrease sheet metal air ducts.** The sheet steel used to make ducts has a thin petroleum or fish oil coating primarily intended to inhibit corrosion during transportation and storage of the steel. This coating may trap dirt particles, some people find the odor objectionable and there are concerns that the emissions from the coating could affect individuals with asthma or allergies. One solution is to remove the coating from the duct using a mild cleaning agent, such as a household dishwashing liquid, in conjunction with a heated high-pressure sprayer.
- **Seal air ducts to prevent HVAC system air leakage.** In addition to significant energy losses, air leakage from HVAC ducts and air handling units cause significant IAQ problems due to unexpected airflow between indoors and outdoors and between areas within the school. Air leakage from supply or return duct work contributes to the condensation of humid air in building cavities and/or on the neighboring surfaces. Air leakage can be especially problematic for ducts or AHUs that are located outside the conditioned spaces. The primary goals for the designer are to keep all air ducts within the conditioned space and to specify that the joints and seams of all ducts, including return ducts, are sealed using an appropriate material.

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## Types of Air Distribution

Nearly all schools currently use the mixed-airflow method for distribution and dilution of the air within the occupied space. Designers should investigate a method called vertical displacement ventilation or thermal displacement ventilation. This approach successfully uses natural convection forces to reduce fan energy and carefully lift air contaminants up and away from the breathing zone.

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## Exhaust Air

Quick removal of concentrated air contaminants and building pressurization are two ways that exhaust systems affect IAQ. Special use areas such as science labs, vocational/technical shops, cafeterias and indoor pools already have well established regulatory codes regarding ventilation with outdoor air and negative pressure requirements with respect to adjacent spaces. Less well recognized areas in schools where special exhaust ventilation is desirable are janitor closets, copy/work rooms and arts/crafts preparation areas where off-gassing from significant quantities of materials or products may occur. These areas should be maintained under negative pressure relative to adjacent spaces.

- **Provide exhaust ventilation for janitor's closets.** If housekeeping and maintenance supplies are properly stored in janitor closets, only enough air need be exhausted to place the closet under negative pressure relative to surrounding rooms. As long as air does not easily leak into or from the closet through openings such as plenums or utility chases, 10 CFM of air exhausted from the room will typically make it negative and prevent the buildup of air pollutants.
- **Provide exhaust ventilation for copy/work rooms.** In addition to the code-required amount of outdoor air being supplied to this room for general ventilation, it is desirable to determine what types of equipment and activities the school plans for this room and to supply special exhaust ventilation for concentrated pollutant sources. Two examples of sources are copy machines and work areas for adhesives.

Most copier manufacturers can provide an optional vent kit, which is usually a simple plastic fitting, that allows a piece of 3" or 4" diameter flexible duct to be connected between the copier and an exhaust fan. This captures much of the heat, particles, ozone and other pollutants and exhausts them outdoors before they can spread throughout the workroom. A small exhaust hood over a work surface, similar to a fume hood in a science lab, would also be helpful to reduce exposure when adhesives, sprays, paints and solvents are being used in the workroom.

- **Provide exhaust ventilation for arts and crafts preparation areas where off-gassing from significant quantities of materials or products may occur.**
  - **Consider specifying a differential pressure monitor to monitor building pressurization.** IAQ problems are often traced to improper pressurization, which causes unexpected airflow between indoors and outdoors and between areas within the school. To reduce introduction of unconditioned moist air and pollutants from outdoors, the building should be designed to operate between zero and 0.03 in. w.g. (0 to 7 Pa) positive, relative to outdoors.
  - **Do not operate exhaust systems when the HVAC system is turned off to avoid bringing in unconditioned moist air that may condense on cooler indoor surfaces.**
-

## Designing for Efficient Operations and Maintenance

- **Ensure that all system components, including air handling units, controls and exhaust fans are easily accessible.**

To help ensure that proper operation and maintenance of HVAC system components will be performed, it is critical that the designer makes the components easily accessible. AHUs, controls and exhaust fans should not require a ladder, the removal of ceiling tiles, or crawling to gain access. Rooftop equipment should be accessible by way of stairs and a full-sized door, not a fixed ladder and a hatch.

- **Label HVAC system components to facilitate operations and maintenance.**

Labeling of HVAC components is an inexpensive and effective method for helping facilities personnel properly operate and maintain the HVAC systems. The labels should be easy to read when standing next to the equipment and durable to match the life of the equipment to which they are attached. At a minimum, the following components should be labeled in each ventilation zone of the school and should correspond with the HVAC diagrams and drawings. "AHU" refers to any air handling unit that is associated with outdoor air supply.



The number or name of the AHU (e.g., AHU ##, or AHU for West Wing)



The outdoor air (OA), supply air (SA), return air (RA) and exhaust or relief air (EA) connections to the AHU, each with arrows noting proper airflow direction



The access door(s) for the air filters and the minimum filter dust-spot (or MERV) efficiency (Air Filters, minimum xx% dust spot efficiency)



The filter pressure gauge and the recommended filter change pressure (Filter Pressure, max 0.x in. w.g.)



The access door(s) for the condensate drain pan (Drain Pan)



Other pertinent access doors such as to energy recovery ventilation wheels or plates (Energy Recovery Ventilation Unit)



The minimum amount of outdoor air for each AHU (### CFM minimum during occupied times)



The outdoor air damper (OA Damper), with special marks noting when the damper is in the fully closed (Closed), fully opened (open) and minimum designed position (Min)



If a motorized relief damper is installed (EA Damper), note the same positions as above.



The access door to any outdoor air controls (OA Control(s)) such as damper position adjustments, outdoor airflow measuring stations, resets, fuses and switches)



Breakers for exhaust fans (Exhaust Fan ##), AHU, unit ventilators



Access doors for inspection and maintenance of air ducts



Any dampers and controls for air side economizers (as appropriate)



The number or name of all exhaust fans, including the air quantity exhausted (EF##, ###CFM)

## 2.2 Type of HVAC systems – single split system ,multi split system ,VRF AND VRV SYSTEM

HVAC, or heating, ventilation and air conditioning, is designed to control the environment in a space. It can control the temperature, humidity, ventilation, pressure, and some special conditions like smoke removal. And there are 3 different types of commercial HVAC systems in the market now.

Commercial HVAC systems can be utilized by almost any commercial property types, including office spaces, distribution facilities, schools, conditioned storage facilities, hotels, etc. There are many benefits that go with an HVAC system. But when the HVAC system gets old, the amount of energy it uses will typically double. Thus, it is important to take actions to reduce commercial HVAC waste and replace the old system when necessary.

Now, you should have a basic understanding about HVAC systems. Let's go back to today's topic—different types of HVAC systems. According to The Cooling Company, the 3 types of commercial HVAC systems are single-split system, multi-split system, and VRF or VRV systems.

### Single-Split Systems

As its name indicates, a single-split system connects one indoor unit to an outdoor unit. It is the most popular types of commercial HVAC systems because it is more affordable and suitable for small commercial facilities.

It works especially well for buildings that have many small, individual rooms. It allows the occupants of the rooms to control the indoor environment independently. The single-split system of each room also does not affect other rooms. If one breaks down, the others are still working.

However, one disadvantage of single-split system is that it requires one indoor unit pair with one outdoor unit, which will take up a lot of space.



## Single-Split Systems

### Multi-Split Systems

A multi-split system can connect multiple indoor units to one outdoor unit. Depending on the provider, multi-split systems can connect up to ten units to a single outdoor unit. By using inverter technology, the compressor can run on various speeds, allowing each indoor unit to have its own setting. Thus, a multi-split systems take up less outdoor space and allow better management over the indoor units.

However, it requires more pipework to connect with each indoor unit, so the installation fee will be much higher than a single-split system.

### VRF or VRV Systems

Last but not least, a VRF (variable refrigerant flow) or VRV (variable refrigerant volume) system is a more sophisticated commercial HVAC system. The VRF system and VRV system are the same, and these two words can be used interchangeably.

Similar to a multi-split system, a VRF or VRV system also connects multiple indoor units to one outdoor unit. What's more, the system is able to capture heat absorbed from the air during the cooling process and redirects the heat to other parts of the facility that need the heat. It works especially well for facilities that require customized heating and cooling over multiple zones, such as restaurants, office buildings, and factories.

Moreover, a VRF or VRV system is more powerful. It can meet larger building's heating and cooling requirements and the installation is quick and easy. Even though VRF/VRV systems have been around for

decades, they have only just gained popularity in the United States in the last 10 years. A VRF or VRV system still represents the latest and greatest technology in heating and cooling comfort.

However, the costs and installation fee of a VRF or VRV system are much higher than the other two types of systems. However, this concern can be mitigated with the selection of proper financing options and the expectation that VRF or VRV systems will generate increased energy savings over time, allowing for a return on investment.



Technician checking HVAC systems

Overall, each type of commercial HVAC systems has its advantages and disadvantages. Before selecting which type you want to install for your facility, it is important to determine how you want to use it and what you need to achieve with it.

### 2.3 Air conditioning - Refrigerant-based, Non-refrigerant:

[Comparison of various refrigerants \(R-410A, R-22, R-32, R-290, R-134A, R-600A\) used for Air Conditioners and Refrigerators](#)

Table of Contents

1. [What is a refrigerant?](#)
2. [Old and Modern refrigerants](#)
3. [Conclusion](#)

While growing up in the 1990s I used to hear a lot about CFCs (or chlorofluorocarbons) and their involvement in depletion of ozone layer. There were talks that all the refrigerants that cause environmental harm will be phased out. But as the years passed by, the thought of checking if a refrigerator or air conditioner that is being purchased has environmentally friendly refrigerant or not, vanished, as the presumption was that the CFCs have been phased out and we only get environmentally friendly refrigerants these days. But is that true? Or do we really care? In this article, we will look at various refrigerants that are used in air conditioners and refrigerators that are available in Indian market.

## What is a 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 20<sup>th</sup> 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. Manufacturers, who use these refrigerants, claim that they have taken good care in using these refrigerants and the appliances are absolutely safe. 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.

Below is the data for Global Warming Potential of various refrigerants ([source](#)):

Refrigerant	Global Warming Potential	Ozone Depletion Potential
R-22	1810	Medium

R-410A	2088	Zero
R-32	675	Zero
R-134A	1430	Zero
R-290	3	Zero
R-600A	3	Zero

### Conclusion

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.

### 2.4 System Capacity Sizing, Ventilating-Mechanical ventilation, natural ventilation, hvac – economizers “free cooling”

#### All You Need to Know About Air Conditioner Sizing



When buying an air conditioner, there are many considerations one has to keep in mind: [efficiency ratings](#), inverter technology, reversibility, Energy Star certification, and a few more. But perhaps one which is the most important is the air conditioner sizing or cooling capacity.

Wondering, what size air conditioner do I need? You'll know precisely the right size for you in this article. It's also vital to understand what cooling capacity, BTU or tonnage is, how it affects air conditioner operation, and how to choose the right sized air conditioner for your room. Let's go over these questions and help you get the best air conditioner for you!

If you're all set to make an air conditioner purchase, you may also be interested in [smart AC controllers](#) or smart thermostats. They allow you to control your air conditioning from your phone and set intelligent triggers for increase energy efficiency.

### **What Is Ton/Btu When It Comes to AC Cooling Capacity?**



When talking about an air conditioner's cooling capacity, we mean the amount of area an air conditioner can effectively cool. Properly sizing any [type of air conditioner](#) according to the site to be cooled is very important. This is not only for achieving a comfortable environment but also to cut down your energy costs.

But first, we have to understand how the cooling capacity of an air conditioner is measured. The cooling capacity is expressed in BTUh (British Thermal Units per Hour) or ton/tonnage. In technical terms, the amount of heat required to raise the temperature of one pound of water by one Fahrenheit. A higher AC BTU means that it is capable of cooling or heating a larger interior space.

Tonnage is the total amount of heat an air conditioner unit can remove from your home within one hour. One tonnage is equal to 12000 BTU. When figuring out what ton of AC you need, keep in mind that residential air conditioners usually range from 1.5 to 5 tons. You can convert BTU to ton and vice versa using [this calculator from Convert World](#).

Ton/ BTU can be used interchangeably when identifying an AC's cooling capacity. However, in the US, the cooling capacity is mostly measured in BTUs.

### What Air Conditioner Size Do I Need?



Wondering how to find your air conditioner size correctly? Here are some important considerations to keep in mind based on which you can determine the correct BTU requirements for you.

While general calculation used as a rule of thumb for sizing an AC unit requires the size of your room, extremely accurate determination of AC size would need to include a whole host of other factors. These can consist of wall insulation, wall material, air volume coming into the room compared to that exiting, the temperature difference between the inside and outside, humidity levels throughout the year, location of the room in the house, flooring material, and much more.

Let's look at some of the major factors and how they can affect your air conditioner sizing:

#### 1. Room Size Guidelines

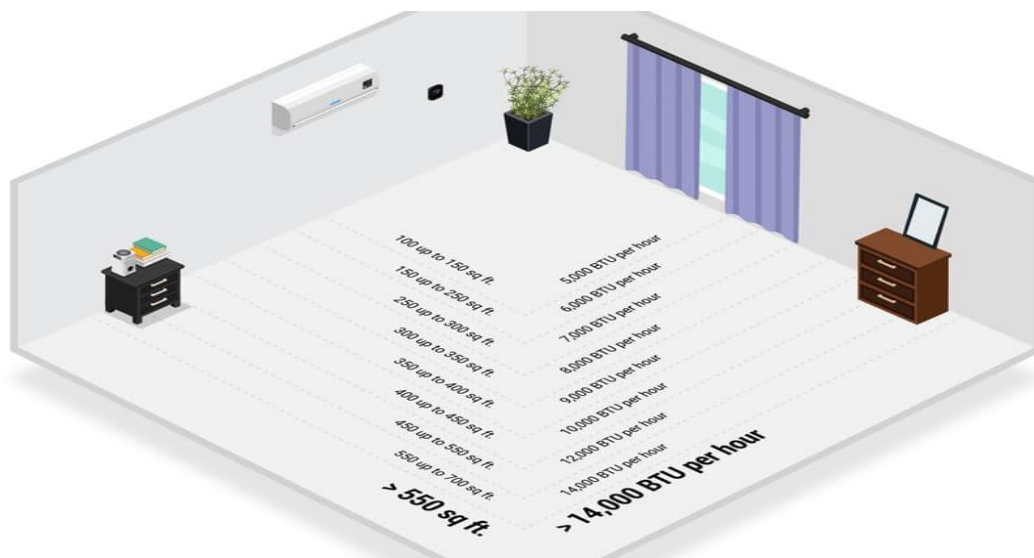
To calculate the best air conditioner size for your space, you first need to calculate the size of your room. This is pretty straightforward: Simply multiply your room's length and width. This helps to calculate the space's area that is required to be cooled (or heated).

If your room is not a perfect rectangle or square, you can make your task easy by dividing the room into separate sections to calculate the precise size. Here is a nifty [room size calculator](#) to help you out.

The next part is the tricky one. You need to calculate the AC BTUs that would be suitable for your room. You can multiply your room's total area by 25 to get the BTU required. As a rule of thumb for sizing AC units, a system needs [20 BTUs for each square foot](#) of space occupied.

This number is a safe figure and caters to different daily weather conditions such as rain and humidity. For example, a room with a length of 10 feet and a width of 14 feet has an area of 140 square feet. To figure out how many BTUs you need for your air conditioner, multiply the area by 25 to get the minimum cooling capacity required for your air conditioner, which comes out to be 3,500 BTUs.

Below is a handy AC sizing chart [based on Energy Star's recommendations](#). It's very helpful to determine the best AC size for your room based on the size of your room.



If you look ahead at the safe figures, your cooling capacity may slightly differ based on your room conditions. If sunshine falls on your room all day, your cooling capacity may need to increase by 10% or be reduced by 10% if the room is in a shaded area. You may need more BTUs if many people occupy the space. Read on to discover more about this in the 'essential considerations' section.

These calculations only serve to provide a rough estimate of the minimum cooling needed. The actual required cooling power depends on many other factors. These factors include the thermal conductivity of the walls and building materials, temperature differences, humidity, amount of airflow in the room, and much more.

## 2. Room Height

Although we have sized air conditioners according to a room's area, we have so far not considered the height! The height of a room also plays a part in determining how adequate a specific cooling capacity is.

Rooms with a very high ceiling will have a much more significant air amount that needs to be cooled. Moreover, wall-mounted mini-splits are more effective at cooling all the air present in a room than window-mounted air conditioners. This is because a wall-mounted mini-split is positioned much higher on the wall, and as we know, [warm air rises](#). The warm air is hence cooled more effectively with a mini-split than a window air conditioner.

### **3. Wall Insulation**

Wall insulation is a thermally non-conductive material that embeds into the room walls. It helps to keep it cool in the summer and warm in winter. This is possible because wall insulation is an excellent thermal insulator. This means it does not conduct heat efficiently, thus preventing loss of cooling in the summers.

If you have good wall insulation, your air conditioning requirement would be less. The room will not be losing heat quickly. If you do not have insulation, the room will get warm quickly after you turn the AC off. You need to have it running for more extended periods and on higher power settings.

### **4. Humidity Levels**

Higher humidity means more need for air conditioning. An air conditioner works to provide cool air in the room and works as a dehumidifier. Removing the excess moisture from the air will immediately make a marked difference in the temperature. You feel and make the environment more comfortable.

If you live in an area with a high moisture content year-round, it's better to invest in some extra capacity for your air conditioner.

### **5. Location**

Think of Colorado vs. Florida. Depending on a region's general climate and humidity levels, the same sized houses will have different air conditioning requirements. Homes in cooler or dry areas require a smaller air conditioner size than houses in warmer and humid regions.

Does sunlight fall directly over your house, or you have trees around protecting your space with shade? [Energy Star recommends](#) increasing your AC BTUs by 10% if the room in which you plan to place an air conditioner lies in a shaded area. Your cooling capacity will increase by 10% if direct sunlight falls over the room.

The type of room in which you plan to place your AC also affects cooling capacity. Your required cooling capacity will increase by 4,000 BTU if the air conditioner is used in the kitchen.

## 6. Windows

The type of windows and the number of windows in a room can affect your air conditioner sizing requirements. [Energy-efficient windows](#) such as low-e or double-pane windows can reduce the number of BTUs required.

Some windows can be a source of energy loss, and unless treated or fixed. They can increase your cooling capacity or BTU requirements.

Windows also account for incoming light. Natural light is an excellent source to brighten your room. But it is also a source of unwanted heat gain during hot weather. Numerous windows can add as much as 10% to your BTU requirement. You can also prevent unwanted heat gain from windows by energy-saving treatments such as tinting, etc.

## 7. Number of People

Energy Star recommends increasing the required cooling capacity by 600 BTU per person. This criterion applies if multiple people occupy the room for large parts of the day. Human bodies generate heat, making it vital to consider the number of people a room will occupy.

### Mechanical Ventilation in HVAC

#### Ventilation in HVAC

**HVAC** stands for Heating, Ventilation, and Air Conditioning. **The objective of HVAC** is to control the temperature of air inside the designated “Air Conditioned” space along with control of moisture, filtration of air and containment of air borne particles, supply of outside fresh air for control of oxygen and carbon dioxide levels in the air conditioned space, and finally control of the movement of air or draught. Ventilation is the process of changing the air or replacing the air of any space by **outside air** as well as the circulation of the air between spaces for the basic purpose of maintaining the air quality. It removes the moisture, odors, bacteria, smoke, air-borne particles, etc. The ventilation of the space is an important process in maintaining the air quality indoors. As per ASHRAE standard 62 ventilation should be done for acceptable **Indoor Air Quality** (IAQ) standard. The purpose of ASHRAE standard 62 is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to minimize the potential of adverse health effects. The World Health Organization estimates that 30 % of all buildings suffer from Sick Building Syndrome due to improper indoor air quality and improper ventilation and air treatment.

#### Types of Ventilation

The acceptable air quality has to be maintained by supplying adequate air of specified quality and quantity in the space. The ventilation of the building can be done by natural ventilation by means of windows and skylights or by mechanical ventilation.

Natural ventilation is the ventilation of a building without the aid of fans or other mechanical systems. Historically all buildings were ventilated naturally with the help of windows and skylights. **Natural ventilation** use the pressure difference or temperature difference to allow the flow of air through the

building. Natural ventilation is not very effective as humidity control is not proper, but when used in conjunction with mechanical systems they can save electricity.

**Mechanical ventilation** is also called forced or induced ventilation and is done by fans and other mechanical means. This means of ventilation is very effective in controlling the humidity and air quality inside an air conditioned space. As it is a positive means of ventilation it can control the odors, contaminants and humidity as well. There are many examples of mechanical ventilation like our kitchens and bathrooms that have exhaust fans.

## Naturally Ventilated Building and Ducts for Mechanical Ventilation

### Mechanical Ventilation

Mechanical ventilation is a method of forced or induced ventilation by using mechanical air handling systems, commonly called HVAC systems. Mechanical ventilation is more controllable than natural ventilation.

In **Mechanical Ventilation** blowers, fans, filters, and **ducts** are used for transporting and removing air from a space. There are two types of fans used for the transmission of air. When the air enters the impellers axially and is discharged radially from the impeller, it is called a centrifugal or radial flow fan. When the air flows parallel to the axis of impeller, it is called an axial flow fan.

**Centrifugal Fan:** Centrifugal fans are very popular in the duct air conditioning system. The centrifugal fan has an impeller mounted in a volute casing. The fan impeller of the centrifugal fan can have the following profiles:

- Radial or straight blades: It is a simple impeller construction. The blades run straight from a central point. These fans provide very high pressure at high speeds of rotation.
- Forward Curved Blades: These blades are shallow in depth. These fans are efficient and have less noise.
- Backward curved blades: They have to be operated at higher speeds for same pressure. Due to their higher speeds they can be directly coupled to the motors.

**Axial Flow Fan:** These fans are never used in duct air conditioning system as they cannot develop high pressures, however they can handle large quantities of air. The axial flow fans are of the following types:

- Propeller Fan: A propeller fan consist of a propeller in a mounting ring. They are used when the resistance to air movement is small as in the ventilation of bathrooms, and attic spaces.
- Tube Axial Fan: It consists of a propeller fan housed in a simple cylinder. These types of fans can be installed in round ducts. The air flow in the tube is spiral on its way out.

**Vane Axial Fan:** A vane axial fan has a tube axial fan along with guide vanes to stop the spiral movement of air.

## Images

### Air Changes Required

ASHRAE standard 62 states that certain amount of **fresh air** should always be supplied to all the areas of the building or the air conditioned spaces, which is dependent on the activity being done and the number of people present. For example dancing floors and smoking areas will require more air changes than other areas.

The air changes required by various spaces are as follows:

Bathroom and toilets: 3-8

Offices: 4-6

Meeting Rooms: 7-10

Restaurants: 8-12

Public Toilets: 10-15

### **Natural Ventilation**

#### BREADCRUMB MENU

// PASSIVE DESIGN // **NATURAL VENTILATION**

Natural ventilation is the use of wind and thermal buoyancy to create air movement in and out of your home without the use of mechanical systems, with the goal of bringing fresh air into your home. During nighttime in the summer months natural ventilation can provide free cooling and reduce your home energy use. Natural ventilation design is typically considered during the home design phase.

The following video demonstrates how natural ventilation works. Then we discuss the [factors that affect natural ventilation](#), and the [types of natural ventilation](#) techniques typically included in home design. Lastly, further [design considerations](#) are introduced.

Video by: Hologram Digital

#### Factors Affecting Natural Ventilation

The effectiveness of natural ventilation varies based on:

- Dominant wind speed and direction
- Surrounding environment

- Building footprint and orientation
- Outdoor temperature and humidity
- Window sizing, location, and operable

### Types of Natural Ventilation

There are two commonly used natural ventilation techniques: wind driven ventilation and stack ventilation.

#### WIND DRIVEN VENTILATION STACK VENTILATION

#### Design considerations

If you're considering natural ventilation in your new home you should consider the following main design techniques:

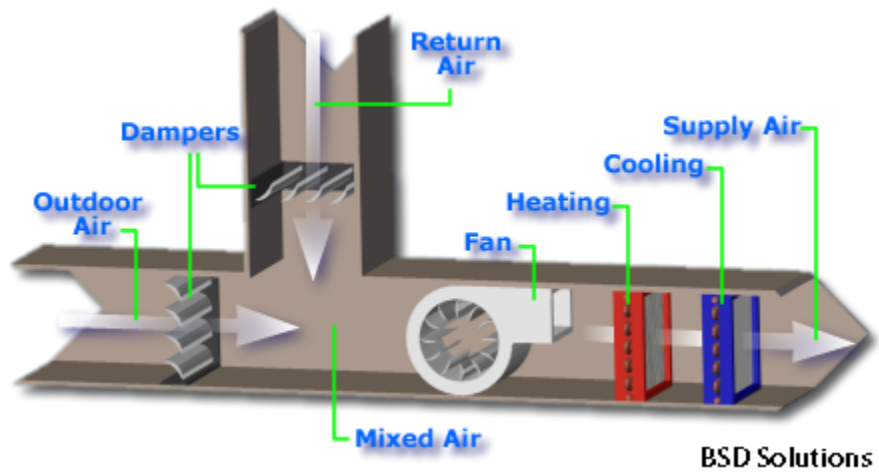
- BUILDING ORIENTATION AND LOCATION
- BUILDING FORM AND DIMENSIONS
- WINDOW TYPOLOGIES AND CONTROLS
- EXTERNAL ELEMENTS
- AIR INLETS AND OUTLETS
- RIDGE VENTS
- BE CAREFUL NOT TO COMPROMISE FIRE EXITS

### Free Cooling (economizers)

“Free cooling,” refers to any technique used to reduce the energy consumed by cooling systems or the time that the cooling units run by using the outside temperature of air or water to cool the data center or other facilities. Generally, it comes from the use of air-side and water-side economizers. Air-side economizers work in two ways. Mainly, they use direct fresh-air cooling by filtering (and possibly adjusting the humidity of) outside air, which is piped in to cool the data center. In cold climates, it may even be warmed by the hot air being expelled, so as not to be too cold. Air-side economizers can also work without bringing direct air into the data center, but by heat transference from warmer inside air to cooler outside air.

#### What is an Economizer?

An economizer is a part of a building’s cooling system that uses cool outdoor air to cool the building instead of operating the air conditioning compressor. An economizer is an add-on feature to an HVAC air handler that draws in outdoor air and mixes it with return air from indoors.



Economizers cool buildings using outdoor air at night (free cooling). Economizers also ventilate many buildings.

**Free Cooling**

A controller in the economizer measures the temperature and humidity of the outdoor air. When the outdoor temperature is favorable, the control switches the air conditioning compressor off and cools the building with outdoor air instead. The economizer cools the building using far less energy compared to air conditioning.

Economizers typically operate at night when the outdoor air is cooler than the indoor air in a process known as “free cooling”. Economizers mix enough outdoor air into the indoor air in order to meet the thermostat setpoint without using the compressor. Fresh air that economizers bring in while they save cooling energy at night can count as ventilation. Therefore the ventilation system can run for fewer hours and avoid operating during the day’s peak electrical load.

**Economizers for Ventilation**



This packaged HVAC system has an economizer.

Many buildings use economizers as their ventilation system. Economizers don't normally have heat recovery or energy recovery function, so ventilating with an economizer can have an energy penalty compared to a heat recovery ventilator. However, in California's most mild climates ventilating with an economizer might be an acceptable option for a high-performance building. When buildings use an economizer for ventilation, its dampers are open a small amount while the HVAC system is heating, cooling, or operating on the fan-only option. The fan-only option is for when you need ventilation but not heating or cooling.

To run efficiently, the economizer would require very sophisticated control that tracks the amount of ventilation air delivered during the free cooling mode and during the ventilation mode. A controller similar to LBNL's [RIVEC controller](#) could measure and regulate outdoor air into the building.

### Economizers Frequently Malfunction

Economizers can also waste a lot of energy if their dampers get stuck open. Many economizers have installation flaws that cause them to under ventilate or over ventilate a building. There are a lot of energy savings available just from fixing economizers and installing smarter controls.

## 2.5 Air-conditioning of houses, offices, hotels, restaurants, departmental stores and shopping complex

1. [Energy Saver](#)
2. Maintaining Your Air Conditioner



An air conditioner's filters, coils, and fins require regular maintenance for the unit to function effectively and efficiently throughout its years of service. Neglecting necessary maintenance ensures a steady decline in air conditioning performance while energy use steadily increases. Check out our [Energy Saver 101 Infographic: Home Cooling](#) for more ways to help improve your comfort and the efficiency of your air conditioner.



**Replacing or cleaning air conditioner filters is a critical maintenance task. | Photo courtesy of ©iStockphoto/firemanYU.**

Air Conditioner Filters

**Image**



The most important maintenance task that will ensure the efficiency of your air conditioner is to routinely replace or clean its filters. Clogged, dirty filters reduce the amount of airflow and significantly reduce a system's efficiency. In addition, when airflow is obstructed, air can bypass the filter and deposit dirt directly into the evaporator coil and impair the coil's heat-absorbing capacity. Replacing a dirty, clogged filter with a clean one can lower your air conditioner's energy consumption by 5% to 15%.

For central air conditioners, filters are generally located somewhere along the return duct's length. Common filter locations are in walls, ceilings, or in the air conditioner itself. Room air conditioners have a filter mounted in the grill that faces into the room.

Some types of filters are reusable; others must be replaced. They are available in a variety of types and efficiencies. Clean or replace your air conditioning system's filter or filters every month or two during the cooling season. Filters may need more frequent attention if the air conditioner is in constant use, is subjected to dusty conditions, or you have fur-bearing pets in the house.

### Air Conditioner Coils

#### Image



The air conditioner's evaporator coil and condenser coil collect dirt over their months and years of service. A clean filter prevents the evaporator coil from soiling quickly. In time, however, the evaporator coil will still collect dirt. This dirt reduces airflow and insulates the coil, reducing its ability to absorb heat. To avoid this problem, check your evaporator coil every year and clean it as necessary.

Outdoor condenser coils can also become very dirty if the outdoor environment is dusty or if there is foliage nearby. You can easily see the condenser coil and notice if dirt is collecting on its fins.

You should minimize dirt and debris near the condenser unit. Your dryer vents, falling leaves, and lawn mower are all potential sources of dirt and debris. Cleaning the area around the coil, removing any debris, and trimming foliage back at least 2 feet (0.6 meters) allow for adequate airflow around the condenser.

#### Coil Fins

#### Image



The aluminum fins on evaporator and condenser coils are easily bent and can block airflow through the coil. Air conditioning wholesalers sell a tool called a "fin comb" that will comb these fins back into nearly original condition.

### Condensate Drains

Occasionally pass a stiff wire through the unit's drain channels. Clogged drain channels prevent a unit from reducing humidity, and the resulting excess moisture may discolor walls or carpet.

### Window Seals for Room Air Conditioners

At the start of each cooling season, inspect the seal between the air conditioner and the window frame to ensure it makes contact with the unit's metal case. Moisture can damage this seal, allowing cool air to escape from your house.

### Preparing for Winter

In the winter, either cover your room air conditioner or remove and store it. Covering the outdoor unit of a central air conditioner will protect the unit from winter weather and debris.

### Hiring a Professional

#### **Image**



When your air conditioner needs more than regular maintenance, such as when it does not reduce the indoor temperature to a comfortable level, hire a professional service technician. A well-trained technician will find and fix problems in your air conditioning system.

The technician should:

- Check for correct amount of refrigerant
- Test for refrigerant leaks using a leak detector
- Capture any refrigerant that must be evacuated from the system, instead of illegally releasing it to the atmosphere
- Check for and seal duct leakage in central systems
- Measure airflow through the evaporator coil
- Verify the correct electric control sequence and make sure that the heating system and cooling system cannot operate simultaneously
- Inspect electric terminals, clean and tighten connections, and apply a non-conductive coating if necessary
- Oil motors and check belts for tightness and wear
- Check the accuracy of the thermostat.

What are the Different Types of Commercial Air Conditioning System?

6th November 2014

Air conditioning is used in most commercial properties, ranging from small shops and cafés to large office buildings and public spaces.

To meet these diverse applications, air conditioning systems have different heating and cooling capacities and come with various setups and layouts.

There are almost infinite configurations within each category, but the main types of commercial air conditioning are:

- Single Split System
- Multi-Split System
- VRF or VRV System

They all use the same basic technology and identical wall- or ceiling-mounted indoor units. However, they have very different applications, so it's important to find out which is best for you.



**Split System Air Conditioning**

Single splits are the most affordable type of air conditioning system and suitable for use in small commercial buildings. They provide heating and cooling to individual rooms, making them ideal solutions for small offices, shops, cafés and [server rooms](#).

They can also be used in combination to serve larger spaces and multiple rooms. The only downside is that you need enough external space to have one outdoor unit for every indoor unit.

However, there are advantages to doing it this way. Firstly, it's often cheaper than installing a central system, and, as each system is self-contained, if one [unit breaks down](#), the others remain fully functional.

Even though they're the cheapest type of air conditioning, single splits are effective and energy-efficient systems. Their versatility makes them great for all kinds of applications and they're extremely [popular with small businesses](#).



### **Multi-Split System Air Conditioning**

Multi-splits work in exactly the same way as single splits but, depending on the model, you can connect up to nine indoor units to one outdoor unit. They're most frequently used in places like restaurants, offices, doctor's surgeries and shops.

It's always preferable to have fewer outdoor units, particularly if you lack space or want to [preserve your building's external appearance](#). That gives multi-splits a distinctive advantage over several single splits.

Another selling point is that you aren't limited to using just one type of indoor unit. If you wanted to, you could have any combination of wall- and ceiling-mounted air conditioning units, along with an air curtain over the entrance.

However, multi-split systems are slightly more complex and require more pipework than several single splits. That can make the installation more expensive and take longer, particularly if you're only looking to install a few indoor units.

Ultimately, the best solution depends on the layout of your building and the heating and cooling capacity you require.



### **VRF or VRV Air Conditioning**

VRF stands for variable refrigerant flow, while VRV stands for variable refrigerant volume. It might seem confusing but they mean exactly the same thing.

Daikin originally developed the technology, calling it VRV, but then protected the term to stop other manufacturers from using it. That's why everyone else calls it VRF.

VRF/VRV air conditioning is the best solution for medium to large applications, including hotels, [retail spaces](#), [larger offices](#) and mixed-use buildings.

The systems are extremely efficient, reliable and easy to control, capable of meeting larger buildings' complete heating and cooling requirements. They also come with reduced installation times, minimising disruption.

There are two types of VRF/VRV system, heat pump and heat recovery. Heat pump VRF/VRV systems can provide either heating or cooling to a building at any given time, making them ideal for open plan areas.

Heat recovery VRF/VRV systems are capable of providing simultaneous heating and cooling to different areas at the same time, making them perfect for buildings with lots of individual rooms. The most efficient commercial air conditioning systems, they recover waste heat from around the building, using it to heat other rooms and hot water. Heat recovery systems are also more flexible, as you have the option to heat one room while cooling another.

## 2.6 Air-conditioning of theatres and auditoriums,

### **HVAC systems for theatres, auditoriums and cinema halls: the art and science of system design.**

The design consideration for any air-conditioning system depends largely on its application. It is a known fact that theatres, auditoriums, concert halls or motion picture theatres (cinema halls) are high occupancy (persons per sq.ft) areas. Consequently, the fresh air requirement is high in order to dilute the CO<sub>2</sub> concentration. High occupancy also leads to a greater amount of latent load emitted by the human beings. All these considerations need to be taken into account by the designers when calculating the air-conditioning load. The inside design condition is as per the ASHRAE standard for human comfort. Typically, the comfort band on temperature varies between 21.1 and 24.4 °C with RH not exceeding 65%.

## 2.7 Air-conditioning of hospitals and medical establishment

### **HVAC Systems Control Temperature and Humidity, Ventilation, and Air Filtration, Which All Matter to Hospitals**

Air conditioning systems and HVAC systems, in general, are designed to create and maintain comfortable environments for buildings' occupants. Hospital HVAC systems are also designed to keep employees, patients, and visitors comfortable.

Yet the importance of air conditioning in hospitals and HVAC systems also relates to air ventilation and other factors that promote safe and healthy indoor air.

“

Hospitals must consider the spread of airborne diseases and the exact temperature and humidity conditions required for intensive care units and other hospital areas when designing their air conditioning systems.

”

### **COVID-19, Air Ventilation, and HVAC Systems**

As a result of the COVID-19 pandemic, the importance of indoor air quality and ventilation systems in regard to public health has never been greater.

In some cases, there is a higher risk of infection due to coronavirus transmission in hospitals, as both infected and healthy individuals occupy the same place. Therefore, wards with COVID-19 patients must be well ventilated to prevent the spread of disease and to protect both patients and staff.

It's important to clarify that having a well-maintained commercial ventilation system won't always protect a building's occupants against infection. But when installed and used correctly, ventilation systems can manage air distribution to mitigate airborne diseases.

To reduce risk from COVID-19, a hospital can take steps to ensure that the airflow from various hospital sections does not cross and that temperature and humidity levels are maintained for both people and medical equipment.

### **Hospital HVAC Systems Affect Air Quality, Comfort, and Health for All**

Air conditioning systems and HVAC systems keep air comfortable but also help prevent cross-contamination, improve patient outcomes, and enhance the quality of life for all staff and patients.



It's easy to take indoor air that's cool and comfortable for granted, but heating, ventilation, and air conditioning systems are all critical to air quality, comfort, and safety.



Here are some additional reasons why a good HVAC system is so vital for a hospital.

#### [Preventing Cross-Contamination](#)

Hospitals admit patients with a wide variety of illnesses, and it is important to prevent the spread of airborne diseases. Patients can also pick up airborne particles and pathogens, making them sicker.

It is vital to maintain correct air ventilation and temperature and humidity control, as recycled contaminated air can be dangerous.

#### [Better Patient Outcomes](#)

While staying comfortable is key for building occupants, adequately cooled or warmed rooms with comfortable humidity levels can be conducive to healing. Concerning the body, heat stress protection and proper thermoregulation rely on environmental temperatures and conditions.

HVAC systems, which control air supply, temperature and humidity, and ventilation are, therefore, important to healing.

#### [Filtering Air](#)

High-efficiency particulate (HEPA) air filters can remove pollutants and microbial particles that are as small as .3 microns. Filters help to filter air by reducing the spread of airborne diseases and pathogens, including viruses that latch onto particles.

HEPA filters play a critical role in filtering air throughout the hospital or medical facility. They also help to clean the air supply going into patients' rooms, preventing harmful contaminants, substances, or air-borne diseases from reaching vulnerable patients.

#### [Comfort](#)

For hospital patients, staff, and all occupants, a well-maintained HVAC system is crucial for keeping comfortable. Staff work long shifts, and patients frequently stay in hospitals for days or weeks.

Air that's kept at a comfortable temperature and humidity level is simply easier to breathe and helps staff focus on healing.

### **Other Health Care Facilities Needing Well-Functioning HVAC**

Aside from hospitals, a high-quality HVAC system is necessary for other types of medical and care facilities as well, like:

- Inpatient and outpatient clinics
- Hospice facilities
- Nursing homes and assisted living facilities
- Doctors offices
- Medical billing centers
- Research facilities

### **United Mechanical: Hospital HVAC Systems Experts**

The HVAC technicians and service providers at United Mechanical have worked to maintain and service various hospital HVAC systems. These systems can be quite large and complex, even compared to other commercial systems. But our team is experienced, qualified, and capable when it comes to servicing, upgrading, and installing hospital systems.

We always love to share more information, tips, and background knowledge with customers and with anyone who's interested in learning more about HVAC systems.

## **2.8 Energy code items related to hvac equipment and Controls**

HVAC codes and standards: cooling and energy efficiency

**Codes and standards dictate the design of HVAC systems; however, there are ways to improve the design of nonresidential buildings to achieve maximum energy efficiency.**

BY GAYLE DAVIS, PE, CGD, CXA, STANLEY CONSULTANTS, AUSTIN, TEXAS AUGUST 15, 2016

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**Learning objectives:**

- Examine owner and local codes for cooling system designs.
  - Define HVAC codes and standards.
  - Understand cooling systems to maximum energy efficiency.
- 

Data from the 2012 Commercial Buildings Energy Consumption Survey (CBECS) shows that the United States consumes 6,963 trillion Btu of energy generated for commercial buildings. Figure 1 shows that 44% of commercial building energy use is for HVAC and refrigeration. National survey data shows approximately 50% of the HVAC energy is used for cooling, ventilation, and refrigeration purposes.

Efforts to reduce energy use led to the development of energy codes and standards to establish minimum efficiency requirements for new-building construction, building additions, and renovations. Providing comfort cooling and energy efficiency in nonresidential buildings is an ongoing task for engineers and designers as they increasingly have to focus on energy-efficient building codes and high-performance buildings. A building's energy impact is determined by initial design decisions, operations, and the owner's project budget. Energy codes and standards present designers with guidelines to enforce minimal energy savings through efficient design and implementing various equipment technologies.

### **Adopting codes and standards for energy efficiency**

Designers in the HVAC industry must be familiar with codes and standards. Standards define the industry's agreed-upon minimum technical requirements, procedures, guidelines, and instructions for engineers, designers, or manufacturers. They also establish the industry's minimum standard of care. Standards in the United States are mostly voluntary consensus standards, which means they are regularly maintained and are developed through a consensus process. Examples of industry organizations that develop voluntary consensus standards are [ASHRAE](#), [Sheet Metal and Air Conditioning Contractors' National Association \(SMACNA\)](#), [NFPA](#), and [IEEE](#). These standards may or may not be written in enforceable language.

In contrast, a code is a standard that has been enacted into law by an authority having jurisdiction (AHJ) such that a designer is legally required to comply with that standard. The code may also include references to additional standards that can also be enforced. This procedure is called, "incorporation by reference." An AHJ may amend the standard to incorporate or remove requirements, such as adding figures, charts, or tables, or amend the standard's language, such as replacing the word "should" with "shall."

In the U.S., the [Department of Energy \(DOE\)](#) is required by the Energy Conservation and Production Act to support, evaluate, and participate in energy code development as managed by ASHRAE and the International Code Council (ICC). DOE activities include evaluating energy and cost benefits associated with changes to [ASHRAE Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings](#) and [International Energy Conservation Code \(IECC\)](#). DOE evaluates ASHRAE Standard 90.1 as the reference standard for commercial-building energy efficiency, and IECC as the reference standard for residential-building energy efficiency.

IECC and ASHRAE Standard 90.1 address building systems such as building envelope, lighting (exterior and interior), minimum HVAC equipment efficiency, HVAC systems, service water heating, and system controls. The standards also set the minimum energy efficiency and system design requirements. Both references have adopted code language to increase state adoption and improve enforceability.

The U.S. does not have a national energy code or standard, even though the federal government supports the development of energy codes and standards. Because there is no national energy code, energy codes and standards are adopted at the state and local jurisdiction levels. The path that energy codes and standards take for adoption varies by locality. In general, energy code adoption is initiated when the DOE issues a positive determination based on the most recent version of ASHRAE Standard 90.1. The publication of a positive review sets in motion statutory requirements directing states and local authorities to certify they reviewed their building codes. All necessary updates are completed to meet or exceed the current edition of ASHRAE Standard 90.1. Many states also have their own code-update cycles that occur independently of ASHRAE, DOE, and IECC updates.

Each new edition of ASHRAE Standard 90.1 requires the DOE to issue a determination on whether the new edition will improve energy efficiency in commercial buildings over the existing edition. On Sept. 26, 2014, the DOE released a final determination that ASHRAE Standard 90.1-2013 would achieve 8.7% energy savings, 8.5% source-energy savings, and 7.6% site-energy savings above buildings designed under ASHRAE Standard 90.1-2010. Each state has 2 years to adopt ASHRAE Standard 90.1-2013 or update its existing commercial building codes and standards. With the 2014 determination, states will have until Sept. 26, 2016, to file compliance certifications with the DOE or request an extension.

Figure 2 shows the status of state energy code adoption as of April 2016. The codes, standards, and editions in force vary. Many states have adopted the IECC commercial code, which allows for an alternate compliance path through ASHRAE Standard 90.1. In jurisdictions that allow either compliance path, the designer must choose either IECC or ASHRAE Standard 90.1 as the design energy code and must complete the entire design using the chosen code. Designers are encouraged to consult with their local permitting agency and the AHJ to determine energy code requirements for states without an energy code.

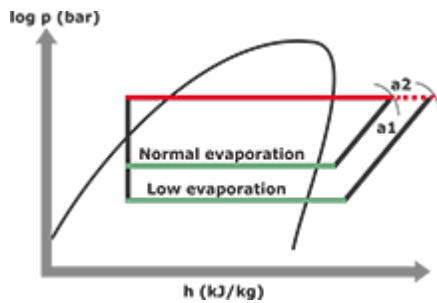
Table 1 provides a summary of the HVAC cooling system energy and efficiency requirements according to the IECC and ASHRAE Standard 90.1. Corresponding equivalent code requirements between IECC and ASHRAE Standard 90.1 have been listed adjacent to each other where applicable. The IECC and ASHRAE have worked together over the years to make the two codes' language and requirements documents similar, if not identical. However, some differences do exist between the two documents; most notably, regarding allowable exemptions to particular code provisions.

### **Unit 3.0 Low Temperature Refrigeration**

#### **Low Temperature Refrigeration**

Operating at very low evaporation temperatures (e.g. when providing cooling for a deep-freezer and still using ambient air or similar as a heat sink for the condenser) often requires special system solutions.

Low-temperature evaporation requires low evaporation pressures while the condensing pressure is at normal levels. It is often beneficial, and in some cases necessary, to separate the evaporation and condensing pressure levels by more than one compressor step. This is because when the pressure ratio over the compressor increases, the discharge temperature out of the compressor will also increase. Simultaneously, the compressor efficiency decreases, which increases operating costs. High discharge temperatures may cause both the refrigerant and the lubrication oil to decompose. This in turn will shorten the life of the compressor. **Figure 10.15**, point (a1), shows the higher discharge temperature of a single-step refrigeration system with low evaporation temperature.



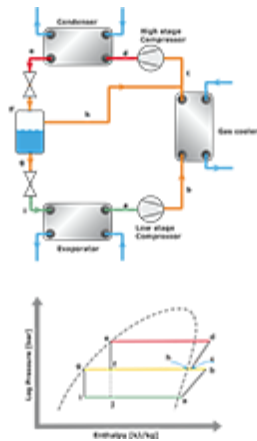
**Figure 10.15** A log P/h diagram showing the resulting higher discharge temperature for a larger compression step.

### Two-stage systems

Intermediate gas cooling is often used between the two compressor steps. By cooling the refrigerant vapor after the first compressor, the discharge gas leaving the high-stage compressor can be kept at an acceptable temperature level. The intermediate cooling also increases the compressor efficiency, which reduces the compressor power consumption.

A two-stage system is a refrigeration system working with a two-stage compression and mostly also with a two-stage expansion. A schematic system layout and the corresponding process in a log P/h diagram are shown in **Figure 10.16**. Flash gas is separated from liquid refrigerant in an intermediate receiver between the two expansion valves. The high-stage compressor will then remove the flash gas, as shown in **Figure 10.16**. The removal of the gas between the expansion stages reduces the quality of the refrigerant vapor that enters the evaporator from the state 'j' (which would be the vapor quality if only one expansion valve were used) to the state 'i', as shown in the log P/h diagram of **Figure 10.16**.

Due to a lower quality entering vapor, each mass unit of refrigerant passing through the evaporator will be able to absorb more heat, reducing the required refrigerant mass flow rate for a given cooling capacity. This in turn reduces the required low-stage compressor size. Because of the enhanced heat transfer coefficient in the evaporator, the heat transfer area needed is also reduced.



**Figure 10.16** Schematic layout of a two-stage low-temperature refrigeration system (right) with a log P/h diagram (above).

### 3.1 Meaning and definition of cryogenics, Importance of cryogenics studies

#### Concept of Cryogenics

ryogenics is defined as the scientific study of materials and their behavior at extremely low temperatures. The word comes from the Greek *cryo*, which means "cold", and *genic*, which means "producing". The term is usually encountered in the context of physics, materials science, and medicine. A scientist who studies cryogenics is called a *cryogenicist*. A cryogenic material may be termed a *cryogen*. Although cold temperatures may be reported using any temperature scale, the Kelvin and Rankine scales are most common because they are absolute scales that have positive numbers.

Exactly how cold a substance has to be to be considered "cryogenic" is a matter of some debate by the scientific community. The U.S. National Institute of Standards and Technology (NIST) considers cryogenics to include temperatures below  $-180\text{ }^{\circ}\text{C}$  ( $93.15\text{ K}$ ;  $-292.00\text{ }^{\circ}\text{F}$ ), which is a temperature above which common refrigerants (e.g., hydrogen sulfide, freon) are gases and below which "permanent gases" (e.g., air, nitrogen, oxygen, neon, hydrogen, helium) are liquids. There is also a field of study called "high temperature cryogenics", which involves temperatures above the boiling point of liquid nitrogen at ordinary pressure ( $-195.79\text{ }^{\circ}\text{C}$  ( $77.36\text{ K}$ ;  $-320.42\text{ }^{\circ}\text{F}$ ), up to  $-50\text{ }^{\circ}\text{C}$  ( $223.15\text{ K}$ ;  $-58.00\text{ }^{\circ}\text{F}$ ).

Measuring the temperature of cryogens requires special sensors. Resistance temperature detectors (RTDs) are used to take temperature measurements as low as 30 K. Below 30 K, silicon diodes are often used. Cryogenic particle detectors are sensors that operate a few degrees above absolute zero and are used to detect photons and elementary particles.

Cryogenic liquids are typically stored in devices called Dewar flasks. These are double-walled containers that have a vacuum between the walls for insulation. Dewar flasks intended for use with extremely cold liquids (e.g., liquid helium) have an additional insulating container filled with liquid nitrogen. Dewar flasks are named for their inventor, James Dewar. The flasks allow gas to escape the container to prevent pressure buildup from boiling that could lead to an explosion.

## Cryogenic Fluids

The following fluids are most often used in cryogenics:

Fluid	Boiling Point (K)
Helium-3	3.19
Helium-4	4.214
Hydrogen	20.27
Neon	27.09
Nitrogen	77.36
Air	78.8
Fluorine	85.24
Argon	87.24
Oxygen	90.18
Methane	111.7

## Uses of Cryogenics

There are several applications of cryogenics. It is used to produce cryogenic fuels for rockets, including liquid hydrogen and liquid oxygen (LOX). The strong electromagnetic fields needed for nuclear magnetic resonance (NMR) are usually produced by supercooling electromagnets with cryogenics. Magnetic resonance imaging (MRI) is an application of NMR that uses liquid helium. Infrared cameras frequently require cryogenic cooling. Cryogenic freezing of food is used to transport or store large quantities of food. Liquid nitrogen is used to produce fog for special effects and even specialty cocktails and food. Freezing materials using cryogenics can make them brittle enough to be broken into small pieces for recycling. Cryogenic temperatures are used to store tissue and blood specimens and to preserve experimental samples. Cryogenic cooling of superconductors may be used to increase electric power transmission for big cities. Cryogenic processing is used as part of some alloy treatments and to facilitate low temperature chemical reactions (e.g., to make statin drugs). Cryomilling is used to mill materials that may be too soft or elastic to be milled at ordinary temperatures. Cooling of molecules (down to hundreds of nano Kelvins) may be used to form exotic states of matter. The Cold Atom Laboratory (CAL) is an instrument designed for use in microgravity to form Bose Einstein condensates (around 1 pico Kelvin temperature) and test laws of quantum mechanics and other physics principles.

## Cryogenic Disciplines

Cryogenics is a broad field that encompasses several disciplines, including:

**Cryonics** - Cryonics is the cryopreservation of animals and humans with the goal of reviving them in the future.

**Cryosurgery** - This is a branch of surgery in which cryogenic temperatures are used to kill unwanted or malignant tissues, such as cancer cells or moles.

**Cryoelectronics** - This is the study of superconductivity, variable-range hopping, and other electronic phenomena at low temperature. The practical application of cryoelectronics is called **cryotronics**.

**Cryobiology** - This is the study of the effects of low temperatures on organisms, including the preservation of organisms, tissue, and genetic material using **cryopreservation**.

### **Cryogenics Fun Fact**

While cryogenics usually involves temperature below the freezing point of liquid nitrogen yet above that of absolute zero, researchers have achieved temperatures below absolute zero (so-called negative Kelvin temperatures). In 2013 Ulrich Schneider at the University of Munich (Germany) cooled gas below absolute zero, which reportedly made it hotter instead of colder!

### **3.2 Properties of engineering materials at cryogenic temperatures, mechanical properties, thermal properties, electric & magnetic properties,**

The design of systems for operation at cryogenic temperatures requires the use of material properties at these low temperatures. The properties at cryogenic temperatures can be much different than the room-temperature values. In addition, some properties can be strong functions of temperature. Property data at cryogenic temperatures are not easy to find. Many measurements were made at the National Institute of Standards and Technology (NIST) and other laboratories about 50 years ago. Some of the results were published in reports that are now out of print, which makes the results unavailable to most researchers. To correct that problem, NIST initiated a program to critically evaluate cryogenic material properties and to curve fit the available data for temperatures in the range of about 4 K to 300 K. The properties available include thermal conductivity, specific heat, linear thermal expansion, thermal expansion coefficient, and Young's modulus. Not all properties are available for all materials. The materials currently in the database are ones commonly used in the construction of cryogenic hardware.

### **3.3 Super conducting materials, thermo electric materials, composite materials,**

#### Superconductivity

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**Superconductivity** is a set of physical properties observed in certain materials where **electrical resistance** vanishes and **magnetic flux fields** are expelled from the material. Any material exhibiting these properties is a **superconductor**. Unlike an ordinary metallic **conductor**, whose resistance decreases gradually as its temperature is lowered even down to near **absolute zero**, a superconductor has a characteristic **critical temperature** below which the resistance drops abruptly to zero. An **electric current** through a loop of **superconducting wire** can persist indefinitely with no power source.

The superconductivity phenomenon was discovered in 1911 by Dutch physicist **Heike Kamerlingh Onnes**. Like **ferromagnetism** and **atomic spectral lines**, superconductivity is a phenomenon which can only be explained by **quantum mechanics**. It is characterized by the **Meissner effect**, the complete ejection

of [magnetic field lines](#) from the interior of the superconductor during its transitions into the superconducting state. The occurrence of the Meissner effect indicates that superconductivity cannot be understood simply as the [idealization](#) of *perfect conductivity* in [classical physics](#).

In 1986, it was discovered that some [cuprate-perovskite ceramic](#) materials have a critical temperature above 90 K (−183 °C). Such a high transition temperature is theoretically impossible for a [conventional superconductor](#), leading the materials to be termed [high-temperature superconductors](#). The cheaply available coolant [liquid nitrogen](#) boils at 77 K, and thus the existence of superconductivity at higher temperatures than this facilitates many experiments and applications that are less practical at lower temperatures.

#### Thermoelectric material

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**Thermoelectric materials** show the [thermoelectric effect](#) in a strong or convenient form.

The *thermoelectric effect* refers to phenomena by which either a [temperature](#) difference creates an [electric potential](#) or an electric current creates a temperature difference. These phenomena are known more specifically as the [Seebeck effect](#) (creating a voltage from temperature difference), [Peltier effect](#) (driving heat flow with an electric current), and [Thomson effect](#) (reversible heating or cooling within a conductor when there is both an electric current and a temperature gradient). While all materials have a nonzero thermoelectric effect, in most materials it is too small to be useful. However, low-cost materials that have a sufficiently strong thermoelectric effect (and other required properties) are also considered for applications including [power generation](#) and [refrigeration](#). The most commonly used thermoelectric material is based on [bismuth telluride](#) ( $\text{Bi}_2\text{Te}_3$ ).

Thermoelectric materials are used in thermoelectric systems for [cooling or heating in niche applications](#), and are being studied as a way to [regenerate electricity from waste heat](#)

#### composite material

**composite material**, also called **composite**, a [solid](#) material that results when two or more different substances, each with its own [characteristics](#), are combined to create a new substance whose properties are superior to those of the original components in a specific application. The term composite more specifically refers to a structural material (such as plastic) within which a fibrous material (such as silicon carbide) is embedded.

### 3.4 Properties of cryogenic fluids.

It is generally agreed that cryogenic fluids are those whose boiling points (bp) at atmospheric pressure are about 120 K or lower, although liquid ethylene with its boiling point of 170K is often included. A list of the cryogenic fluids, together with some selected properties, is given in [Table 1](#). Detailed properties are available commercially on computer disc. (Cryodata Inc.)

**Table 1. Some properties of cryogens at their normal boiling point<sup>a</sup>**

	He <sup>4</sup>	n-H <sub>2</sub>	D <sub>2</sub>	Ne	N <sub>2</sub>	CO	F <sub>2</sub>	Ar	O <sub>2</sub>	CH <sub>4</sub>	Kr	Xe	C <sub>2</sub> H <sub>4</sub>
Normal boiling point (K)	4.22	20.4	23.7	27.1	77.3	81.7	85.0	87.3	90.2	111.6	120.0	165.0	169.4
Liquid density (kg/m <sup>3</sup> )	125	71.0	163	1205	809	792	1502	1393	1141	423	2400	3040	568
Liquid density/vapour density	7.4	53	71	126	175	181	267	241	255	236	270	297	272
Enthalpy of vaporisation (kJ/kg)	20.42	446	301	86	199	216	175	161	213	512	108	96	482
Enthalpy of vaporisation (kJ/kg-mole)	80.6	899	1211	2333	5565	6040	6659	6441	6798	8206	9042	12,604	13,534
Volume of liquid vaporised by energy input of 1W-hr (cm <sup>3</sup> )	1410	114	74	35	22	21	14	16	15	17	14	13	13
Dynamic viscosity of liquid (μNsec/m <sup>2</sup> )	3.3	13.3	28.3	124	152	—	240	260	195	119	404	506	170
Surface tension (mN/m)	0.10	1.9	≈3	4.8	8.9	9.6	14.8	12.5	13.2	13.2	5.5	18.3	16.5
Thermal conductivity of liquid (mWm <sup>-1</sup> K <sup>-1</sup> )	18.7	100	≈100	113	135	—	—	128	152	187	94	74	192
Volume of gas at 15°C released from 1 volume of liquid	739	830	830	1412	681	806	905	824	842	613	689	520	475

\* Pressure of 1.01325 bar.

Source: *Cryogenic Engineering*, ed. B.A. Hands, Academic Press (1986).

Perhaps the most important and widely-used fluids are *liquefied natural gas or LNG* (bp = boiling point about 120 K), *liquid oxygen* (bp 90.2 K) and *liquid nitrogen* (bp 77.3 K).

The availability of cryogenic fluids forms an essential part of the infrastructure of a modern industrialized and civilized society. One of the major reasons for using liquid cryogenics is to allow transport and storage as liquid at atmospheric pressure, rather than as high-pressure gas in thick-walled vessels, although there is an energy penalty involved in [Refrigeration](#). However, the distillation of *liquid air* (air separation) enables the production of very high-purity oxygen and nitrogen. Plants producing up to several hundred tonnes per day and more of oxygen are commonplace, sometimes connected permanently to a chemical plant or steel works. Liquid nitrogen—formerly a by-product of the process—is now a product in its own right, being used principally as a convenient source of refrigeration, especially in the frozen food industry.

The other important by-product of air separation is *liquid argon*, which again can be produced at a very high purity. For welding, it is increasingly being stored as liquid at the factory rather than being delivered in high-pressure cylinders.

All cryogenic fluids except [Helium](#) and [Hydrogen](#) behave as 'normal' fluids, their common distinguishing features in general being a low specific heat and enthalpy of vaporization. All gaseous cryogenics are odorless and all liquid cryogenics are colorless apart from [Oxygen](#), which is pale blue, and [Fluorine](#), which is pale yellow. They are all diamagnetic except oxygen, which is quite strongly paramagnetic.

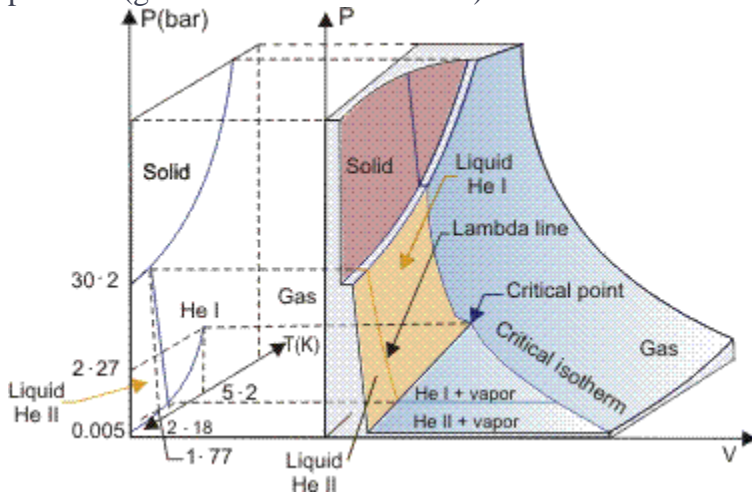
With the exception of oxygen, all the gases are asphyxiants, and even oxygen will not support human life in concentrations greater than about 60%. Fluorine and oxygen are powerful oxidizers even in liquid form. Some cryogenics are flammable; hydrogen is especially delicate to handle.

Hydrogen is an unusual fluid in that the molecule exists in two forms known as ortho and para, with somewhat different properties. The ratio of ortho to para is determined by conventional thermodynamics and is dependent on temperature. There are also different forms of isotopes (deuterium and tritium).

An explanation of the behavior of the hydrogen molecule requires a knowledge of quantum mechanics and will not be discussed here. At low temperatures, equilibrium hydrogen (e-H<sub>2</sub>) is entirely para. At room temperature, the ortho: para ratio is 3. The equilibrium state at room temperature is often known as normal hydrogen or *n-hydrogen*. The transition from the ortho to the para state involves a heat of conversion — which can be greater than the enthalpy of vaporization — so that the vaporization rates of hydrogen are often much larger than expected. It is for this reason that a catalyst is often included in a hydrogen liquefier to ensure that only para hydrogen is present in the liquid.

Helium is the one cryogenic fluid which can be claimed to be unique. Because of its low molecular weight and chemical inertness, quantum mechanical effects are important. There are two isotopic forms: the natural form  $\text{He}^4$ , which has a nucleus consisting of two protons and two neutrons; and the comparatively rare man-made form  $\text{He}^3$ , with only one neutron. The two isotopes have markedly different properties due to their different nuclear spins.  $\text{He}^3$  is not considered here.

Below 2.2 K,  $\text{He}^4$  becomes 'superfluid', and is often known as HeII, the 'normal' liquid being known as 'HeI'. The locus of the HeI/HeII transition is known as the 'lambda line' from the shape of the curve of specific heat as a function of temperature. The phase diagram of  $\text{He}^4$  is shown in [Figure 1](#), in which features of particular interest are the absence of a triple point and the fact that the liquid can only be solidified under pressure (greater than about 26 bars.)



**Figure 1. From Cryogenic Engineering (1986) by permission of Academic Press Ltd.**

The temperature of the normal/superfluid transition depends somewhat on pressure. One end of this boundary forms with solid HeI and HeII the "upper lambda point" (at 1.77 K and 30.2 bars). The other end of the line (at 2.18 K, 0.005 bar) where vapor, HeI and HeII coexist is known as the 'lower lambda point.' HeI behaves as a conventional liquid (except when near the  $\lambda$  line) but requires much more care in handling than other cryogenic fluids, principally because of its extremely low latent heat of vaporization. HeII is quite different, having a variety of properties quite different from those of any other liquid. It will, for instance, climb up over the edge of a container and drip off the bottom; it has a small or zero viscosity and a very large thermal conductivity. Flow velocity through fine capillaries is independent of the pressure head and is greater in tubes of smaller diameter. Flow may be induced by a temperature gradient in the absence of any pressure gradient. A consequence of the very high thermal conductivity is that below the  $\lambda$  point, boiling ceases and the liquid becomes "quiescent;" although the rate of heat transfer remains very high. Vinen has published a brief but useful review of the properties of superfluid helium.

### 3.5 Applications of cryogenic systems: Super conductive devices such as bearings, motors, magnets, space technology,

Cryogenics is used in a variety of applications. It can be used to produce cryogenic fields for rockets, in MRI machines that use liquid helium and require cryogenic cooling, storing large quantities of food, special effects fog, recycling, freezing blood and tissue samples, and even cooling superconductors. At extreme temperatures, cryogenic applications demand the most of all their components, especially bearings. As systems approach absolute zero (0 °K), the ability to utilize liquid lubrication becomes increasingly challenging and specialist options must be introduced. Standard 52100 steel bearings will offer

poor performance resulting in short service life, unexpected premature failure or even initial machine seizure.



Cryogenic testing of bearings for use in Liquid Hydrogen, Liquid Nitrogen, Liquid Natural Gas, and other cryo pumps is carried out by highly skilled technicians at Carter Manufacturing Limited. In order to maximize performance of your cryogenic bearing, the support of experienced suppliers can prove vital.

Carter Manufacturing has decades of experience dealing with extremely low temperature bearing applications in the cryogenics sector through [UNASIS Special Environment Bearings](#). As proud members of the British Cryogenic Council, Carter employees have extensive application understanding and can draw on a vast resource of information to help you solve your cryogenic bearing problems.

A common problem with bearing design and selection is clearance control within the bearing assembly. The coefficient of thermal expansion mismatch between the housing, bearing and shaft can eliminate the bearing clearance rendering the bearing useless. Therefore it is imperative to collaborate with bearing experts, like Carter Manufacturing representing UNASIS Bearings, with thousands of successful projects which positively influence their bearing design.

### Motors for Cryogenic Applications

e+a Elektromaschinen und Antriebe AG has been supplying motor elements for operation in cryogenic pumps (2.5kW – 250kW) since 2013.

Design Challenges:

- Electrical insulation and durability
- Frictional losses when operating in liquids
- Rotor sleeve design for permanent magnet retention

Expertise:

- Operation of e+a rotors & stators immersed in liquid natural gas (LNG, -160 ° C) and liquid nitrogen (LN, -196 ° C)
- Testing of different materials for operation in cryogenic liquids
- New rotor manufacturing variant developed and successfully tested.
- Evaluation of increased power density in cryogenic liquids

Based on experience gained in the LNG and LN markets, e+a is now taking the next steps to develop and manufacture motor elements for operation in liquid hydrogen (LH2, -253 ° C). Test results still pending.

### Cryogen Free Superconducting Magnet Systems

Cryomagnetics offers a full line of high quality cryogen free superconducting magnet systems that are mechanically cooled to 4.2K eliminating the need for liquid cryogenics, allowing one to avoid the issues associated with handling liquid cryogenics. This is very important in many areas of the world where liquid helium prices are exorbitant, or in environments where transferring liquid cryogenics is difficult. Due to the elimination of liquid cryogen reservoirs, liquid cryogen free systems are often a fraction of the size and weight of conventional, liquid-based systems. This allows placement of cryogen-free superconducting magnet systems in areas not suited for liquid-based systems. Finally, the simplicity of cryogen-free system operation is very attractive. Simply plug in the cryocooler and operate the system. Today's cryocoolers are very reliable with minimal routine maintenance required.

Cryomagnetics offers cryogen-free systems based on two different cryocooler types – 4.2K Gifford-McMahon or 4.2K pulse tube.

### application of cryogenics in space technology

**Cryogenic detectors have driven the utilisation of cryogenics in space, determining the requirements in terms of operating temperature, temperature stability and architecture of the payload system.** This trend is now well- established across the electromagnetic spectrum.

Cryogenic detectors have driven the utilisation of cryogenics in space, **determining the requirements in terms of operating temperature, temperature stability and architecture of the payload system.** This trend is now well- established across the electromagnetic spectrum.

### Cryogenics in biology and medicine, food preservation and industrial applications.

#### What is Cryobiology?

The word *cryobiology* literally signifies the science of life at icy temperatures. In practice, this field comprises the study of any biological material or system (e.g., proteins, cells, tissues, and organs, insects, seeds or plant embryos) subjected to any temperature below their normal range (from moderate hypothermia or over-wintering conditions, down to deep cryogenic temperatures).

### **Applications of cryobiology include:**

- Preservation of cells and tissues for purposes of long-term storage
- Cryosurgery, a minimally invasive approach for destruction of unhealthy tissue
- Lyophilization (freeze-drying) of pharmaceuticals
- The study of cold-adaptation of plants and animals.

Food materials are perishable by nature. They require processing or preservation techniques to enhance the storage life. Cryogenics is a branch of engineering wherein production of cryogen and the maintenance of low temperature technologies are studied. One such cryogen, liquid nitrogen (LN<sub>2</sub>) has a tremendous potential to be used as a total loss refrigerant. In this paper, the different aspects of the utilization of LN<sub>2</sub> as a refrigerant and as a gas are discussed in details. In freezing for individual quick freezing LN<sub>2</sub> can be used as a refrigerant to get an ultra rapid freezing. Due to its rapidity LN<sub>2</sub> freezing is capable of producing small ice crystals in size and there by helps immensely in retaining quality reducing substantial amount of drip loss. LN<sub>2</sub> has gained tremendous popularity for the transportation of frozen foods. Apart from the intermittent spraying of LN<sub>2</sub>, dump charging method has been also developed wherein the refrigerant required for a point to point transportation is supplied to a frozen cargo before the commencement of the journey eliminating the requirement of LN<sub>2</sub> vessel to be taken on board. Grinding is a technique which reduces the size of spices, considerably increasing the surface area available to impart flavor to any prepared food. Unfortunately, a substantial amount of flavoring compounds is lost due to the increase in temperature while using conventional grinding methods. LN<sub>2</sub> can act as a rescuer for retention of quality by reducing the spice as well as grinder temperature substantially. Experimental analysis reveals that the loss of volatile component and particle size distribution of the ground spices are more than the satisfaction level of the processor. LN<sub>2</sub> has the capacity to both lower the temperature and flush off the inside air of a closed container. This serves a dual purpose: The temperature of the closed chamber is brought to the desired level almost instantaneously and the gas composition can be changed immediately. The application of LN<sub>2</sub> helps to minimize the need for high-capacity refrigeration system. Only 10% of the installation capacity is required for maintaining the desired temperature.

### **What is Cryogenics?**

What is Cryogenics?

**Cryogenics is the production of and behavior of materials at very low temperatures.**

Ultra-cold temperatures change the chemical properties of materials. This has become an area of study for researchers who examine different materials as they transition from gas to liquid to a solid state. These studies have lead to advances in not only our understanding of different materials, but the creation of entirely new technologies and industries.

The temperature of any material is the measure of the energy that it contains. Rapidly moving molecules have a higher temperature than slower moving molecules.

For example, while water transforms from a liquid to a solid at 32° F (0° C), cryogenic temperatures range much lower; [from -150°C to -273° C](#). The temperature -273° C is the absolute lowest that can be achieved. At this temperature the actions of all molecules stop, causing the molecules to be at the lowest possible state of energy.

Liquid gases at or below -150° C are also used to freeze other materials. Once a gas begins to liquefy, the environment is considered a cryogenic one. The most common gases that are turned to liquid for cryogenics are oxygen, nitrogen, hydrogen and helium.

## History of Cryogenics

The word cryogenics comes from the [Greek word “kyros,” which means cold](#). This combined with the abbreviated English word “to generate” make the word we know as cryogenics.

Temperatures that are very cold are not measured in degrees Fahrenheit or Celsius, but in Kelvins. Kelvins use the unit symbol K. It is named after Baron Kelvin who believed that at very low temperatures a new scale was needed that was not measured by the material state change of water like Fahrenheit or Celsius. Zero degrees Kelvin (0 K) is the theoretically coldest possible temperature.

In 1877 Rasul Pictet and Louis Cailletet liquefied oxygen for the first time, both using different methods for the process. Eventually a third method of liquefying oxygen was discovered, and at this point in history oxygen was able to be liquefied at 90 K. Soon after, liquid nitrogen was achieved at 77 K. Scientists all over the world began competing to lower the temperature of matter to absolute zero.

The next breakthrough came in 1898 when James DeWar liquefied hydrogen at 20 K. This presented a new problem to researchers, as [20 K is also at a boiling temperature](#). However, this presented a further issue on how to handle and store gases at such temperatures. Hence the creation of DeWar flasks, which are used to store gases today.

The last major advance in the cryogenics industry came in 1908 when the physicist Heike Kamerling Onnes liquefied Helium at 4.2 K and then 3.2 K. The advances in cryogenics following this development have been much smaller because it is thermodynamic law that you can approach absolute zero, but never actually reach it. Technology has advanced much more since this last major discovery, and we can now freeze materials within very small distances from absolute zero, yet scientists still have not been able to break thermodynamic law where every particle has zero energy.

## What Is Cryogenics Used For?

Cryogenics is used in a variety of applications. It can be used to produce cryogenic fields for rockets, in MRI machines that use liquid helium and require cryogenic cooling, storing large quantities of food, special effects fog, recycling, freezing blood and tissue samples, and even cooling superconductors.

## Applications and uses:

### Cryosurgery

Cryosurgery is a type of surgery that uses cryogenic temperatures to eliminate unwanted tissue or tumors. Historically, cryosurgery has been used to treat a variety of diseases, most commonly, benign and malignant

skin conditions. This type of surgery is effective because it works by using the freezing temperatures on cells that need to be removed from the body. Ice crystals begin to form on the cells and ultimately tear them apart.

### Cryoelectronics

The ultra-frozen temperatures that cryogenic fluids can provide offer the ability for electrons in materials to move freely with little resistance. This is of great benefit for superconductors and in spacecraft design. For example, oxygen and hydrogen when stored as cryogenic fluids are highly advantageous sources that can be used to power space rockets.

### Cryobiology

Cryobiology is the study of the effects of low temperatures on organisms. [There are six major areas of cryobiology:](#)

- The study of cold-adaptation of microorganisms, plants, animals and vertebrates
- Cryopreservation of cell tissues and embryos used in invitro fertilization
- Preservation of organs
- Lyophilization, the freeze-drying of pharmaceuticals
- Cryosurgery falls under this category
- Supercooling as applied to biological systems

### Food Preservation

To preserve packaged foods such as produce, the food items can be [sprayed with liquid nitrogen](#) to absorb the heat within the produce. Eventually, the nitrogen evaporates before the food is consumed. With this application of cryogenics, foods can be kept preserved longer without any chemical threat to human consumption.

### Transportation of Gases

Cryogenics is also used to transport gases that are not typically cryogenic. For example, using cryotechnology, gases can be transformed into liquids to make them easier to transport from one place to another. Take natural gas (LNG) which is a combination of ethane, methane and other gases. When these gases become liquefied, they take up far less space than if they remained gaseous. Therefore, transportation expenses become lower and the process becomes much easier.

### Cryotherapy

Cryotherapy is the term used to describe when the human body is exposed to extremely cold temperatures. The most common use of this application is the new trend of cryospas. In these areas, people can stand in a cryosauna filled with cryogenic fluids for several minutes. Studies have shown that this treatment touts [many benefits to the body](#), such as reducing inflammation, increasing energy, managing pain, and

even can boost metabolism, amongst other claims. Research on cryotherapy is still very new, and benefits have not been fully researched or understood.

## Cryonics

The cryo-preservation of animals and humans is called cryonics. Researchers in this field give their subjects hope that by freezing their body they may be able to resuscitate them in the future. Hundreds of people (and their pets!) are currently frozen via cryo-preservation worldwide. The science of cryonics is not proven and [most scientists are dubious of the claims](#).

## What's Next for Cryogenics?

As technology rapidly evolves areas of cryogenics will continue to develop and eventually expand to more applications. While we can't predict what developments will come next, what we do know is that safety around cryogenic fluids is a must, no matter which direction the research will progress.

## Unit-4.0 Ice production and Industrial Applications

Ice is very important for a range of industries such as healthcare, hospitality, food service and convenience stores. While it keeps medical equipment and drugs safe for human administration, it chills drinks and foods for future use.

Types of commercial ice include block ice, cube ice, tube ice, flaked ice, plate ice, and shaved ice. It can be manufactured for an industrial application using special equipment. There are large ice factories that make tones of ice for commercial use in a day. Here, let us discuss how ice is made and the commercial industries that mostly use it.

### COMMERCIAL MANUFACTURE OF ICE

Before a company qualifies as an ice manufacturer, it has to invest in a lot of resources such as manufacturing equipment and machinery that will produce ice on a large-scale. Also, companies have to device channels of distributing their ice to customers. This means lease trucks and hiring drivers.

In the United States, ice manufacturing industries have to meet tough rules set by the Food and Drug Administration. The packaging of ice is also an important consideration as it needs to arrive at the customer's establishment in its chilled state. To solve this headache, manufacturers have to use mobile refrigeration systems.

To make ice, industries use large free-standing icemaker machines. An ice tray is attached to several pipes that exchange heat just like an ordinary refrigerator. Refrigerant fluid is driven by a compressor through a narrow condenser tube. After condensation, ice is passed into a large evaporating tube where it expands.

When selecting commercial ice, companies must consider the procedures that were followed in its manufacture. For example, ice for foodservice has to adhere to the highest sanitation standards. The

reputation of the manufacturer is often an important consideration. Other factors are costs, equipment used and the ice's shelf life.

## USE OF ICE IN MANUFACTURING, INDUSTRIAL AND PROCESSING INDUSTRIES

The United States is among the leading consumers of commercial ice. Further, companies in the processing, manufacturing, and industrial sectors cross the world have an insatiable demand for ice. Examples of these companies are [Coca-Cola](#), [Pepsi](#), Reddy Ice, Nestle, [Groupe Danone](#) and Arctic Glazier among others. Convenience Stores and Supermarkets are easily among top consumers of ice. They need it to keep fruits, vegetables, meats, canned foods, beverages, milk and other food products chilled. They usually keep it in large refrigerators and displays. These days, large supermarkets manufacture their ice for convenience.

Restaurants, bars, cafes, hotels and other foodservice establishments should treat ice just as they treat food. Sadly, 47.8 million people in America suffer from food-related diseases annually. This is often attributed to unsafe handling of ice in convenience stores. Employees need to be trained on proper transportation, safe use, and sanitation.

### 4.1 Introduction, principles of ice production, different methods of ice manufacturing

An **icemaker**, **ice generator**, or **ice machine** may refer to either a consumer device for making [ice](#), found inside a home [freezer](#); a stand-alone appliance for making ice, or an industrial machine for making ice on a large scale. The term "ice machine" usually refers to the stand-alone appliance.

The *ice generator* is the part of the ice machine that actually produces the ice. This would include the evaporator and any associated drives/controls/subframe that are directly involved with making and ejecting the ice into storage. When most people refer to an ice generator, they mean this ice-making subsystem alone, minus refrigeration.

An *ice machine*, however, particularly if described as 'packaged', would typically be a complete machine including refrigeration, controls, and dispenser, requiring only connection to power and water supplies.

The term *icemaker* is more ambiguous, with some manufacturers describing their packaged ice machine as an icemaker, while others describe their generators in this way.

#### *Applications*

Ice produced from the **Tube Ice Plant** and **Cube Ice Maker** is mostly used in the hospitality industry to mix or chill drinks. Flake ice from the **Flake Ice Machine** is commonly used to keep food fresh in your local shops and other applicable places. This also applies to the ice from **Plate Ice Plants**. Whereas ice from the **Block Ice Machine** can be left in its original shape and size or be crushed for any of the previously mentioned purposes.



### *Industrial ice makers*

Although the above mentioned are mostly industrial machines, some of the ice produced with these machines or systems can be consumed, however, the use of these machine are mostly for the production of large quantities of ice for industries such as fishery, fresh meat storage, construction, medicine, hospitality etc.

Apart from the **Block Ice Plant**, other industrial ice making machines may include the **Tube Ice Machine**, **Flake Ice Maker**, **Cube Ice Machine** and **Flake Ice Plant**.



### *Consumer block ice makers*

For domestic and small scale ice production, the consumer block ice machines are ideal. These include **Freezer Ice Makers**, **Portable Ice Makers**, **Built-in / Freestanding Ice Machines** etc.

## **4.2 Treatment of water for making ice, Brines, freezing tanks, ice cans, quality of ice.**

## **4.3 Types and design of industrial icemakers- Block ice made in plants, Shell ice ,Flake ice, Tubeice, Plate ice and Slush, slurry or binary ice.**

### **Refrigeration on ice: Basics of industrial icemakers**

Ice has been used for cooling for a very long time. The use of ice as a cooling medium offers several advantages over mechanical refrigeration: It has a large cooling capacity for a given weight and involves little or no complication in the design and operation of the storage space.

Ice, in addition to keeping a product cool, also keeps it moist and prevents the drying that may accompany other chilling methods. Ice melts at a fixed temperature, so there is some control over product temperature.

With good contact between product and ice, cooling can be quick.

## Applications for industrial ice

Industrial ice is used in many industries for processing, storage, transport, and manufacturing. The following are some of the many applications for industrial ice:

**Fishing industry.** Ice is used to ice product on-board vessels and for in-plant processing. For on-board requirements, the ice plant can be located on shore and ice conveyed to the dock side for loading into fishing vessels. Icemakers can be located on board as well.

**Poultry production.** Ice is used in spin chillers (tank with large auger, which moves the birds along slowly) to remove body heat from poultry after slaughter and dressing. Ice is also used for icing birds in packages, top icing of shipping containers, trucks and rail cars.

**Produce icing.** Field heat is removed from many vegetables using ice. A product called “liquid ice,” which consists of a solution of water with 40% to 50% ice, may also be used to ice wax impregnated boxes that have holes in the sides and bottom.

**Baking process.** During the mixing of dough, shear heating occurs and can be minimized with the addition of ice, which fulfills the water requirement as well. The yeast responsible for the leavening of the dough can be sensitive to this heating as well as some of the other dough ingredients.

**Chemical processes.** Application of ice has been used in the manufacture of colors, dyes, optical brighteners used in soaps, and the manufacture of certain herbicides.

**Concrete making.** Ice can be used, rather than water (up to 100%) during the mixing of concrete. Ice is required for critical pours where there is a requirement for rapid removal of the heat generated during the curing process.

**Meat production.** Ice is mixed with sausage to absorb the heat of friction generated during the blending process. Ice also provides moisture, which can enhance the quality of the product.

**Thermal energy storage (TES).** Ice builders and ice harvesters are used to store refrigeration capacity in the form of ice. The ice builders consist of an insulated tank of water in which tubes are immersed carrying refrigerant or cold brine.

Ice harvesters typically consist of icemakers positioned over an insulated tank of water into which the ice is harvested. In both cases, the stored refrigeration capacity can be built during off-peak hours when demand is low and electricity may be cheaper.

**Packaged ice industry.** Ice that is used for drinks and coolers, which is usually sold in small bags (e.g., 5 to 20 lb).

## Types and design of industrial icemakers

Ice making has evolved over the years from cutting blocks of various sizes from lakes and storing in sawdust in barns, to using mechanical refrigeration to make blocks of ice.

Block ice plants, however, are being gradually replaced by more modern, automatic ice-making equipment.

There are six basic types and size of ice that can be used for industrial applications:

- Block ice made in plants;
- Shell ice;
- Flake ice;
- Tube ice;
- Plate ice; and
- Slush, slurry or binary ice.

The four main types of fragmented ice (shell, flake, tube, and plate) are illustrated in Figure 1.

**Block ice manufacture.** Block ice is produced by placing water in galvanized iron cans or molds that are immersed in a secondary coolant, brine (calcium or sodium chloride), which is kept cold by refrigerant (often ammonia) expansion coils. Cans vary with the weight of ice blocks required (from 25 to 182 kg).

Ice cans are usually filled by means of a filler device, generally a multi-faucet arrangement that is constructed as to automatically shut off the water supply when the can is filled to the proper height. Once the water in the cans is frozen, the ice is removed by lifting the cans out of the brine and spraying them with or dipping them in warm water.

This loosens the ice so that when the can is inclined on its side, the block slides out. Ice cans are often tapered to facilitate ice removal. The can is refilled and the process repeated.

Freezing tanks can be made of such materials as wood, steel, or concrete. Tanks made of wood have a relatively short life and are subject to leaks.

The freezing tank contains direct-expansion freezing coils equally distributed throughout the tank and submerged in brine. The tank is provided with a suitable hardwood frame for supporting the ice cans and an agitator for keeping the brine in motion to promote good heat transfer.

The brine in the tanks acts as a medium of contact only; the refrigerant evaporating in the freezing coils extracts the heat from the brine, which again absorbs the heat from the water in the cans, thereby freezing it. The brine temperature is usually maintained at 10° to 20°F (-12.2° to -6.6°C), which is equivalent to temperature of 5° to 15°F (-15° to -9.4°C) in the coils.

Freezing takes from 8 to 24 hours, so large production space is required. The rate of freezing is time regulated to prevent too rapid freezing, which could result in a brittle product. The freezing cycle takes about 8 hours for three harvests per day for a total daily capacity of 3 to 10 tonne (2.7 to 9.07 ton).

**Shell ice manufacture.** Shell ice is produced by freezing a falling film of water on the inside and outside of a stainless steel tube. The freezing cycle is normally between 8 to 15 min, with the final ice thickness being from 3 to 20 mm following the curvature of the tube.

Shell icemakers use a sump and recirculating pump, where the excess water not converted to ice is collected and applied to the freezing surface for ice making. Harvesting is accomplished using a hot gas defrost.

The application of hot gas to the refrigerant circuit of the tubes causes the ice surface touching the tube to reach its melting point and thereby releasing the ice.

The ice falls by gravity from the tubes to a storage bin, beater or cutter bar, or an auger that can further reduce the size of the ice. Freezing time, harvest time, and the water, pump, and refrigeration can be controlled by adjustable electrical timers and relays, or electronic devices such as programmed logic controllers.

The ability to adjust these parameters makes the shell icemaker very flexible in that different thicknesses and degrees of hardness can be achieved. By adjusting the thickness and/or hardness, shell ice can be made to suit the application required.

Softening of the ice is possible by adding salt and/or adjusting the amount of subcooling applied during the refrigeration cycle. The shell icemaker can make a reasonably thin (adjust thickness and subcooling) soft ice (adding salt) used for icing fish without damaging the delicate flesh or a very thick, hard clear ice, desirable for the packaged ice industry.

The curvature of shell ice helps prevent bridging in storage. The curvature also enables the ice to conform to the shape of many products that are to be cooled, thus facilitating effective heat transfer.

As noted earlier, a type of fresh water slush ice called liquid ice, which is a solution of water and 40% to 50% shell ice, can also be made.

Using a special tank and mixing device, the shell ice is kept in suspension so it can be transferred with a specially designed pump through a 4- to 6-in.-dia hose.

A new modular shell ice-maker design, the “Ice/Berg LS” can produce a lot of ice in a small amount of space. The design allows for expansion as well.

The modularity is achieved through an arrangement of four main system components: Ice making on the low side, refrigeration on the high side, the condenser and a new SC5 controller. By adding icemaking

modules in nominal 5-ton increments, the user can boost production while using the same SC5 controller. The installer or contractor can supply their own refrigeration unit.

The ice-making section of the modular shell icemaker is 304 stainless steel. Front discharge minimizes space requirements, and an optional conveyor is available for multiple module configurations.

**Flake ice manufacture.** Flake ice is made by freezing water in thin layers either on the inside or outside of a smooth refrigerated surface. The surface is usually a drum that is oriented horizontally or vertically and may be stationary. The ice is removed by mechanical action, for example by a scraper on a cylindrical surface.

The ice thickness can be varied marginally from 1.5 to 3 mm by adjusting the speed of the rotating drum, varying the evaporator temperature, and regulating the water flow on the freezing surface. The ice is produced on a continuous basis as opposed to a freeze-and-harvest cycle typical of shell, tube, and plate icemakers.

This continuous operation without a harvest cycle results in less refrigeration capacity per ton of ice than any other types of manufactured ice if similar makeup water and evaporating temperatures are compared.

Flake icemakers are operated at lower evaporating temperatures than shell, tube, or plate icemakers and the result is that the ice is colder as it comes off the ice-making surface. The rapid freezing of flake ice results in the opaque to white appearance, which is caused by entrained air.

**Tube ice manufacture.** Tube or cylindrical ice is formed by freezing a falling film of water either on the outside of a stainless steel tube with evaporating refrigerant on the inside of the tube or freezing water on the inside of tubes surrounded by evaporating refrigerant on the outside.

Ice is harvested as a cylinder by introducing hot discharge gas into the refrigerant in the freezing section, which releases the ice from the tubes. The ice falls to a motor-driven cutter plate, which is adjusted to cut the ice cylinders to the length desired.

Typical dimensions of the pieces are 40 mm dia with a hole 10 mm dia and 40 mm long. This shape makes tube ice ideal for the hotel drink industry. It has a bulk density of about 35 lb/cu ft. The shape, however, is such that voids are present when this tube ice is used to ice fish and produce.

The large size and shape is a disadvantage for icing fish and produce, as the tube ice does not conform to the shape of the product, thus inhibiting good and effective heat transfer.

**Plate ice manufacture.** Plate ice is made on icemakers that build ice on a flat vertical surface. During the freezing cycle, water is applied above and flows by gravity over the freezing plates. Liquid refrigerant is contained in the internal circuiting inside the plate.

The freezing cycle time governs the ice thickness. Cycle times from 12 to 45 minutes producing ice of a thickness in a range of 6 to 20 mm are typical.

The water is recirculated by a sump system and a hot gas defrost is used. The freezing time, harvest time and the water, pump and refrigeration are controlled by adjustable electric timers and relays or PLCs.

The ice produced is flat and usually comes off the evaporator surface at a temperature that is such that, combined with the shape of the ice, can lead to possible bridging. The flat shape of the ice allows the ice surfaces to interface and bond together forming masses of ice. This is not desirable when using the ice to cool food products that require full contact and filling of void spaces for effective cooling

**Slush, slurry or binary ice manufacture.** Slush, slurry or binary ice consists of ice from a brine or seawater solution, which forms small ice crystals in a solution that is supercooled.

The slush ice generator consists of a standard refrigeration unit that supplies refrigerant to a scraped surface heat exchanger. Ice does not form on the cooling surface as in shell, flake, tube, and plate icemakers. Rather, it is formed inside a solution that is cooled below the solution's freezing temperature in the form of small ice crystals.

The ice crystals are generated by cooling the inner surface of a stainless steel cylinder through which brine or seawater is passed. A scraper mechanism removes the ice crystals, which become suspended in the fluid and form a liquid, pumpable ice.

The slush ice may be stored in a reservoir and possibly recirculated back through the ice plant to increase the percentage of ice crystals in the mixture ("ice fraction"). The ice fraction can be as high as 60% ice before it becomes too viscous and pumpability is lost.

This is known as the limit of pumpability. These ice generators require operator adjustment and attention so as to avoid possible freeze up.

The temperature of the slush ice is lower than that of conventional fresh water ice and is dependent upon two factors: The brine strength or seawater salinity and the percentage of ice fraction in the slush ice mix.

The lower temperatures that can be achieved with slush ice are such that partial freezing of product surface may occur. This could be disadvantageous in certain applications. Uptake of salt is a consideration as well.

#### **4.4 Production of dry ice.**

##### **How Dry Ice is Made**

## What Is Dry Ice?

Dry ice is made by liquefying carbon dioxide and injecting it into a holding tank, where it's frozen at a temperature of  $-109^{\circ}\text{F}$  and compressed into solid ice. Depending on whether it's created in a pelletizer or a block press, dry ice can then be made into pellets or large blocks.

Unlike regular ice, dry ice doesn't melt into a liquid as it warms up. Instead, it converts directly back into its gaseous form in a process known as sublimation. At  $-109^{\circ}\text{F}$ , dry ice is also significantly colder than the  $32^{\circ}\text{F}$  surface temperature of regular ice.

**Dry ice** is the [solid](#) form of [carbon dioxide](#). It is commonly used as it does not have a [liquid state](#) and [sublimates](#) directly from the solid state to the [gas state](#). It is used primarily as a [cooling agent](#), but is also used in [fog machines](#) at theatres for dramatic effects. Its advantages include lower temperature than that of [water ice](#) and not leaving any residue (other than incidental frost from moisture in the atmosphere). It is useful for preserving [frozen foods](#) (such as ice cream) where [mechanical cooling](#) is unavailable.

Dry ice sublimates at  $194.7\text{ K}$  ( $-78.5^{\circ}\text{C}$ ;  $-109.2^{\circ}\text{F}$ ) at Earth [atmospheric pressure](#). This extreme cold makes the solid dangerous to handle without protection from [frostbite](#) injury. While generally not very toxic, the [outgassing](#) from it can cause [hypercapnia](#) (abnormally elevated carbon dioxide levels in the blood) due to buildup in confined locations.

### 4.5 Ice-cream manufacturing, refrigeration for breweries, selection of refrigerant for rewereries. Air conditioning in textile and photographic industries

**Industrial refrigeration isn't air conditioning**—it goes beyond that, both in scale and in the little details. Industrial refrigeration can be defined as the **equipment and accessories projected to remove heat from large-scale processes or materials**, lowering the temperature to a desired value. Depending on different parameters like the production scale, temperature difference, accuracy or expected temperature, there are **multiple methods used to apply [industrial refrigeration](#)**. Industrial refrigeration has been of paramount importance since the early years of the twentieth century. Historically, industries like Food and Beverages, Pharmaceuticals or Petrochemicals, achieved important developments thanks to systems indicated for reducing the temperature of their products or processes, or **conserving them in optimal conditions** to avoid safety issues. In industries where bioprocesses are involved, products and processes have to be developed and stored in ideal conditions to achieve the maximum yield in reactions, or to avoid the decay of products. Sometimes refrigeration is necessary to **maintain safe conditions in the process or product** to avoid accidents or chain reactions, e.g. in compounds with a low boiling point. In addition, **[cooling](#) may be applied to have an adequate environment** for people or machines to work, like in industries where high amounts of heat are produced or for equipment that needs to dissipate the heat generated.

## Applications of Refrigeration in 7 Different Industries

Refrigeration and [cooling systems](#) are designed to fulfil determined requirements based on the specific characteristics of each industry. The main industries that require refrigeration or cooling systems are:

1. District Cooling
2. Electricity Production
3. Chemical and Petrochemicals
4. Pharmaceutical
5. Food & Beverages
6. Data Centres
7. Other industries

### 1. District Cooling

One of the top markets for cooling is focused on **providing cooled air to urban and touristic areas**, thus keeping enclosed ambiances comfortable independently of the outside weather. In big hotels, resorts and district areas, refrigeration production is usually delivered by [District Cooling systems](#).



The concept of [District Cooling](#) is based around the generation of cooling streams (mainly chilled water) with **different technologies in a central plant**. It is then distributed to different populated places like homes, offices, venues, or other residential or commercial projects. By centralising the [cooling production](#), a **higher efficiency is achieved**. This, due to optimization of industrial equipment and electricity consumption compared to **individual refrigeration systems** for each building. In addition, District Cooling has other advantages, like a **reduction in capital, operation, and maintenance costs** with respect to individual cooling systems. Combined with energy storage systems, a considerable reduction in peak electricity demand can be achieved. [District Cooling](#) provides **important economic and environmental benefits** to residential communities and touristic areas. Depending on the size of the district or area that

needs to be refrigerated, District Cooling production requires varying equipment and technologies. A fundamental issue for the selection of **the most suitable cooling method** in each case is the availability on water or seawater resources, since it is the usual mechanism to generate and/or distribute cooling streams. Cooling towers and direct/indirect condensation systems are among the most used cooling technologies. However, in places like the Middle East region, where water supply is limited, alternative systems like geothermal chillers or seawater-cooled systems can be used.

## 2. Electricity Production

**Electricity generation** is often based on the combustion of different fuels. To **achieve a higher efficiency**, inlet air must be in determined conditions. If the temperature of the inlet air is too high, its density decreases, suffering a decline in the electric production. To avoid this problem, **systems like [Turbine Inlet Air Cooling System](#)**, a system in ARANER's portfolio, are used to cool down these air streams.

Other parts of production and distribution systems, like electric generators or distribution plants, also generate heat when operating. To minimize maintenance operations, refrigeration systems are necessary. This refrigeration equipment is usually **based on [compression](#) or [absorption cycles](#)**.



## 3. Chemical & Petrochemical

Although chemical and petrochemical reactions are not as strictly controlled as the reactions in the Pharmaceutical field, **control of temperature is an important factor** in reaching high efficiency in their transformations. Distillations, crystallizations or condensations are operations requiring the removal of heat; hence **refrigeration systems are necessary to obtain their products**. In chemical and [petrochemical](#)

[industries](#), **large scale cooling plants are used** in their processes. Due to the high flow required and the location of the industries, river water or seawater is used as refrigerant.

Compression cycles and absorption cycles are used to cool down the hot stream after the heat has been dissipated in the different operations. Moreover, since hot streams are also required in other parts of the process, heat exchangers are usually applied to heat these streams and **maximize the efficiency of the operation**.

#### **4. Pharmaceutical**

The Pharmaceutical industry is based around operations where fulfilment of **strict conditions is essential for the success of every process**. Going further, many production procedures imply biological or biochemical reactions that only take place in strict conditions in which microbiological species generate chemical compounds at their maximum yield. This is why it is so important that [Pharmaceutical](#) firms develop their products in clean disinfected rooms.

**One of the most important parameters** in this industry is temperature. Moreover, strains used for drug and medicine production are stored in **very controlled conditions, usually at low temperatures**. For these reasons, the Pharmaceutical industry must rely on highly **sophisticated refrigeration systems** that permit the temperature adjustment of rooms and storage units to extremely precise temperatures. For Pharmaceuticals, the size of [cooling plants](#) tends to be smaller, since the production capacity of pharmaceutical industry equipment is limited. Normally, this industry **utilizes a central cooling plant** with transformer stations and refrigerants that are distributed through the different clean rooms of the factory. Other **refrigeration systems** that can be found in this industry are oxy-chlorination plants, ammonia/chlorine/oxygen liquefaction plants, or compressed air cooling.

*Discover: [Energy management in pharmaceutical industry](#)*

#### **5. Food & Beverages**

**Maintaining the cold chain in the [F&B industry](#) is vital** for preserving products and avoiding possible microbiological contamination. Each product has its own optimal conditions for storage and preservation.

In the preparation process, **temperature is one of the most important parameters** to assure food safety. In products like fish, poultry, meat, dairies or fruits, **refrigeration systems are necessary** to keep products in low temperatures and extend the recommended consumption period. Other types of F&B industries—like a brewery—require several refrigeration systems to finish the biological and chemical reactions that take place during the process, and to **preserve the optimal conditions of the product** once the process is finished.



In the Food & Beverages industry, **several refrigeration systems can be used**. If the cooling system is necessary during processing, the most typical refrigeration system is the use of **chilled water**. There are other refrigerants than can be used instead of water, but it is important to avoid chemical contamination in case of spillage. Thus, **water is the most recommended refrigerant** to be used in F&B. However, when the product is finished and packed, temperatures below 0°C are necessary, so other systems like compression or absorption cycles, may be used. These systems use other refrigerants besides water, with better characteristics (high latent heat or absorption capacity) to get lower temperatures that freeze the products.

*Keep reading: [Chilled Water System on your next project: save up to 40% of energy](#)*

## 6. Data Centres

[Data centers](#) store groups of servers used to process and distribute data. The servers naturally **produce heat during operation**, and if the heat is not removed, the temperature rises. Unfortunately, this can adversely affect the functioning of the servers. To prevent this problem, **powerful [air-cooling systems](#) are usually placed** in these data centers, dissipating the heat produced and minimizing maintenance operations. These cooling systems are commonly air-based or liquid-based, depending on exterior conditions. Furthermore, new cooling systems are starting to be **more environmentally friendly**, using seawater as a refrigerant.



## 7. Other Industries

There are other industries such as naval or metallurgical, which **rely on refrigeration for their operations** or to have a comfortable ambient for their workers to develop their activities. Cooling systems for these industries **must be thoroughly designed** to avoid short and long terms problems that can result in very high costs of maintenance and operation.

### **Refrigeration systems: essential for industries!**

**Refrigeration and cooling systems are paramount** for many industries to work adequately, from District Cooling to [Data Centers](#). Industrial refrigeration in [District Cooling](#), in particular, can result in **important economic and environmental benefits** for residential or commercial real estate projects, hotels, hospitals, universities, and offices. Each industry has its own requirements and variables, which is reflected in the numerous cooling systems and sizes available today. In keeping with this, **tailor-made industrial**

**refrigeration systems and solutions** that are easily implemented, like the ones offered by [ARANER](#), are a **powerful tool to enhance efficiency and improve production**, regardless of the industry you operate in.

## **What is Industrial Air Conditioning? Explanation, Necessity & Applications**

**Aim of industrial air conditioning:** “To provide desired air conditions required for any process or equipment in industry”. In industrial air conditioning, element of human comfort is not considered.

### **Necessity of Air Conditioning for Industrial Sector**

Many industrial processes concerned to printing, photography, paper making, cloth making (textile) require definite and controlled temperatures. Thus, the purpose or aim of industrial air conditioning system is to provide essential and desired conditions of air required for,

- Carrying out any industrial processes efficiently.
- Proper functioning of any industrial equipment or machine with maximum efficiency.
- Control of moisture content in the air.
- Governing the rate of chemical reactions.
- Precision manufacturing of articles.
- Providing clean and standard room for work.
- Providing clean, filtered air for trouble-free operation and production Of goods.
- Providing comfort to workers.

### **Applications of Industrial Air Conditioning**

- Machines or Equipments like computers, electronic devices, measuring instruments etc. require specific air conditions (i.e. temperature, humidity etc.) to work accurately.
- Many industrial processes concerned to printing, photography, paper making, cloth making (textile) etc. require definite and controlled temperatures.
- Candy and Gum.
- Drugs and Chemicals.
- Libraries and Museums.
- Metal working.
- Laboratories and Cabinets.

**Explain the necessity of air conditioning in industrial sector With the help of suitable examples and reasons.**

Many industrial processes concerned to printing, photography, paper making, cloth making (textile) require definite and controlled temperatures. Thus, the purpose or aim of Industrial air conditioning system is to provide essential and desired conditions of air required for carrying out any industrial processes efficiently and proper functioning of any industrial equipment or machine With maximum efficiency. Below given are three examples illustrating the specific needs of air conditioning in industrial applications.

### **Photographic industry**

In this case, there is a requirement of accurate control over temperature and humidity from process point of view. Photographic film is made of cellulose coated with silver salt emulsion. Photographic paper used for the films is manufactured by supplying emulsion coating on a particular highly pure wood pulp paper. All these processes are carried under controlled conditions, because they are sensitive to surrounding temperature and humidity. Therefore, there is a measure of significance of air conditioning system in the field of photographic industry.

### **Textile industry**

Air conditioning plays an important role in textile industry. Air conditioning is essential for production of quality textile products and reduction in the waste. The industry producing cotton, silk, rayon, wool and nylon require controlled humidity during manufacturing process. The produced goods like soft fibers become durable under controlled temperature and humidity conditions.

### **Machine tool industry**

Modern technology machines like CNC, automats, hydraulic, pneumatic computer controlled machines require controlled atmosphere to carry out different machining operations. To maintain dimensional quality on the jobs as well as to maintain and increase life of sensitive electronic components incorporated in the machines, it is essential to have air conditioning system.

In addition to above few more examples are

- **Laboratories** – To make precise measurements.
- **Printing** – To control temperature and humidity.
- **Pharmaceutical** – To reduce air borne bacteria and dirt to preserve products.
- **Hospitals** – Remove bacteria outside.
- **Production** – Manufacturing of precision parts.

## **4.6 Refrigeration in the chemical industry**

Refrigeration plants in the chemical industry

The pharmaceutical industry, as already mentioned, the user refrigeration in freeze-drying processes. Approach, which seems to be popular in the industry, which is also to cool the liquid, and distribute this cold fluids (antifreeze, ethylene glycol or alcohol, for example) the place where refrigeration is needed. Low alcohol can cool jacket vessel, or glycol can be sent by air-cooling coils are located in the room where the powder filling occurs that must be maintained at low humidity.

Chemical, petrochemical and oil-refining industry, often require large refrigeration plants. Some important operations frequently require cooling:

- the splitting of a single gas other way liquefaction more than one gas
- the condensation of gases, such as the capture of removal of gas from liquid storage tank
- solidification of one substance in the mixture to separate it from the other
- contents stored liquid at low temperatures to control the pressure in the vessel, containing the
- removing the heat of reaction
- humidity control for hygroscopic substances

Two main concepts in the provision of refrigeration are direct and indirect.

In direct cooling of the product itself refrigerant and compressed, liquefied and strangled in the form of a liquid at low temperatures. The petrochemical industry is often used propane, ethane, ethylene, for example, as refrigerants. Often these chemical plants, large and traditionally use high-capacity centrifugal compressors, as shown in Fig. 1.6. Object, as shown in the liquefied petroleum gas fractionation plant, where 8 in two stages centrifuges compress propane in the refrigeration cycle. An alternative approach, to provide indirect cooling using a skid-mounted package that uses ammonia or suitable refrigerant freon. Or ammonia refrigerant freon from the package serves as a heat exchanger performing cooling, or in some cases, the pump delivers a low-average temperature of the refrigerant in heat exchanger. The frame is mounted package in Fig. 1.7 provides the low-temperature refrigeration due to the combination of two schemes, one with the use of R-22 and other carbon dioxide.

List only a few industries and temperature range of their cooling requirements: pre-cooling the air before separation<sup>10</sup>, -100C (-148F); condensation of hydrocarbons vapors<sup>11</sup> occurring at -55C (-67F); and in the manufacture of such substances as ammonia/urea, aniline dyes, butadiene, butyl rubber, chlorine, pesticides/herbicides, synthetic rubber, vinyl chloride, and xylenes, as well as in the recovery of solvents.

## **Unit 5.0 Transport Air Conditioning**

### **Bus, Flight and train air conditioning**

Providing a pleasant indoor climate

Train operators understand providing a pleasant indoor climate for their entire journey has top priority no matter the outside weather conditions and the number of passengers.

To meet the demanding requirements for both comfort and high reliability for train air conditioners and bus air conditioning applications, the air conditioning system must be designed considering a wide cooling capacity range and incorporating vibration-resistant components.

In addition to passenger comfort and system reliability, efficient use of energy is another important design factor for the train operator. As a result, lightweight, compact components must be considered for use throughout the system design for transport air conditioning.

Danfoss offers solutions and train- and bus air conditioning parts for reliable, energy efficient air conditioning systems that help ensure a comfortable journey for passengers, and ensures energy-savings as well.

### **5.1 Introduction, automobile air conditioning.**

## How Does AC Work in a Car?

The air-conditioning system in a car works by manipulating refrigerant between a liquid and a gaseous state. As the refrigerant changes states, it absorbs heat and humidity from the vehicle and allows the system to give off cool, dry air.

To change the refrigerant between a liquid and a gaseous state, the air-conditioning system works to control pressure and temperature.

### AC System Refrigerants

In the past, automotive air-conditioning systems used R-12 as the refrigerant. R-12 (aka Freon) is a very effective CFC-based (chlorofluorocarbon) refrigerant that is not flammable and not poisonous to humans. During the late 1980s, scientists discovered that widespread usage of R-12 was damaging the earth's ozone layer.

Manufacturers transitioned to R-134a in the mid-1990s. R-134a is an HFC-based (hydrofluorocarbon) refrigerant that does not have the ozone destroying properties of R-12/Freon. The newest refrigerant is R-1234yf, which produces fewer greenhouse gases. Europe requires the use of R-1234yf, and it will likely be the new standard in the United States in the near future.

### Car AC System Parts

Automotive air-conditioning systems have a few key components. Listed below are the main parts and their roles:

#### Compressor

- Power unit of the system that separates the low-pressure side from the high-pressure side
- Takes in low-pressure gas and compresses it into high-temperature/high-pressure gas
- Mounted to front of engine and driven by serpentine belt

#### Condenser

- Reduces temperature of refrigerant while it maintains high pressure
- Refrigerant changes from gaseous state to liquid state as it cools
- Similar to the engine radiator, it uses forced air (fan or vehicle movement) to transfer heat
- Mounted in front of vehicle, behind grill

#### Dryer

- Removes water from the refrigerant using a desiccant (drying agent)
- Has some system-filtering properties
- Mounted on high-pressure side of system, between condenser and metering device

#### Metering Device

- Either expansion valve or fixed orifice tube
- Lowers refrigerant pressure, which quickly drops refrigerant temperature
- Refrigerant is still in liquid form after leaving metering device
- Mounted on high-pressure side of system, between dryer and firewall

#### Evaporator

- Refrigerant changes back to gaseous state in the evaporator, causing a cooling effect

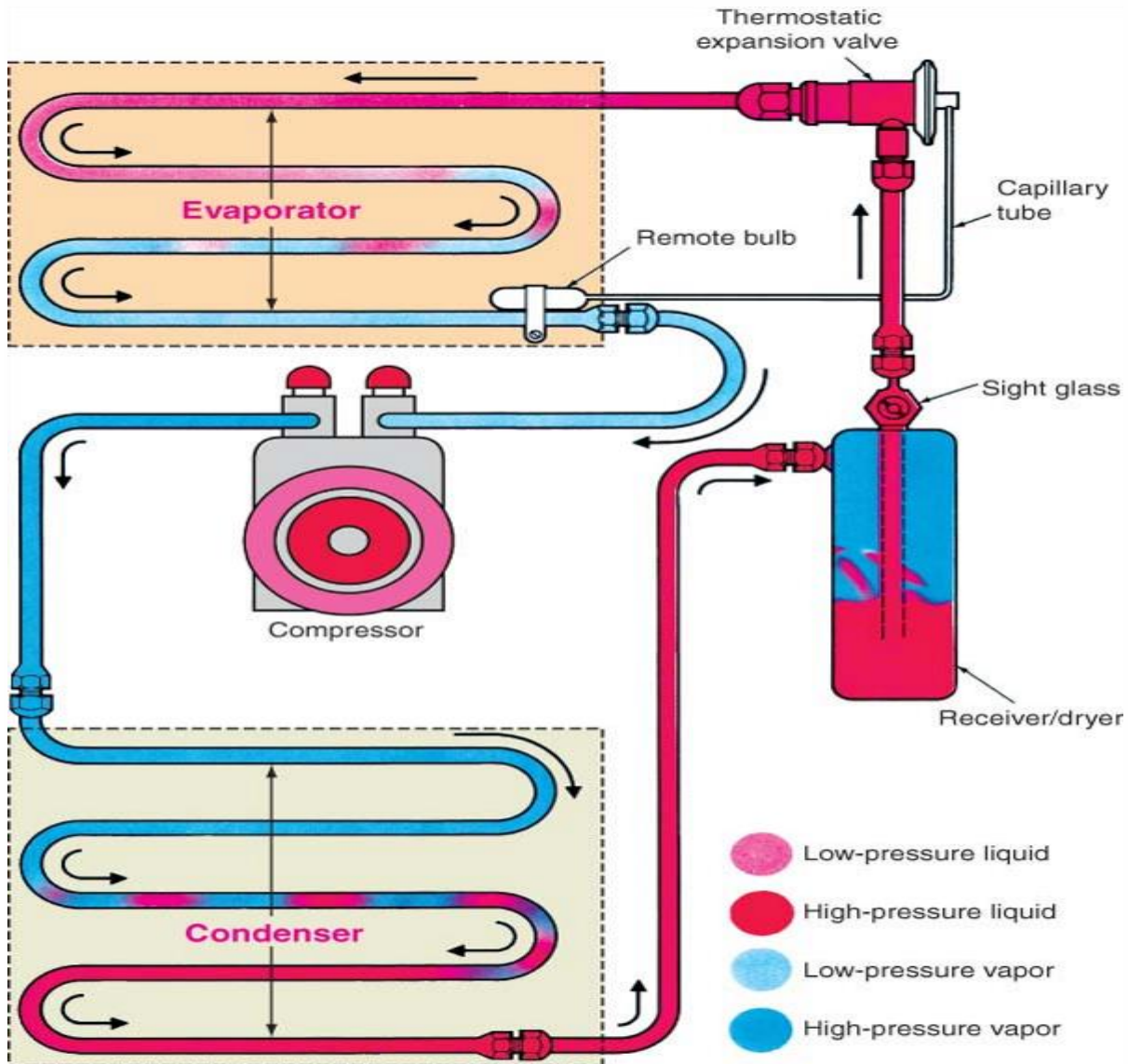
- Cabin air is cooled and dried as it blows across the evaporator
- Only component mounted inside passenger compartment, behind dashboard

Path and characteristics of refrigerant

1. Low-temperature/low-pressure refrigerant enters the compressor (gas)
2. High-temperature/high-pressure refrigerant leaves the compressor (gas)
3. Refrigerant cools and converts to liquid in the condenser
  - Still under high pressure
4. Receiver/dryer removes water from refrigerant
5. Expansion valve reduces refrigerant pressure
6. Refrigerant converts back to gaseous state in the evaporator
  - Absorbs heat; when air blows across evaporator, it is cool and dry

AC System Diagram

Below is an AC system diagram that shows the main components used and how they're connected:



## Common AC System Failures

Because automotive air-conditioning systems operate under pressure, they need to remain completely sealed from the surrounding environment. Anything that allows refrigerant to escape or contaminants to enter can cause a failure.

If a leak is present in any component, simply recharging the system with new refrigerant will be at best a temporary fix. Identify the leak, replace the faulty component, and then evacuate and recharge the system.

Not only will a system leak stop the AC system from cooling, it can damage the compressor. The compressor can overheat and damage itself by trying to run with too little refrigerant in the system. Compressors generally are not serviceable and are an expensive item to replace.

To operate correctly, the AC condenser needs a steady flow of air through its fins. Road debris and dirt may reduce airflow, causing system malfunction. The condenser is mounted directly behind the vehicle grill, leaving it somewhat exposed and at risk for partial blockage.

## 5.2 Refrigeration systems for transport refrigeration

### Robust and reliable transport refrigeration

Transport refrigeration is one of the most challenging refrigeration applications, and therefore transport refrigeration systems require components capable of addressing a range of critical parameters, such as:

- Wide ranging and fluctuating temperatures requiring superior response and control
- Harsh environments requiring corrosion resistance
- Constant shocks and vibrations requiring high stability and reliability
- Space constraints requiring compact components
- Fuel efficiency requiring lightweight component materials

Within the Danfoss transport refrigeration parts, you will find products optimized for a wide variety of transport applications, including refrigerator solutions for trucks, trailers, vans, reefer containers, and bus & train air conditioning that meet these requirements.

Danfoss transport refrigeration equipment are suitable for use with all common refrigerants and have been adapted for use with natural refrigerants. Transportation refrigeration applications are being launched with CO<sub>2</sub> as a natural refrigerant-based solution, where Danfoss as a transport refrigeration part manufacturer has a full product offering available.

Furthermore, we can offer solutions with low noise levels while enabling low operation and maintenance costs.

## Features and benefits

Products suitable for use with all common refrigerants, including natural refrigerants

Superior temperature control

High energy efficiency

Reliable solutions, low operation and maintenance costs

Stainless steel components for higher performance, durability, and reliability

Compact, lightweight components

### 5.3 Railway air- conditioning,

"The Roof Mounted AC Package Unit (RMPU) system of Indian Railways AC coaches replaces air more than 16-18 times per hour just like in OTs," officials said.

Previously, these AC trains had air change six to eight times per hour and 80% of the air that was pushed into coaches was recirculated air, while 20% was fresh air.

However, with the increase in the number of air changes, there has been a 10 to 15% increase in energy consumption.

"This is the price one has to pay for the safety of passengers. This is the new normal. The way an AC works is that it uses recirculated air so that it gets cooler faster. When we use fresh air it takes more time to cool, so there's additional energy consumption," an officer said.

The Railways has also increased the centralised AC's temperature from the usual 23 degrees to 25 degrees as passengers are no longer being provided linen.

Officials said that on the advise of the health experts, the Railways' has modified its non-AC coaches as isolation coaches for treating mild coronavirus cases and said that they have also applied health ministry guidelines to modify the ac units on board the special Rajdhani trains to ensure that the disease does not spread.

### 5.4 Marine air conditioning,

#### Air Conditioning in Ships

Air conditioning in ships is very important for the transported goods as well as for the crew. The onboard air conditioning provides the crew with a comfortable climate for carrying out their daily tasks. Simultaneously, the machinery and cargo onboard ships need to be provided with fresh and cool air as well. Heinen & Hopman has provided numerous AC systems for many different types of ships.

#### Custom-built air conditioning in ships

Heinen & Hopman is renowned for making customized HVAC systems. Whatever our clients' needs are, we design the smartest solutions and use product of the highest quality. We can design energy efficient air conditioning systems as well for any type of vessel. Often installed air conditioning systems are:

- Single duct air conditioning system
- Air handling units
- Split air conditioner
- Packaged air conditioning units
- Cabin air conditioning units
- Direct expansion system
- Single-duct & Twin-duct Marine Air Conditioning System
- Ships travel the world and are therefore subject to various climatic conditions. The crew of the ship must be provided with reasonable conditions in which to work regardless of the weather. Temperature alone is not a sufficient measure of conditions acceptable to the human body. Relative humidity in conjunction with temperature more truly determines the environment for human comfort.
- relative humidity, expressed as a percentage, is the ratio of the water vapour pressure in the air tested, to the saturated vapour pressure of air at the same temperature. The fact that less water can be absorbed as air is cooled and more can be absorbed when it is heated is the major consideration in air conditioning system design. Other factors are the nearness of heat sources, exposure to sunlight, sources of cold and the insulation provided around the space.

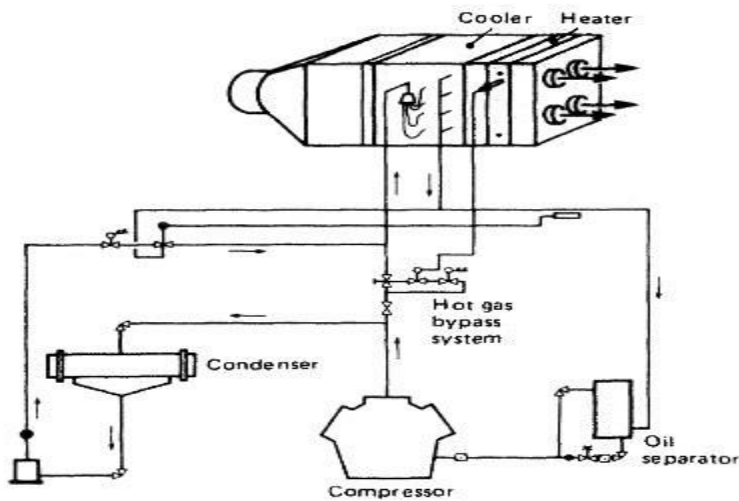


Fig: Direct-expansion refrigeration system for an air cooler

An air conditioning system aims to provide a comfortable working environment regardless of outside conditions. Satisfactory air treatment must involve a relatively 'closed' system where the air is circulated and returned. However, some air is 'consumed' by humans and some machinery so there is a requirement for renewal. Public rooms and accommodation will operate with a reduced percentage of air renewal since the conditioning cost of 100% renewal would be considerable.

Galleys and sanitary spaces, for instance, must have 100% renewal, but here the air quantities and treatment costs will be much smaller. Systems may however be designed for 100% renewal of air

although not necessarily operated in this way. Noise and vibration from equipment used in the system should be kept to a minimum to avoid a different kind of discomfort. Three main types of marine air conditioning system are in general use, the single duct, the twin duct and the single duct with reheat, The single-duct system is widely used on cargo ships .

Several central units are used to distribute conditioned air to a number of cabins or spaces via a single pipe or duct. In warm climates a mixture of fresh and recirculated air is cooled and dehumidified (some water is removed) during its passage over the refrigeration unit. In cold climates the air mixture is warmed and humidified either by steam, hot water or electric heating elements. The temperature and humidity of the air is controlled automatically at the central unit. Within the conditioned space control is by variation of the volume flow of air.

The twin-duct system provides increased flexibility and is mainly used on passenger ships . A central unit is used with cooled dehumidified air provided through one duct. The other duct is supplied with cooled air that has been reheated. Each treated space is provided with a supply from each duct which may be mixed as required at the outlet terminal. In cold climates the preheater will warm both supplies of air, resulting in a warm and a hot supply to each space.

The 'single duct with reheat' system is used for vessels operating in mainly cool climates. The central unit will cool and dehumidify or preheat and humidify the air as required by outside conditions. In addition, before discharge into the treated space a local reheating unit will heat the air if required, depending upon the room thermostat setting.

The refrigeration system used in the central unit is shown in Figure . A direct-expansion system is shown using a reciprocating compressor, sea water cooled condenser and a thermostatically controlled regulating valve. The air to be cooled passes over the evaporator or cooler. The cooling effect of the unit may need to be reduced if there is no great demand and the hot gas bypass system provides this facility.

Maintenance of the above systems will involve the usual checks on the running machinery and the cleaning of filters. Air filters in the central units are usually washable but may be disposable. The filters should be attended to as required, depending upon the location of the ship.

#### Air Conditioning system requirement

All equipment must be maintained in good condition as per maker's recommendations. Drains and scuppers on heat exchangers and plummer boxes must always be clear. The Chief Engineer has to verify that the air is correctly distributed.

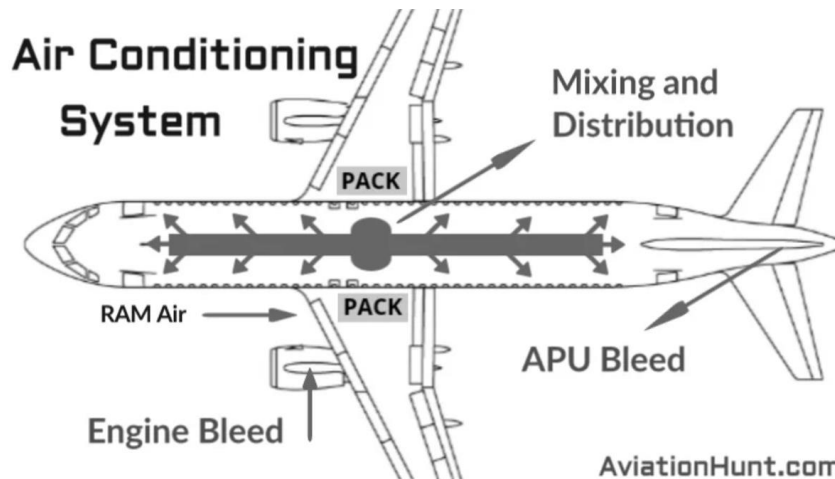
Accommodation doors must be closed at all times, while air conditioning is in operation. Air conditioning must be maintained at such a level to be beneficial to the crew, with a correct difference, external/internal temperature and humidity degree, which indication Chief Engineer will find on maker's instructions.

Excessively cool accommodation results in high consumption and discomfort to crew and passengers. It should be noted that operative air conditioning is fundamental to the welfare of the crew. Accordingly any repairs that are required to be made to the air conditioning system should be considered as important and advice/assistance requested from the management office if required.

## 5.5 Aircraft air Conditioning

### How does Air Conditioning work on an Airplane?

By AviationHunt Team Updated on September 12, 2020 [Systems](#)



Air conditioning is provided in aircraft for the comfort of passengers. The same conditioned air is also used for [cabin pressurization](#) in the airplane.

- [Air Conditioning System](#)
- [PACK](#)
- [Components](#)
- [Air supply](#)
- [Operation of PACK](#)
- [Air distribution](#)
- [Recirculation](#)
- [Temperature Control](#)

Air Conditioning System in modern aircraft

The air conditioning system is supplied by air processed through two packs that regulate airflow and temperature as required. Airplane air conditioning system mix hot and cold air to achieve the desired temperature.

Aircraft types vary, but the principles and operations of the air conditioning system are the same in all aircraft. The primary parts of the air conditioning system have these functions:

- Control fresh air flow for airplane pressurization and ventilation
- Control the flight compartment and passenger cabin temperature
- Recirculate cabin air for ventilation

## Air Conditioning Pack

The pack allows bleed air to be cooled for conditioning the flight and passenger compartment. The air conditioning system is based on an Air Cycle Machine (ACM) cooling device, which is mostly used in turbine-powered aircraft. The air cycle system is often called the air conditioning package or Pack.

Usually, Air conditioning packs are located left and right wing to body area near the main landing gear of an airplane. Packs remove the excessive heat from bleed air entering to packs from the aircraft bleed air system and supplies air to the cabin at the desired temperature.

### Air Conditioning Components

Major components of the air conditioning pack are:-

- **Pack valve** – Flow control and shutoff valve (FCSOV) controls the flow of bleed air into the pack.
- **Primary Heat Exchanger** – Cools the engine/APU bleed air.
- **Secondary Heat Exchanger** – Removes the heat of compression of the ACM.
- **Air Cycle Machine (ACM)** – An ACM comprising a compressor and a turbine mounted on the same shaft.
- **Condenser** – Condenser uses refrigerated turbine discharge air to cool incoming bleed air to a temperature low enough (below the dew point) for moisture condensation to occur.
- **Re-heater** – The reheater is used to raise the temperature of the air before it reaches the turbine inlet to vaporize any remaining water droplets for turbine protection.
- **Water Extractor** – The water extractor removes the water from the moisture produced by the condenser.
- **Water Spray Nozzle** – It is located at the secondary heat exchanger inlet and sprays on it water drained from the water extractor in order to increase the cooling capacity of the heat exchanger.

### Air supply for Pack operation

The air cycle air conditioning system is supplied with air by the aircraft pneumatic system. In turn, the pneumatic system is supplied by bleed air tap-offs on each engine compressor section or from the APU pneumatic supply. Bleed air from the pneumatic manifold is directed into a primary heat exchanger of Packs.

### Operation of Air Conditioning Pack

When bleed air goes through the primary heat exchanger, ram air removes some of the heat. This partially cool bleed air goes to the compressor section of the air cycle machine. The compressor section increases the pressure and temperature of the partially cool bleed air. This compressed-air goes to the secondary heat exchanger.

Air from the ACM compressor outlet flows through the secondary heat exchanger. A cross-flow of ram air removes heat before the air enters the ACM turbine inlet.

When the airplane is on the ground, the ACM impeller fan makes a low-pressure zone. This pulls air through the heat exchangers and up through the plenum to the impeller fan. Then the impeller fan sends the air through the diffuser and out the ram air exhaust.

When the airplane is in flight, the ram air pressure flows down the plenum and out the fan bypass check valve.

Bleed air that leaves the secondary heat exchanger goes through the hot side of the reheater. Air that goes through the reheater the first time is cooled by colder air from the condenser. The temperature of the bleed air increases as it goes through the reheater a second time and into the turbine section of the air cycle machine.

The reheater increases the temperature of the air in the air conditioning pack before it enters the turbine of the air cycle machine. This increases the efficiency of the turbine.

An Air cycle machine (ACM) decreases air temperature, by expansion through a turbine.

Air that leaves the turbine goes through the cold side of the condenser. Airflow from the condenser goes through a water extractor. The condenser decreases the temperature of the air in the air conditioning pack to below the dew point, changing water vapor into liquid. The water extractors remove moisture. This moisture goes to the water spray nozzle.

The water spray nozzle sprays the water into the ram air duct. This cools the ram air stream by evaporation and increases cooling efficiency.

#### Air distribution in the airplane cabin

The main air distribution system in aircraft gets air from Air conditioning packs, Ground conditioned air, and Recirculation system. The mix manifold collects and mixes air from any combination of the sources. The flight compartment gets conditioned air from the left pack and the mix manifold. The flight compartment receives conditioned air from the right pack if the left pack is not operational. Passenger conditioned air distribution gets air from the mix manifold. The air goes through riser ducts and up sidewalls to an overhead distribution duct.

#### Recirculation of cabin air

The recirculation system uses two fans to move air from the passenger compartment to the mix manifold. This system reduces the amount of air that the packs need to supply. This part of the A/C system recycles approximately 50 percent of the cabin air for ventilation purposes. This reduces the quantity of fresh air from the pneumatic system for ventilation. The left and right recirculation fans and filters are the primary components.

High-efficiency air filters are used in modern aircraft, which capture more than 99.9% of airborne in filtered air. They are similar to those used in hospital operating rooms.

#### Temperature control

The temperature control system has overheat switches in the supply ducts. The overheat switches give an indication and stop operation when the temperature is out of limits. Temperature bulbs in the passenger cabin and duct that monitor and send temperature data to the cabin temperature control panel. The temperature control panel shows air temperatures.

Air from the pneumatic system adds heat to a zone that needs warmer air. This warm bypassed air must be mixed with the cold air produced by the air cycle system so the air delivered to the cabin is a comfortable temperature. This is accomplished by the mixing valve.

The temperature controller compares the actual temperature signals received from the various sensors with the desired temperature input. An output signal is sent to a valve in the air cycle air conditioning system. This valve has different names depending on the aircraft manufacturer and design of the environmental control systems (i.e. Mixing Valve, Temperature Control Valve, Trim Air Valve). It mixes warm bleed air that bypassed the air cycle cooling process with the cold air produced by it.

## 5.6 Application of refrigeration in pharmaceutical & medical needs like storage and containment during Transportation

### All You Need To Know About Medical-Grade Refrigeration Units For Pharmaceutical Storage And Transport

One of the pillars for a successful healthcare system is the stable maintenance of vaccines, medications, reagents, and patient samples. These tend to be time- and temperature-sensitive. Vaccines and medicines are transferred through a cold chain from creation up to the time it is administered to the patient.



Standard fridges do not suffice in storing medicine and vaccines. They should be kept in specialized medical refrigerators. These medical refrigerators are made with robust materials that are more durable and are less likely to fail. Temperature controls are also more accurate compared to ordinary household ones. They are equipped with alarms that send alerts when a door is left open or if there is a rise or fall in temperature. Grated shelves are used within to allow better airflow and maintain more consistent temperatures. Aside from being used in the healthcare industry, such as in hospitals, clinics, research laboratories, surgery centers, and physician offices, they can also be used in crime labs.

Different types of refrigeration storage units

### Purpose-built/Pharmaceutical-grade/Medical-grade Storage Unit

These are units specifically manufactured for healthcare storage, including clinical products, vaccines, and other biologics. Medical grade units are manufactured with forced air refrigeration, which allows for air to thoroughly circulate inside the unit in order to create a uniform atmosphere, regardless of a top shelf or a bottom shelf location.

### **Stand-alone Storage Unit**

This unit does not depend on any other system or device to exercise its desired function, operation as an independent storage unit. An example of this is when a freezer is used as a freezer only, and a refrigerator is used as a refrigerator exclusively.

### **Household-grade Storage Unit**

A storage unit is intended to be sold for home use. Most often than not, these refrigerators are not able to meet temperature uniformity standards, which may cause some parts of the unit unfit for cold storage.

### **Dormitory-style (Bar-style) storage unit**

This unit is composed of a refrigerator and a freezer with an evaporator plate (cooling coil) and one exterior door. The cooling coil is often found inside the icemaker compartment (freezer). However, these units tend to pose a risk of freezing vaccines, even when used as temporary storage, as they are not designed for temperature stability.

Importance of using a medical-grade fridge

#### **Accurate temperature regulation**

Many vaccines and medicines are required to be kept at a temperature range between 2°C and 8°C (35°F and 46°F) in order to maintain the cold chain during storage and transportation.

Medical grade refrigerators are often equipped with the latest high-tech thermometers in order to monitor and record the temperature inside the vaccine and the fridge unit. Standard fridges are not able to provide the same kind of temperature regulation, and their thermometers do not show the same level of accuracy.

Medical-grade freezer and refrigerators are capable of maintaining superior temperature stability. Fewer deviations and significant, rapid changes in temperature are recorded.

They also have the capacity to retain uniformity in the temperature throughout all areas of the cabinet. Temperature uniformity eradicates hot and cold spots that places contents at risk of temperature deviation. Uniformity depends on storage application, but legitimate medical-grade refrigerators will be able to meet stringent uniformity requirements of +/-1°C.

Medical-grade storage units also have the ability to restore the unit to the set point despite regular door openings or temperature recovery. Faster recovery keeps items at the right temperature during regular use of the units.

## Temperature monitoring

Since keeping temperatures at a constant level is essential for medications, vaccines, patient samples or reagents is important in ensuring a patient's safety, it is crucial to have an accurate temperature monitoring scheme. Medical-grade refrigerators possess microprocessor temperature controllers and digital displays for accurate temperature regulation. Companies like [AKCP also provide NIST traceable, calibrated temperature monitoring systems for medical refrigerators.](#)



**Glycol Jar (Glycol not supplied)**

## Temperature excursion alarms

Medical grade refrigerators are equipped with alarms that sound whenever there's a [temperature excursion](#), power failure, or ajar door. This is important to maintain the integrity of the vaccines and reduce spoilage. Some manufacturers integrate software that allows for displaying historical temperature data, interactive temperature graphs, and event log. These systems also have the capability to input minimum and maximum temperatures needed in a specific period to ensure regulation.

In order to track temperature history in case of a power loss, some medical-grade refrigerators have back-up battery systems in place that can continue monitoring data. Should healthcare facilities use third-party monitoring solutions, some medical-grade refrigerators and freezers have been manufactured to accommodate this type of installation. Depending on the setup, options can include special ports to permit independent temperature probes to be easily placed within the unit.

The alarms immediately notify healthcare staff, which allows them to take action in case of a temperature excursion. In some rare instances, it is possible for the cold chain to be broken and for the vaccines to remain safe to use; however, it is always highly advisable for such a situation to be avoided. A 2019 study estimated that [25% of vaccines are degraded by the time it reaches the demand point.](#) A vaccine is often discarded when it is exposed to temperatures outside the specified range. Due to temperature mistakes in the cold chain, around [US\\$34.1 billion is lost annually.](#)

### Tighter security

Medicines and vaccines can be subject to theft due to their expensive and in-demand nature. Due to this, medical-grade refrigerators often have security features like keyed locks in order to prevent unwanted tampering. Other refrigerators have electronic access security features that use passwords or pins to regulate and track access.

These safety measures do not only prevent theft, but they also ensure that the medical fridges are not accidentally opened by a cold chain staff before its intended purpose.

### Glass door or solid door

Medical grade refrigerators can come with glass or solid doors.

Glass door medical fridges allow healthcare practitioners to view the content of the fridge and determine the current stock of vaccines and medicines. Due to this, the contents would not be opened as regularly, which aids in maintaining the required temperature range.

A solid door serves as an added layer of security, so unnecessary personnel would not be able to see what is inside.

### FDA approval and other certifications

FDA Registered suppliers of medical-grade refrigerators are required to comply with a specific set of high standards compared to other suppliers. [SO 13485 \(Quality Management System for Medical Devices\)](#) requires suppliers to abide by strict regulation regarding product testing and validation, design controls, and post-market observance.

[ISO 13485](#) serves as a guide to ensure that design, manufacture, and support of refrigerators at a quality aligned with the needs of clinical applications. Suppliers must also comply with 21 CFR Part 820 (FDA quality system regulation), which requires regular FDA audits, governance, and accountability measures to maintain consistent quality of equipment and post-sales process.

It is also essential for suppliers to procure Certificates of Calibration to prove that the cold storage unit being offered has been calibrated with a measuring device that is compliant with NIST ISO 17025.

### Custom options and high-quality body construction

There are multiple sizes of medical-grade cold storage equipment offered in the market, but refrigeration units can also be customized depending on the storage need of the client, such as the type, location of drawers, shelves, and baskets.

The right storage equipment is crucial in reducing errors and ensuring patient safety. A conducive setup of the unit allows easy removal and loading of the contents in the refrigerators by healthcare professionals. These shelves and drawers are also designed to enable necessary airflow.

High-quality construction is needed for all medical equipment. The use of stainless steel and other materials produced for routine disinfecting such as FDA and EPA registered anti-microbial powder is necessary to ensure the refrigerators are suitable for medical laboratories.

#### Improper refrigerator repercussions

The use of improper refrigerators for clinical cold storage may put patients at risk by being administered a degraded vaccine due to improper temperature control. Vaccines and medicines are expensive commodities, and the use of low-quality refrigerators for their storage can cause a huge financial loss due to compromised products that would require disposal.

Since patient samples are stored in medical-grade refrigerators, keeping them in improper refrigerators may result in the loss of irreplaceable patient samples that are crucial for lab testing and research success.

Ultimately, the improper use of refrigerators can cause disruptions to the entire workflow. Due to the grave repercussions of unreliable refrigeration, healthcare professionals seek compatible medical-grade refrigerators to increase productivity and reduce the overall risk in the cold chain.

Despite having costly initial acquisition prices to procure medical-grade refrigerators, the investment of purchasing a unit is worth it in the long run. Legitimate and high-quality medical-grade refrigeration units ensure reliability and quality that mitigates the risk of substantial financial loss due to improper storage. It will also limit the need for frequent acquisition of units for replacement, paving the way for long-term savings.

#### Industrial Refrigeration (Lab)

##### A) Suggested Specification Table (For ESE of Laboratory Instruction\*):

Laboratory Instruction Number	Short Laboratory Experiment Titles	Assessment of Laboratory Work (Marks)		
		Performance		Viva-Voce
		PRA	PDA	
LE1.1	Determine performance parameters on food preservation test rig.	15	10	5
LE1.2	Identify the performance parameters of cold storage test rig.	15	10	5
LE1.3	Determine the performance of cold storage using test rig.	15	10	5
LE2.1	Determine performance parameters on air-conditioning test rig.	15	10	5
LE2.2	Determine performance parameters on air-conditioning of fixed volume cabinet	15	10	5
LE2.3	Identify important HVAC controls, including economizers.	15	10	5
LE2.4	Determine fan power	15	10	5

LE3.1	Determine the properties of cryogenic fluid.	15	10	5
LE3.2	Determine the properties of engineering material at cryogenic temperature.	15	10	5
LE4.1	Determine performance parameters on ice plant tutor	15	10	5
LE4.2	Determine performance parameters of air conditioning tutor	15	10	5
LE4.3	Determine performance of water chilling plant.	15	10	5
LE4.4	Check & Adjust of different refrigerant controls, floats, Solenoid Valves, Safety switches	15	10	5
LE4.5	Charge refrigerants & check performance	15	10	5
LE 5.1	Determine the cooling load for automobile car.	15	10	5
LE5.2	Estimate the total heat load of practical workshop using anemometer, calorimeter, sling psychrometer	15	10	5
LE5.3	Determine the properties of air by using sling psychrometer.	15	10	5

**B) Suggested Learning Resources:**

**(a) Books :**

S. No.	Title	Author	Publisher(pl add place and ISBN no)	Edition and Year
1.	Refrigeration and Air Conditioning	Rajput R.K	S.K. Kataria, Delhi	Latest
2.	Refrigeration and Air Conditioning	Arora, Domkundwar.S	Dhanpat Rai, Delhi	Latest
3.	Refrigeration and Air Conditioning	Khurmi R.S, gupta J.K	S. Chand	Latest
4.	Refrigeration and Air Conditioning	Domkundwar. S,	Dhanpat Rai, Delhi	Latest
5.	Principles of Air Conditioning.	Lang Paull .V	CBS publishers	Latest
6.	Refrigeration and Air Conditioning	Manohar Prasad	New age international (P) limited, New Delhi	Latest
7.	Refrigeration and AirConditioning	.Arora C.P	McGraw Hill education (India) (P) limited, NewDelhi	Latest
8.	Principles of Refrigeration	Roy J. Dossat	Pearson education, New Delhi	Latest
9.	Principles of Refrigeration and AirConditioning, 1982.jmk	Stoeker, W.F. and Jones, J.P.	McGraw Hill, New York, Second Edition	Latest

<b>S. No.</b>	<b>Title</b>	<b>Author</b>	<b>Publisher(pl add place and ISBN no)</b>	<b>Edition and Year</b>
10.	Basic Refrigeration and Air Conditioning.	P. N. Ananthanarayanan	Tata McGraw Hill, New Delhi	Latest
11.	Introduction to cryogenic engineering and gas application	Prof. Bose P.K.	Everest Publishing House	Latest