Northern Technical University

Technical College of Engineering / Mosul City

Department of Power Mechanics

Fourth Year

Air Conditioning System Design

Chapter One

“Lecture One”

Types of Air Condition System

Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

Course Book

1. **Course name: Air Conditioning Systems Design**

2. **Lecturer in charge: Assist Prof. Badran Mohammed Salim**

3. **Contact: E-mail: badran.salim@ntu.edu.iq**

4. **Time (in hours) per week: Theory: 3 Hours per week**
Practical: 2 Hours per week

5. **Teacher's Academic Profile**

Educational Background:

- **2007 M.Sc.,** Mechanical Engineer / Thermal Applied / Refrigeration & Air Condition Specification / Mosul University.
- **2003 Bachelors**, Mechanical Engineer / General Branch / Mosul University.

Teaching:

Teaching the following subjects:

- Air conditioning System Design / Fourth Stage.
- Mathematic II / Second Stage.
- Mechanics of Static & Dynamic/First Stage.
- Refrigeration & A/C System Drawing / Third Stage.
- Strength of Materials/Power Dep. / Second Stage.
- Refrigeration and Air Conditioning (I) / Second Stage.
- Refrigeration Systems Design / Fourth Stage.

Presentation:

Presentation the following subjects with the Location:

- Numerical Solution of non Darcian Convective H.T. in Semi-infinite Porous Medium Heated from below Subjected to Periodic Oscillation Temperature / Master Thesis / University of Mosul / College of Engineering.
- Modern Air Conditioning System / Lecture Developmental / Scientific conference in Engineering Technical College/Mosul.
- VRF Air Conditioning System / Lecture Developmental / SAMSUNG & LG Academy for A/C in Erbil City

Certificate:

- Certification for the successful participation in the National Workshop on Refrigeration & Air Conditioning System Process recovery & recycling program/ United Nations Environmental Program (UNEP) / 2012.

- Certificate of Participation from Staff Development Centre for Methods of Teaching Certificate /2011.

Published Works:

- Life Cycle Cost Analysis for three Different Types of A/C Systems Applied on an Apartment Located in a Multi Floors Residential Tower in Mosul City / Engineering & Technology Journal Paper /2014.
- Theoretical Analysis of Flat Plate Solar Collector Placed in Mosul City by Using Different Absorbing Materials and Fluids / KUFA Journal of Engineering / 2014.
- Economic Feasibility Study of Modern and Conventional Central Heating Systems for Villa Located in Duhok City/ Engineering & Technology Journal Paper.
- Comparative Analysis between Modern and Conventional HVAC Systems for Use at Commercial Building in Baghdad City / Iraq. Al-Taqani Journal Paper.

Several Theoretical & Practical Projects for Students in the Final Stage

- Manufacturing Laboratory Device (Variable Water Flow) that Illustrates the Working Principle of VRF A/C System / 2011.
- Improving Performance of Desert Cooler / 2012.
- Manufacturing Laboratory Device (Double Stage Compression Cycle) / 2012.
- Design Air Conditioning System operating room in a Mosul's Hospital / 2013.
- Manufacturing Laboratory Device to Study the Effect of Magnetic Cooling Water on Performance of FCU / 2014.

6. Keywords: Types of A/C system, Room and Central Air Conditioning System Type Selection, Psychrometric Process and Chart, Advanced Air Duct Design, Refrigeration System Design, Water Pipe Design.

7. Course overview:

Study the methods of air conditioning systems, Basic for each system, Advantages, Disadvantages and Application:

- All air systems.
- Single zone air conditioning systems.
- Air variable volume (VAV).
- Reheat.
- Single duct system.
- Dual duct system.
- Air water systems.
- Induction System.
- All water systems.
- Variable Refrigerant Flow System
- Fan coil System

- Direct expansion systems.
- Designs to achieve the building balance Refrigeration and Air Conditioning Branch is a combined process that performs many functions at the same time. It conditions the air, transports it, and introduces it to the conditioned space. It provides heating and cooling from its central plant or rooftop units. It also controls and maintains the temperature, humidity, air movement, air cleanliness, sound level, and pressure differential in a space within predetermined limits for the comfort and health of the occupants of the conditioned space or for product processing.

8. Course objective:

This course deals with the design and implementation of refrigeration and air conditioning systems. The objectives of the course is **to be enable the student**;

1. To understand types of air conditioning system.
2. To understand how to select best A/C system for each application.
3. To understand the basic processes for refrigeration and air conditioning system.
4. To understand the air properties and how to use psychrometric chart with draw each process.
5. To understand types of air distribution within each zone.
6. To understand advanced air duct design.
7. To understand how to selection best air diffuser with all accessories.
8. Difference between more than one term, such as GWP, ODP, ASHRAE and other.
9. To understand how to select best air fan to ensure reach the air into index run of schematic diagram of air duct layout..
10. To understand how to design water pipe and power of water pump.
11. To understand how to calculate the static and dynamic loss within compressible and incompressible fluid.
12. To understand the difference between types of silencer
13. To understand how to recognize between open and closed water system design

9. Student's obligation

The role of students and their obligations throughout the academic year include:

1- The student must attend to the class before the lecture's beginning to understand the lectures.
2- The student must attend to the class to accomplish the examination.
3- The student must attend all quizzes after finalize each chapter.
4- The student must answer the theoretical questions and solve the problems specialized for students.
5- The student must obligation for the time of deliver each report after finished each chapter.

10. Forms of teaching

The lecturer going to use the data show to expose the following items :

1. Expose the lecture as Microsoft power point.
2. Expose the special software and animation move that represent the subject.
3. The lecturer will use the White board in displaying the subject and the figures.
4. The lecturer will depend on his lectures that will receipt the lectures to the students before the lecture.

11. Student learning outcome:

The student going to learn the following items:

1- Demonstrate the ability to do technical work in a variety of heating, cooling, and refrigeration fields.
2- Identify and describe various components in a typical air-conditioning system.
3- Identify and demonstrate correct use of tools, materials, and equipment used in the trade.
4- Evaluate a motor in a hermetic compressor to determine if it is electrically sound and safe to start.
5- Follow the circuit of a typical electric air-conditioning system.
6- Take wet-bulb and dry-bulb temperature readings and determine relative humidity from the psychrometric chart.
7- Use information to determine the level of comfort from the ASHRAE generalized comfort chart.
Explain the basic refrigeration cycle and heat transfer relationships

12. Course Reading List and References:

- **Key references:**

1. ASHRAE Fundamentals Handbook for air conditioning and Refrigeration, SI, 1997.
2. G.F. Hundy , "Refrigeration and Air Conditioning",2010.
3. P. L. Ballaney, "Refrigeration and Air Conditioning ".
4. Stoecker and Lekold W. Jones, "Refrigeration and Air Conditioning", McGraw-Hill, 1982.
5. A Bhatia, HVAC Made Easy: A Guide of Heating and Cooling Load Estimation, PDH online course M196 (4PDH).
6. Carrier, Technical Development program.
7. Handbook of Air Conditioning System Design /Carrier Air Conditioning Co. by Carrier Air Conditioning Pty. Ltd

- **Useful references:**

Any Reference contains the refrigeration and air conditioning is useful reference.

Magazines and review (internet):

- http://www.learnhvac.org/
- https://www.youtube.com/watch?v=gHHYnzgn-_M
- https://www.youtube.com/watch?v=PN9FTV5S9TM
- https://www.youtube.com/user/ESErgovaAlbania
- https://www.youtube.com/watch?v=4I06uXrOs4M
- https://www.youtube.com/watch?v=bjM_Z6LPvYc
- https://www.youtube.com/watch?v=xTGzz1RDly0&list=PLv3hB2xWqDP-qeNRt9Gq5V3aQnwSsztcc
- https://www.youtube.com/watch?v=TDs8ZX8pcGA
- https://www.youtube.com/watch?v=zephL3PidMI&list=PLMtg_PfQdAAVhuTE9VT5VLQkZ9nHo2ReQ
- https://www.youtube.com/watch?v=OvVCCljuluY&list=PLMtg_PfQdAAVhuTE9VT5VLQkZ9nHo2ReQ&index=2
- https://www.youtube.com/watch?v=wvTYDVk_2aM
- https://www.youtube.com/watch?v=6n_qYmbx_1g
- https://www.youtube.com/watch?v=YCogTVa3XOw
- https://www.youtube.com/watch?v=fqvo7bSr6t8
- https://www.youtube.com/watch?v=OvVCCljuluY

13. The Theoretical Topics:

Chapter One: Types of Air Condition System

Topic contents:

- Air conditioning systems, Types of air conditioning systems for building.
- All - air systems, single duct, types, advantages and disadvantages.
- Single zone system, variable volume, advantages and disadvantages.
- Air handling unit advantages and disadvantages..
- Fan coil units advantages and disadvantages.
- Dual duct systems, multiple zone, advantages and disadvantages.
- Air - water systems, characteristic and advantages and disadvantages for each type and comparison with other systems, approaches of components selections.
- Induction systems, advantages and dis advantages
- All - water systems, performance, designs and applications.
- Useful pictures for each A/C system.

Chapter Two: Advanced Air Duct Design

Topic contents:

- Method of design air duct.
- Air duct system resistance.
- Static and dynamic pressure losses calculate.
- Fan total pressure estimate.
- Problems.

Chapter Three: Air Distribution

Topic contents:

- Air distributed inside the room.
- Air distributes requirements inside the rooms.
- Ventilation apertures.
- How to select the air diffuser.
- Types of air diffuser with picture.

Chapter Four: Fan Types and Characteristics

Topic contents:

- Fans design and its selection.
- Fans types and its calculations.
- Selection of fans for design.
- Fan's laws.

Chapter Five: Air Filtration

Topic contents:

- Filter types and its employment.
- Air impurities.
- How to select the air filter.
- HEPA filter with application.
- Modern air filter.

Chapter Six: Psychometric Process and Advanced applications

Topic contents:

- Fast review about process that student took in second stage.
- Explain psychrometric chart.
- Humidification methods.
- Dehumidification methods.
- Advanced applications.

Chapter Seven: Water air condition system design

Topic contents:

- Main components of water air conditioning system with benefits
- Types of water air conditioning system.
- Explain advantages and disadvantages of water air conditioning system
- Water effects.
- Water pipe diameter design.
- Types of pump connection.

- Pump capacity and head calculation.
- Static loss calculates.
- Dynamic loss calculates.
- Reduce loss within pipe.
- Problems.

Chapter Eight: Evaporative cooling applications

Topic contents :

- Study the evaporative cooling system.
- How the system work.
- Performance of evaporative system.
- Advantages and disadvantages.
- Application.

Chapter Nine : Noise and source

Topic contents :

- Definition of Sound.
- Basic of noise.
- Study the source of noise.
- Noise criteria and how to reduce it by using silencers.
- Types of silencer.

Mini Project: Design mini project for different air conditioning systems

Chapter One
Types of Air – Conditioning Systems

1. **Class** : Fourth Year

2. **Subject**: Types of Air Conditioning Systems.

3. **Number of weeks:** Three weeks

4. Central idea: Study the methods of air conditioning systems, Basic for each system, Advantages, Disadvantages and Application:

- All air systems.
- Single zone air conditioning systems.
- Air variable volume (VAV).
- Reheat.
- Single duct system.
- Dual duct system.
- Air water systems.
- Induction System.
- All water systems.
- Variable Refrigerant Flow System
- Fan coil System
- Direct expansion systems.
- Designs to achieve the building balance.

5. **The Test & Problems**:

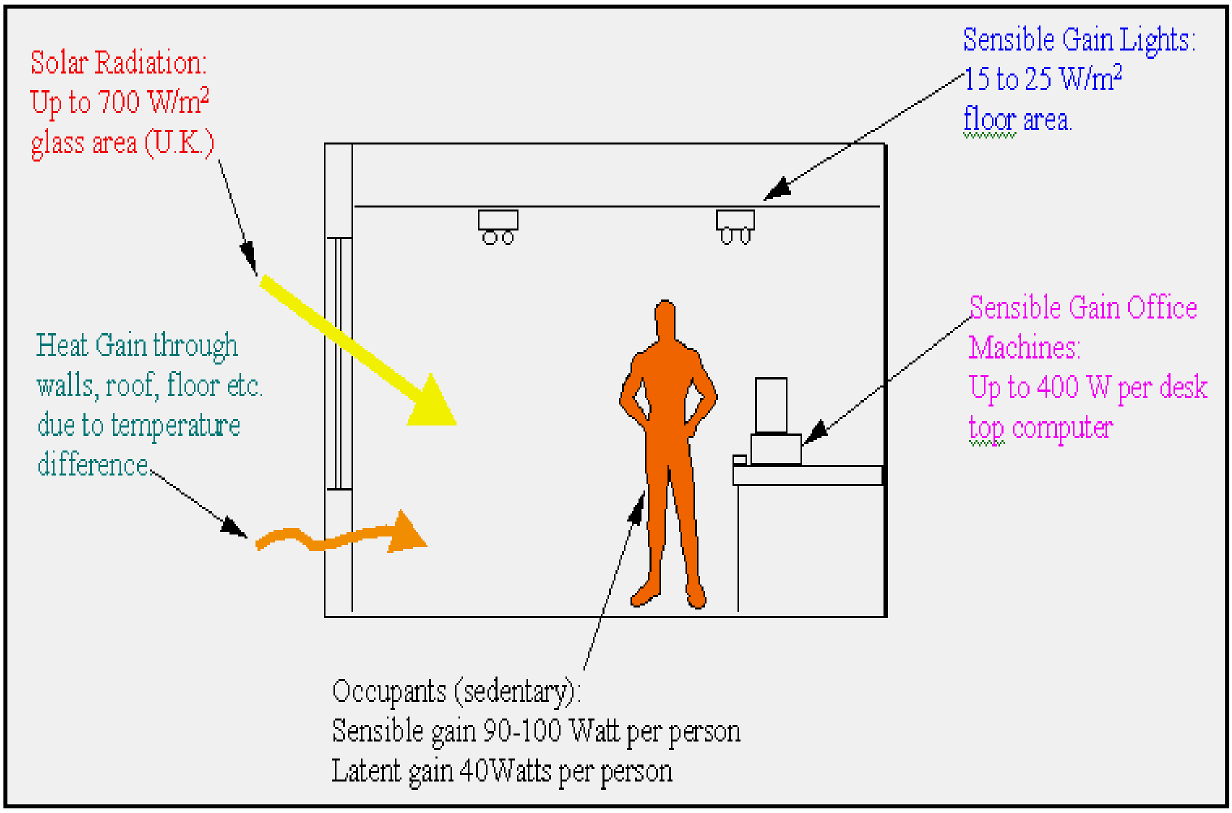
Air Conditioning

Introduction to Air Conditioning:

Air conditioning may be required in buildings which have a high heat gain and as a result a high internal temperature.

The heat gain may be from solar radiation and/or internal gains such as people, lights and business machines.

The diagram below shows some typical heat gains in a room.



If the inside temperature of a space rises to about 25°C then air conditioning will probably be necessary to maintain comfort levels.

This internal temperature (around 25°C) may change depending on some variables such as:

- **Type of building**
- **Location of building**
- **Duration of high internal temperature**
- **Expected comfort conditions.**

- **Degree of air movement**

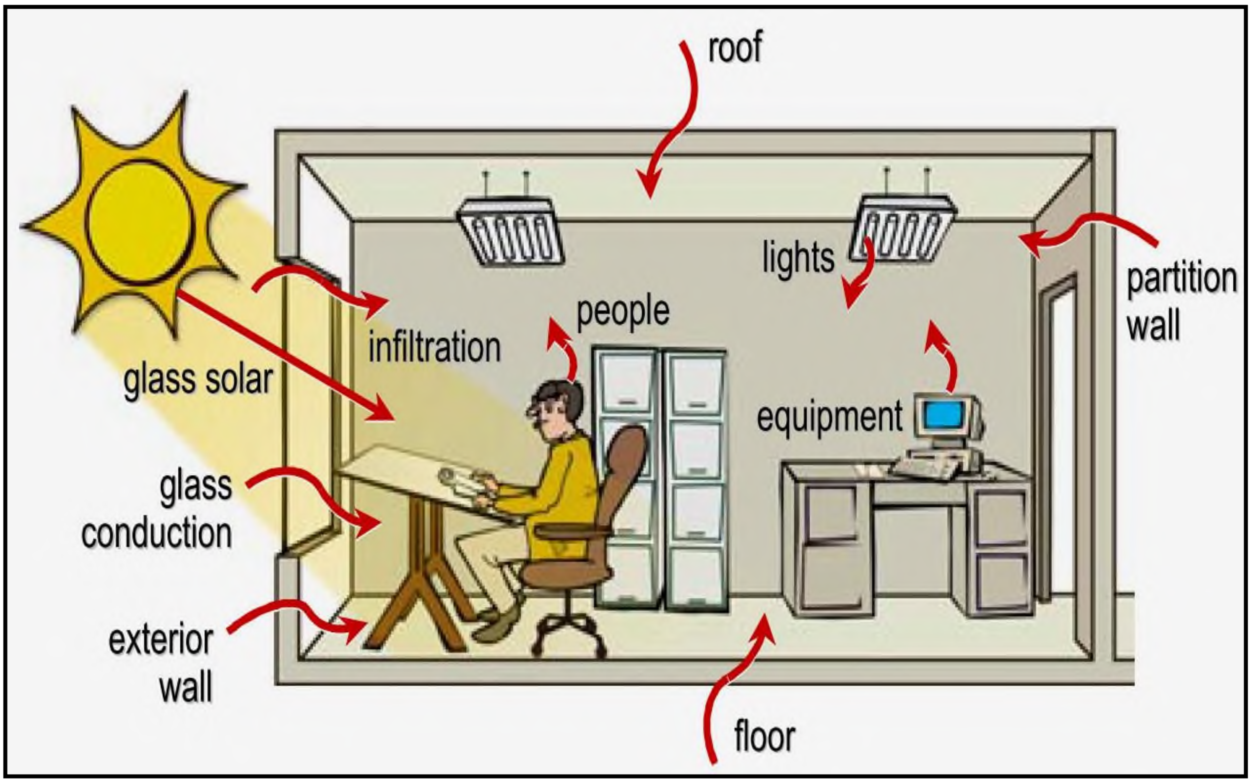
In some buildings it may be possible to maintain a **comfortable environment** with mechanical ventilation but the air change rate will tend to be high (above about 8 air changes per hour) which can in itself cause air distribution problems.

Since air conditioning is both **expensive** to install and maintain, it is best avoided if possible.

This may possibly be achieved by careful building design and by utilising methods such as:

- Window blinds or shading methods
- Heat absorbing glass
- Heat reflecting glass
- Operable windows
- Higher ceilings
- Smaller windows on south facing facades
- Alternative lighting schemes.

The diagram below shows some of these methods.



Describe Load Components

If air conditioning is the only answer to adequate comfort in a building then the main **choice of system** can be considered.

Also the air is cleaned by filters, dehumidified to remove moisture or humidified to add moisture.

Air conditioning systems fall into two main categories:

- **Central plant systems.**
- **Room air conditioning systems.**

Central plant systems have one central source of conditioned air which is distributed in a network of ductwork or water pipe or refrigerant pipe .

Room air conditioning systems are self-contained package units which can be positioned in each room to provide cool air in summer or warm air in winter.

- **Central Plant Systems :**

Introduction:

In order to maintain required conditions inside the conditioned space, energy has to be either supplied or extracted from the conditioned space. The energy in the form of sensible as well as latent heat has to be supplied to the space in winter and extracted from the conditioned space in case of summer. An air conditioning system consists of an air conditioning plant and a thermal distribution system as shown in Fig.(a). As shown in the figure, the air conditioning (A/C) plant acts either as a heat source (in case of winter systems) or as a heat sink (in case of summer systems). Air, water or refrigerant are used as media for transferring energy from the air conditioning plant to the conditioned space. A thermal distribution system is required to circulate the media between the conditioned space and the A/C plant. Another important function of the thermal distribution system is to introduce the required amount of fresh air into the conditioned space so that the required Indoor Air Quality (IAQ) can be maintained.

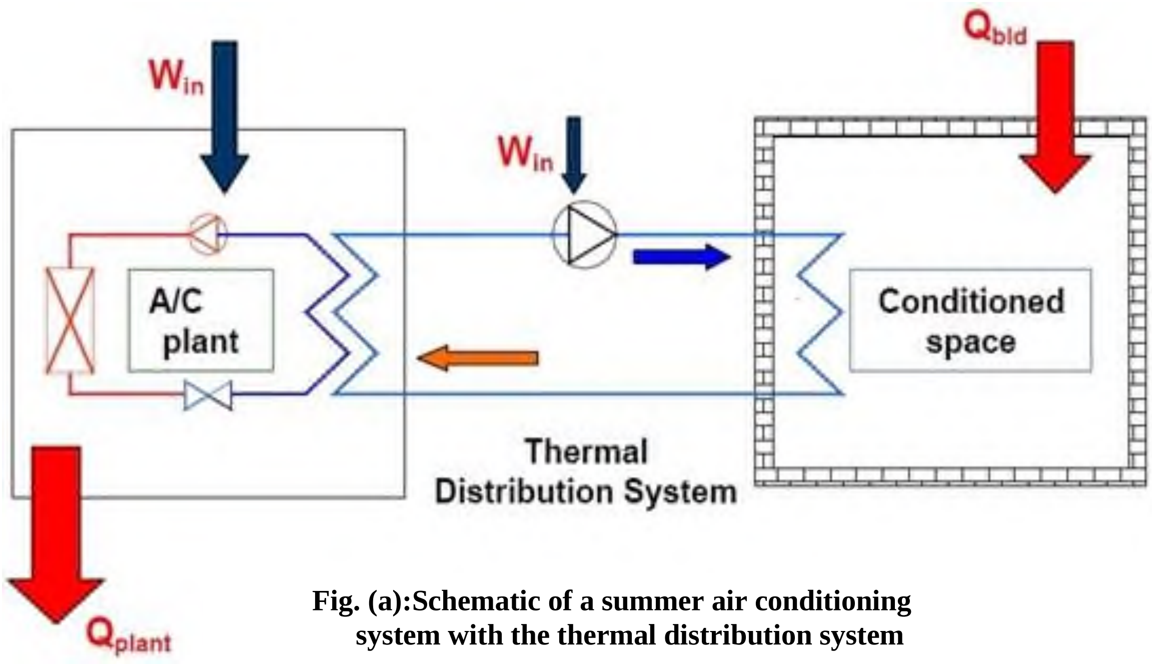


Fig. (a):Schematic of a summer air conditioning system with the thermal distribution system

There are other forms of central plant systems air conditioning:

1. All Air System.
2. Air –Water System.
3. Induction System.
4. All Water System.
5. Variable Refrigerant Flow.

Selection criteria for air conditioning systems:

Selection of a suitable air conditioning system depends on:
1. Capacity, performance and spatial requirements
2. Initial and running costs
3. Required system reliability and flexibility
4. Maintainability
5. Architectural constraints

The relative importance of the above factors varies from building owner to owner and may vary from project to project. The typical space requirement for large air conditioning systems may vary from about 4 percent to about 9 percent of the gross building area, depending upon the type of the system. Normally based on the selection criteria, the choice is narrowed down to systems, out of which one will be selected finally.

1. All air systems:

As the name implies, in an all air system air is used as the media that transports energy from the conditioned space to the A/C plant. In these systems air is processed in the A/C plant and this processed air is then conveyed to the conditioned space through insulated ducts using blowers and fans. This air extracts (or supplies in case of winter) the required amount of sensible and latent heat from the conditioned space. The return air from the conditioned space is conveyed back to the plant, where it again undergoes the required processing thus completing the cycle. No additional processing of air is required in the conditioned space. All air systems can be further classified into:

1. Single duct systems
2. Dual duct systems

The single duct systems can provide either cooling or heating using the same duct, but not both heating and cooling simultaneously. These systems can be further classified into:

1. Constant volume, single zone systems
2. Constant volume, multiple zone systems
3. Variable volume systems

The dual duct systems can provide both cooling and heating simultaneously. These systems can be further classified into:

1. Dual duct, constant volume systems
2. Dual duct variable volume systems

A) Single duct, constant volume, single zone systems:

Figure (1) shows the classic, single duct, single zone, constant volume systems. As shown in the figure, outdoor air (OD air) for ventilation and recirculate air (RC air) are mixed in the required proportions using the dampers and the mixed air is made to flow through a cooling and dehumidifying coil, a heating coil and a humidifier using an insulated ducting and a supply fan. As the air flows through these coils the temperature and moisture content of the air are brought to the required values. Then this air is supplied to the conditioned space, where it meets the building cooling or heating requirements. The return air leaves the conditioned space, a part of it is recirculate and the remaining part is vented to the atmosphere. A thermostat senses the temperature of air in the conditioned space and controls the amount of cooling or heating provided in the coils so that the supply air temperature can be controlled as per requirement.

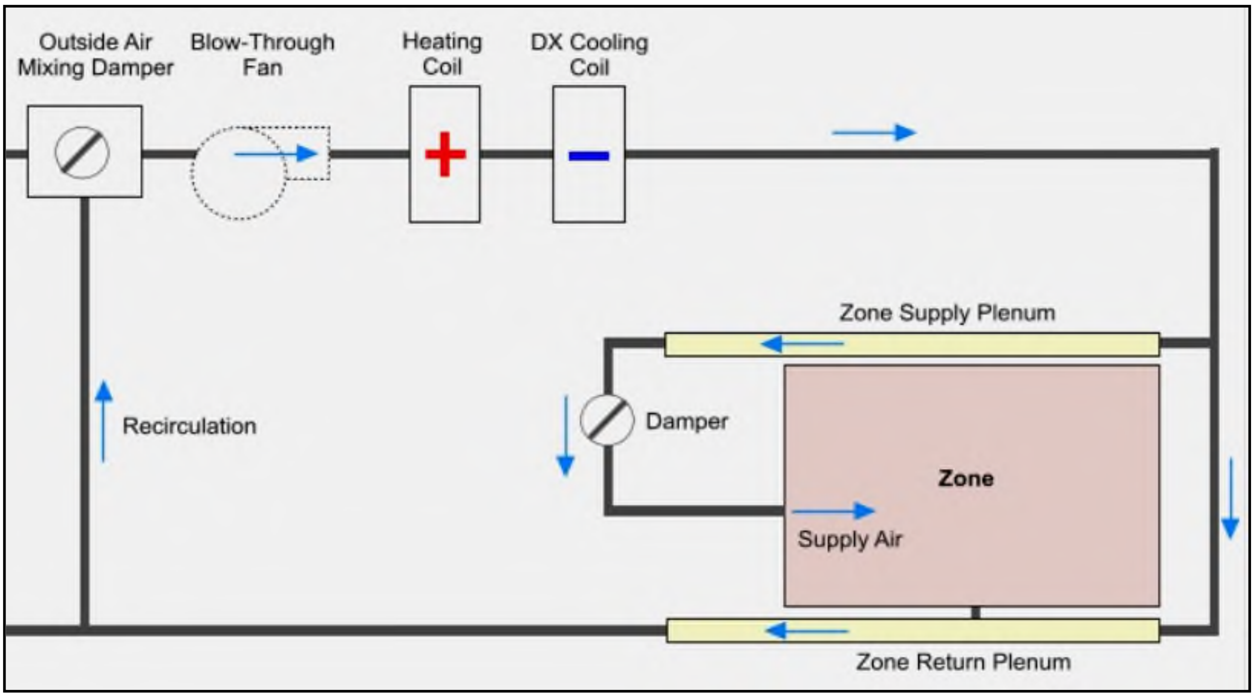


Fig. (1): A Constant Volume, Single Zone System

This system is called as a single duct system as there is only one supply duct, through which either hot air or cold air flows, but not both simultaneously. It is called as a constant volume system as the volumetric flow rate of supply air is always maintained constant. It is a single zone system as the control is based on temperature and humidity ratio measured at a single point. Here a zone refers to a space controlled by one thermostat. However, the single zone may consist of a single room or one floor or whole of a building consisting of several rooms. The cooling/ heating capacity in the single zone, constant volume systems is regulated by regulating the supply air temperature and humidity ratio, while keeping the supply airflow rate constant. A separate sub-system controls the amount of OD air supplied by controlling the damper position

Applications of single duct, single zone, constant volume systems:
1. Spaces with uniform loads, such as large open areas with small external loads e.g. theatres, auditoria, departmental stores.
2. Spaces requiring precision control such as laboratories
The Multiple, single zone systems can be used in large buildings such as factories, office buildings etc.

B) Single duct, constant volume, multiple zone systems:

For very large buildings with several zones of different cooling/heating requirements, it is not economically feasible to provide separate single zone systems for each zone. For such cases, multiple zone systems are suitable. Figure (2) shows a single duct, multiple zone system with terminal reheat coils. In these systems all the air is cooled and dehumidified (for summer) or heated and humidified (for winter) to a given minimum or maximum temperature and humidity ratio. A constant volume of this air is supplied to the reheat coil of each zone. In the reheat coil the supply air temperature is increased further to a required level depending upon the load on that particular zone. This is achieved by a zone thermostat, which controls the amount of reheat, and hence the supply air temperature. The reheat coil may run on either electricity or hot water.

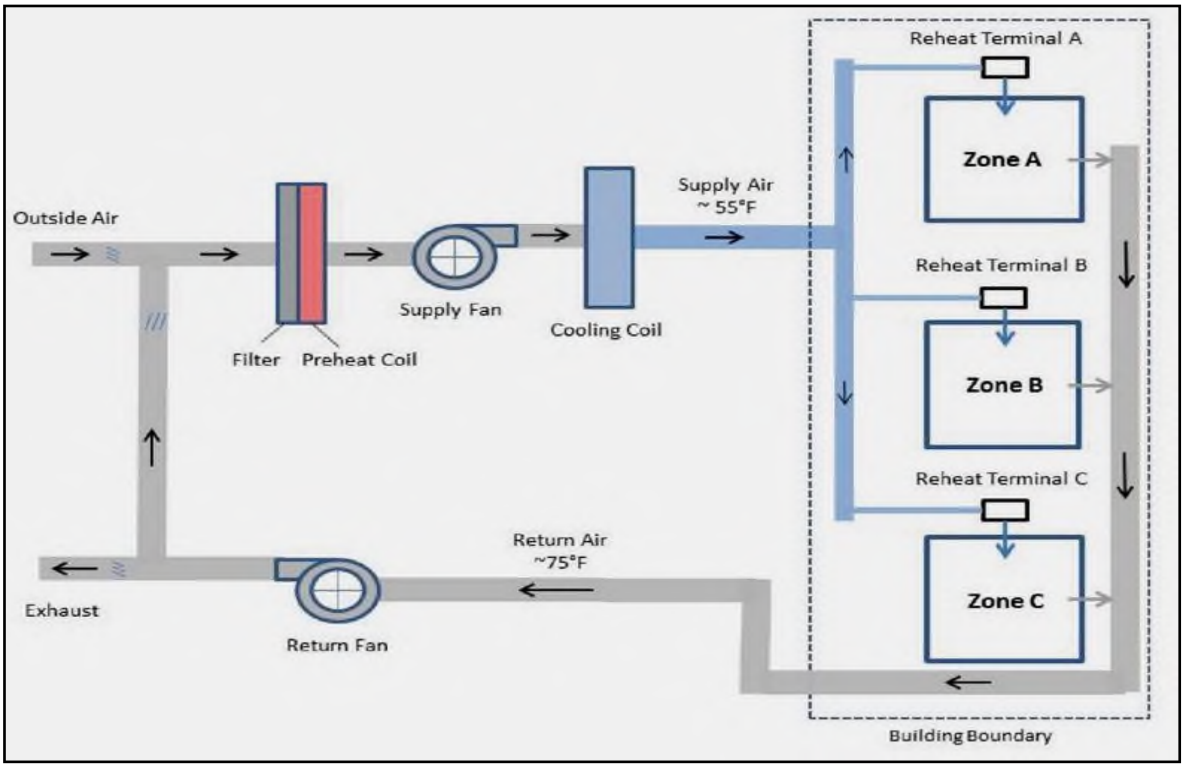


Fig. (2): Single Duct, Constant Volume System with Multiple Zone

Advantages of single duct, multiple zone, constant volume systems:

a) Relatively small space requirement
b) Excellent temperature and humidity control over a wide range of zone loads
c) Proper ventilation and air quality in each zone is maintained as the supply air amount is kept constant under all conditions

Disadvantages of single duct, multiple zone, and constant volume systems:

1) High energy consumption for cooling, as the air is first cooled to a very low temperature and is then heated in the reheat coils. Thus energy is required first for cooling and then for reheating. The energy consumption can partly be reduced by increasing the supply air temperature, such that at least one reheat coil can be switched-off all the time. The energy consumption can also be reduced by using waste heat (such as heat rejected in the condensers) in the reheat coil.

2) Simultaneous cooling and heating is not possible.

C) Single duct, variable air volume (VAV) systems:

Figure (3) shows a single duct, multiple zone, variable air volume system for summer A/C applications. As shown, in these systems air is cooled and dehumidified to a required level in the cooling and dehumidifying coil (CC).

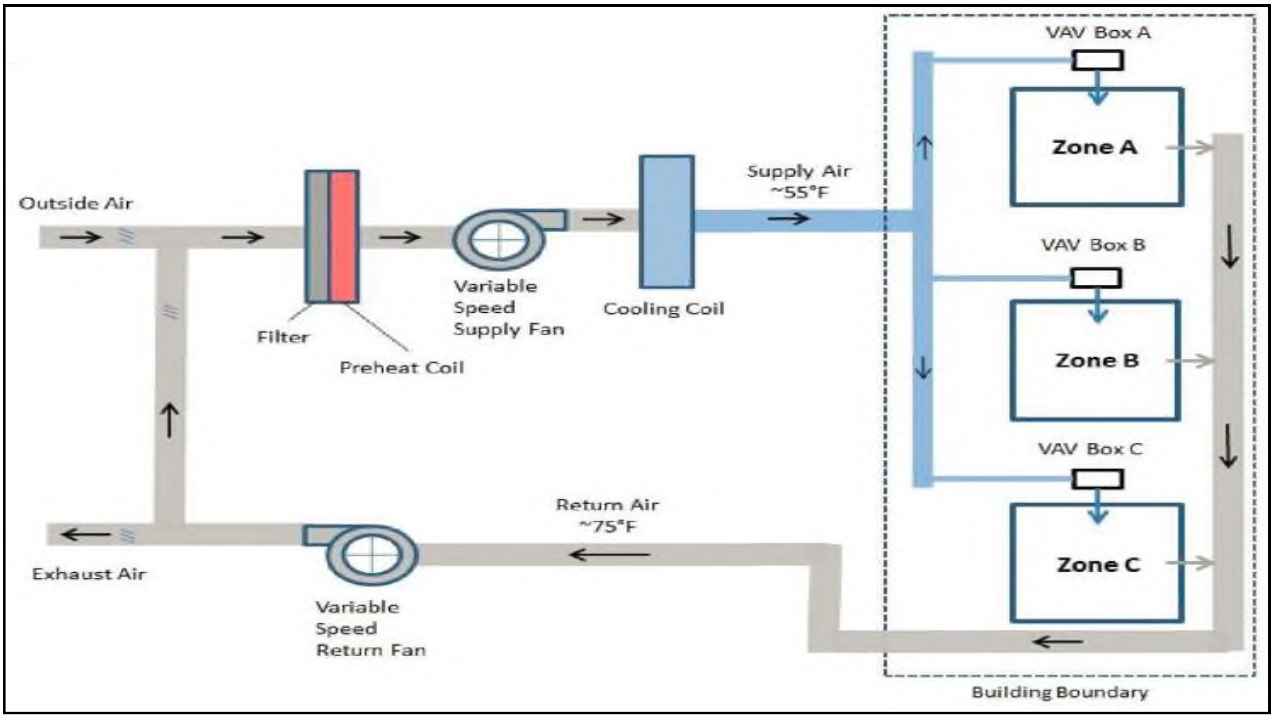


Fig. (3): Single Duct, Multiple zones, Variable Air Volume System

A variable volume of this air is supplied to each zone. The amount of air supplied to each zone is controlled by a zone damper, which in turn is controlled by that zone thermostat as shown in the figure. Thus the temperature of supply air to each zone remains constant, whereas its flow rate varies depending upon the load on that particular zone.

Compared to CV systems, the VAV system offer advantages such as:

a) Lower energy consumption in the cooling system as air is not cooled to very low temperatures and then reheated as in constant volume systems.

b) Lower energy consumption also results due to lower fan power input due to lower flow rate, when the load is low. These systems lead to significantly lower power consumption, especially in perimeter zones where variations in solar load and outside temperature allows for reduced air flow rates.

However, since the flow rate is controlled, there could be problems with ventilation, IAQ and room air distribution when the zone loads are very low. In addition it is difficult to control humidity precisely using VAV systems. Balancing of dampers could be difficult if the airflow rate varies widely.

D) Dual duct, constant volume systems:

Figure (4) shows the schematic of a dual duct, constant volume system. As shown in the figure, in a dual duct system the supply air fan splits the flow into two streams. One stream flow through the cooling coil and gets cooled and dehumidified to about 13°C, while the other stream flows the heating coil and is heated to about 35–45°C. The cold and hot streams flow through separate ducts. Before each conditioned space or zone, the cold and hot air streams are mixed in required proportions using a mixing box arrangement, which is controlled by the zone thermostat.

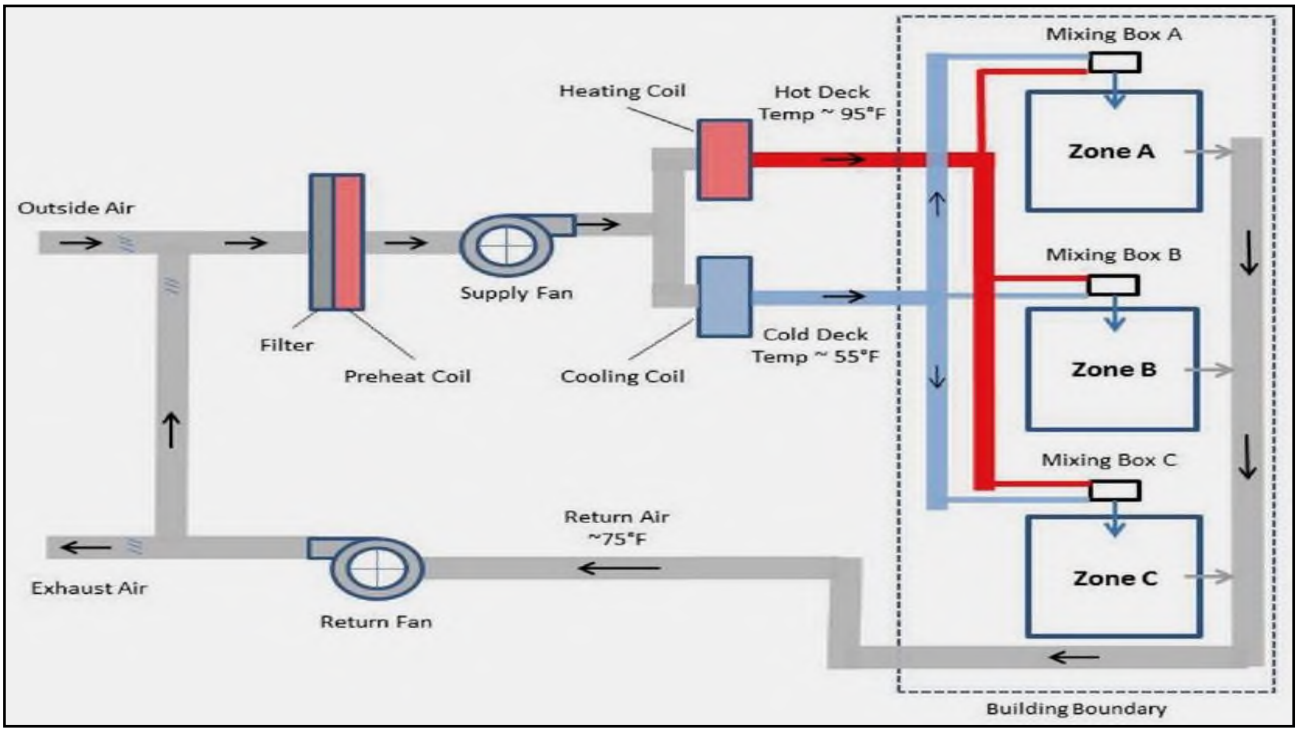


Fig. (4): Dual Duct, Constant Air Volume System

Advantages of dual duct systems:

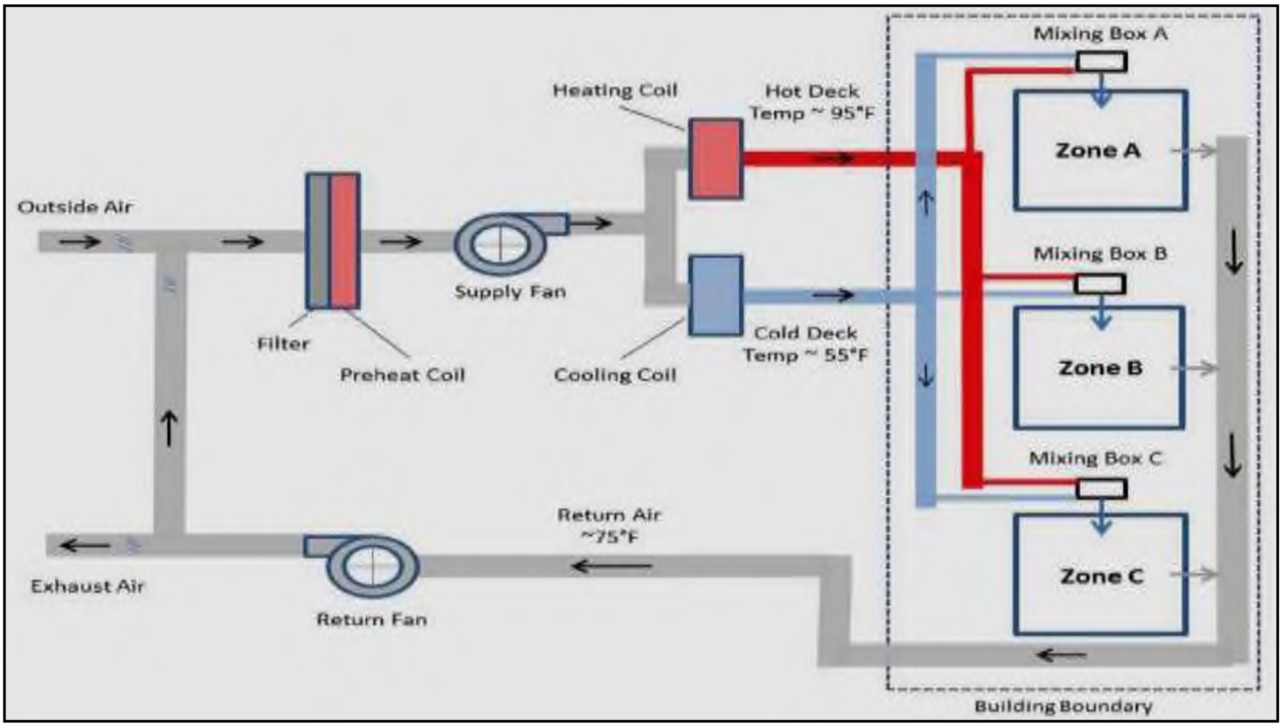
1. Since total airflow rate to each zone is constant, it is possible to maintain proper IAQ and room air distribution.
2. Cooling in some zones and heating in other zones can be achieved simultaneously
3. System is very responsive to variations in the zone load, thus it is possible to maintain required conditions precisely.

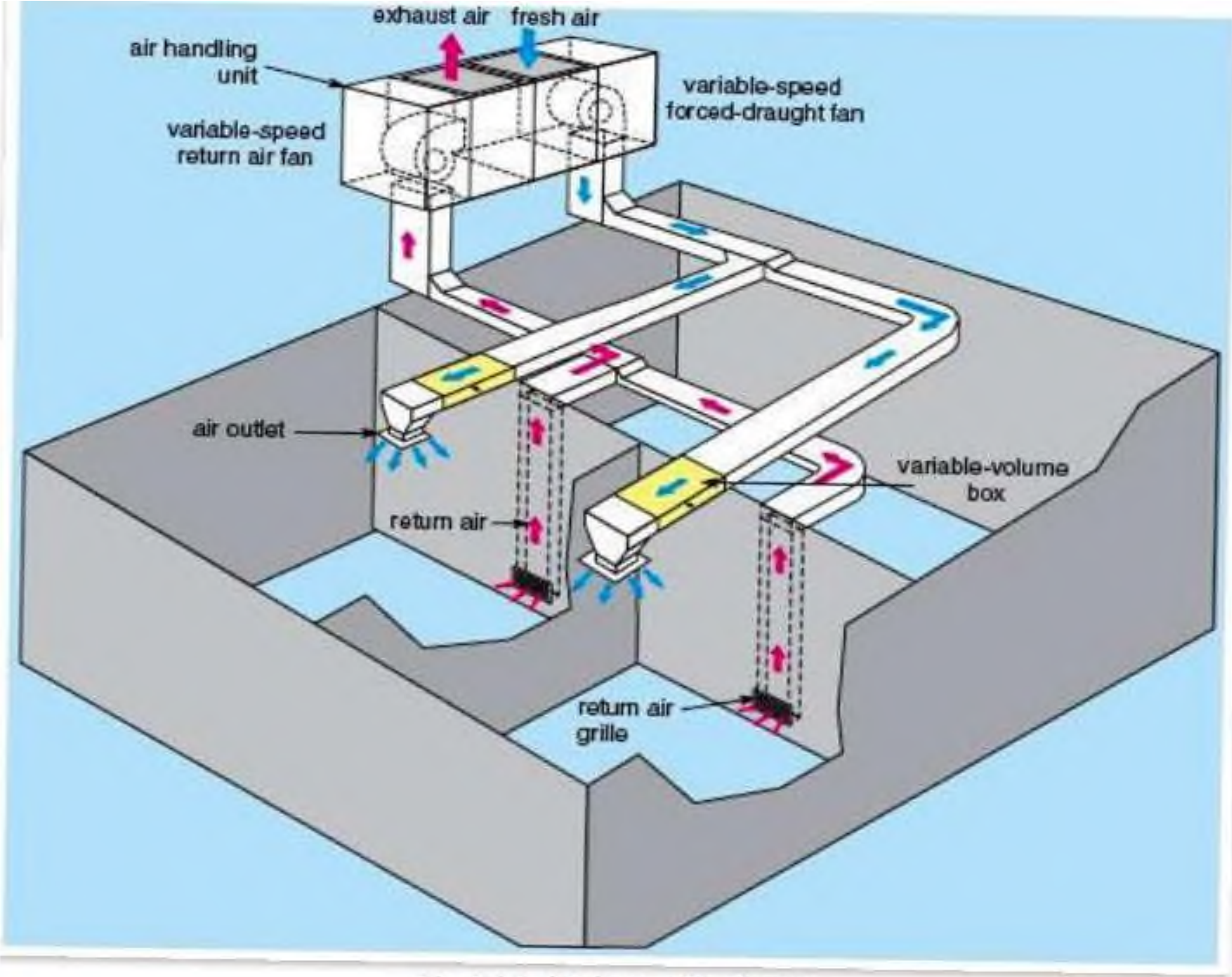
Disadvantages of dual duct systems:

1. Occupies more space as both cold air and hot air ducts have to be sized to handle all the air flow rate, if required.
2. Not very energy efficient due to the need for simultaneous cooling and heating of the air streams. However, the energy efficiency can be improved by completely shutting down the cooling coil when the outside temperature is low and mixing supply air from fan with hot air in the mixing box. Similarly, when the outside weather is hot, the heating coil can be completely shut down, and the cold air from the cooling coil can be mixed with supply air from the fan in the mixing box.

E) Dual duct, variable air volume systems:

This system is shown below similar to dual duct, constant volume systems with the only difference that instead of maintaining constant flow rates to each zone, the mixing boxes reduce the air flow rate as the load on the zone drops.





Variable Volume Systems

Advantages of all air systems:

1. All air systems offer the greatest potential for energy conservation by utilizing the outdoor air effectively.
2. By using high-quality controls it is possible to maintain the temperature and relative humidity of the conditioned space within ± 0.15oC (DBT) and ± 0.5%, respectively.
3. Using dual duct systems, it is possible to provide simultaneous cooling and heating. Changeover from summer to winter and vice versa is relatively simple in all air systems.
4. It is possible to provide good room air distribution and ventilation under all conditions of load.
5. Building pressurization can be achieved easily.
6. The complete air conditioning plant including the supply and return air fans can be located away from the conditioned space. Due to this it is possible to use a wide variety of air filters and avoid noise in the conditioned space.

Disadvantages of all air systems:

1. They occupy more space and thus reduce the available floor space in the buildings. It could be difficult to provide air conditioning in high-rise buildings with the plant on the ground floor or basement due to space constraints.
2. Retrofitting may not always be possible due to the space requirement.
3. Balancing of air in large and particularly with variable air volume systems could be difficult.

Applications of all air systems:

All air systems can be used in both comfort as well as industrial air conditioning applications. They are especially suited to buildings that require individual control of multiple zones, such as office buildings, classrooms, laboratories, hospitals, hotels, ships etc. They are also used extensively in applications that require very close control of the conditions in the conditioned space such as clean rooms, computer rooms, operation theatres etc.

Northern Technical University
Technical College of Engineering / Mosul City
Department of Power Mechanics

Fourth Year
Air Conditioning System Design

Chapter One
"Lecture Two"
Types of Air Condition System

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1. Air-water systems:

In air-water systems both air and water are used for providing required conditions in the conditioned space. The air and water are cooled or heated in a central plant. The air supplied to the conditioned space from the central plant is called as primary air, while the water supplied from the plant is called as secondary water. The complete system consists of a central plant for cooling or heating of water and air, ducting system with fans for conveying air, water pipelines and pumps for conveying water and a room terminal. The room terminal may be in the form of a fan coil unit, an induction unit or a radiation panel. Figure (5) shows the schematic of a basic air-water system.

Normally a constant volume of primary air is supplied to each zone depending upon the ventilation requirement and the required sensible cooling capacity at maximum building load. For summer air conditioning, the primary air is cooled and dehumidified in the central plant, so that it can offset all the building latent load. Chilled water is supplied to the conditioned space to partly offset the building sensible cooling load only. Since the chilled water coil kept in the conditioned space has to take care of only sensible load, condensation of room air inside the conditioned space is avoided thereby avoiding the problems of condensate drainage and related problems in the conditioned space. As mentioned, the primary takes care of the ventilation requirement of the conditioned space, hence unlike in all water systems, there is no need for separate ventilation systems. In winter, moisture can be added to the primary air in the central plant and hot water is circulated through the coil kept in the conditioned space. The secondary water lines can be of 2-pipe, 3-pipe or 4-pipe type similar to all water systems.

Applications of air-water systems:

These systems are mainly used in exterior buildings with large sensible loads and where close control of humidity in the conditioned space is not required. These systems are thus suitable for office buildings, hospitals, schools, hotels, apartments etc.

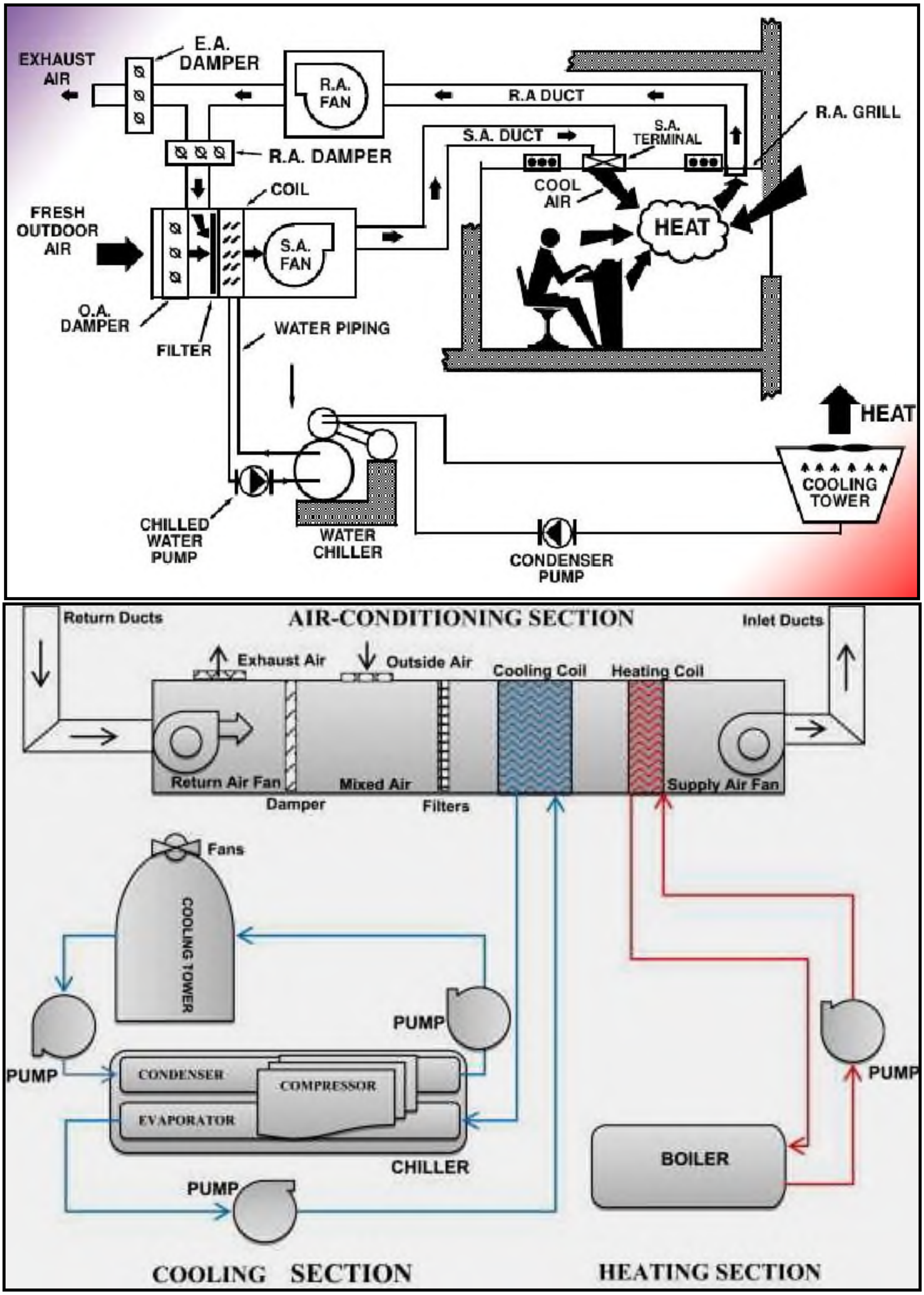


Fig. (5): Basic of Ai-Water System

Advantages of air-water systems:

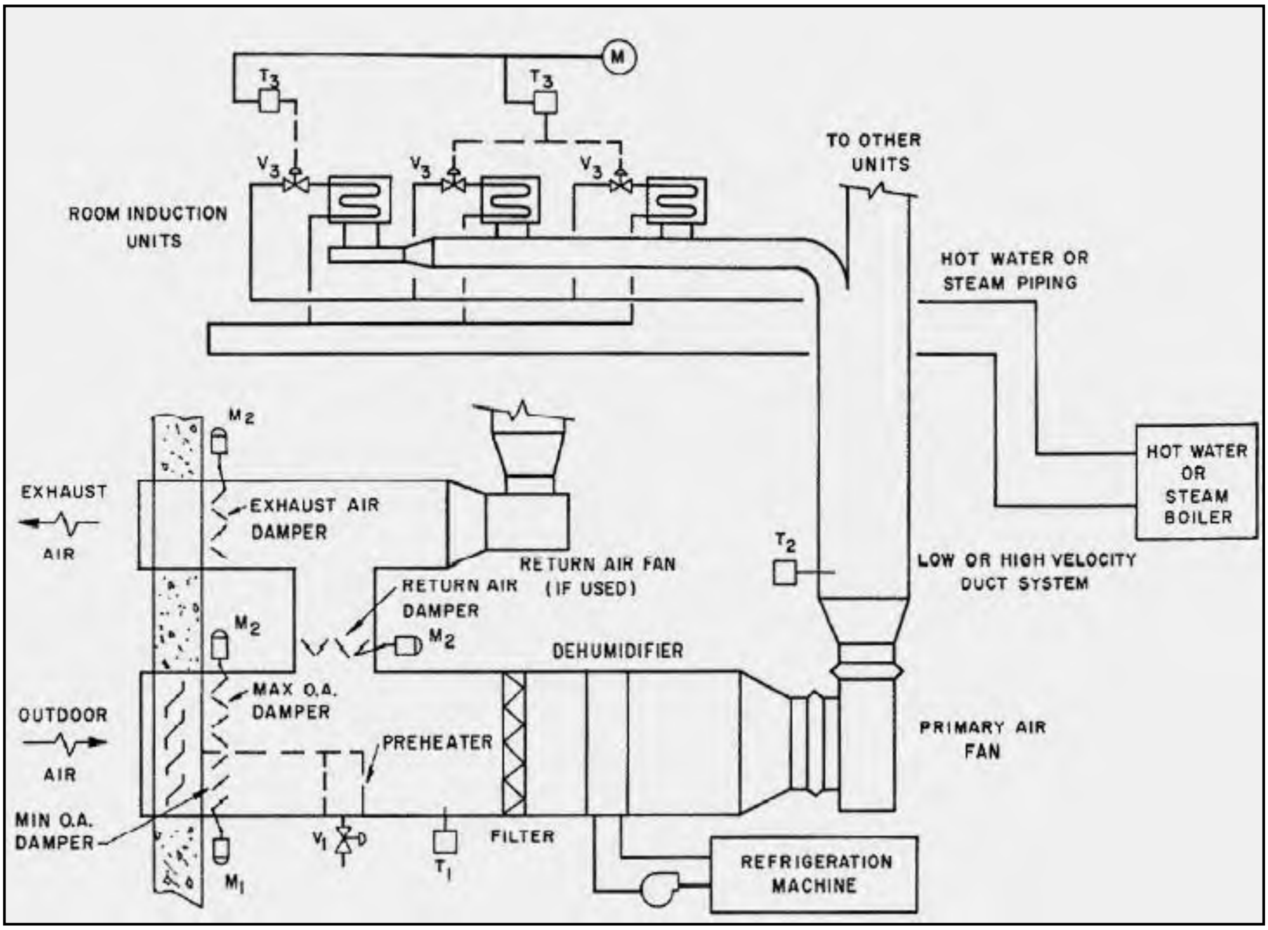
1. Individual zone control is possible in an economic manner using room thermostats, which control either the secondary water flow rate or the secondary air (in fan coil units) or both.
2. It is possible to provide simultaneous cooling and heating using primary air and secondary water.
3. Space requirement is reduced, as the amount of primary supplied is less than that of an all air systems.
4. Positive ventilation can be ensured under all conditions.
5. Since no latent heat transfer is required in the cooling coil kept in the conditioned space, the coil operates dry and its life thereby increases and problems related to odors or fungal growth in conditioned space is avoided.
6. The conditioned space can sometimes be heated with the help of the heating coil and secondary air, thus avoiding supply of primary air during winter.
7. Service of indoor units is relatively simpler compared to all water systems.

Disadvantages of air-water systems:

1. Operation and control are complicated due to the need for handling and controlling both primary air and secondary water.
2. In general these systems are limited to perimeter zones.
3. The secondary water coils in the conditioned space can become dirty if the quality of filters used in the room units is not good.
4. Since a constant amount of primary air is supplied to conditioned space, and room control is only through the control of room cooling/heating coils, shutting down the supply of primary air to unoccupied spaces is not possible.
5. If there is abnormally high latent load on the building, then condensation may take place on the cooling coil of secondary water.

2. INDUCTION UNIT

The induction unit is designed for use either with a complete air conditioning system or with a system providing heating and ventilating only. Fig. (6) show the unit elements which include the air inlet, sound attenuating plenum, nozzle and heating coil. A constant volume of cool conditioned air is supplied to the unit. This air, designated as primary air, handles the entire room requirements for cooling, dehumidification or humidification, and ventilation. The primary air induces room air which is heated by the coil to provide summer tempering (when needed) and winter heating. Room temperature control is achieved by adjusting the flow of hot water or steam thru the coil by a manual or an automatic control valve.



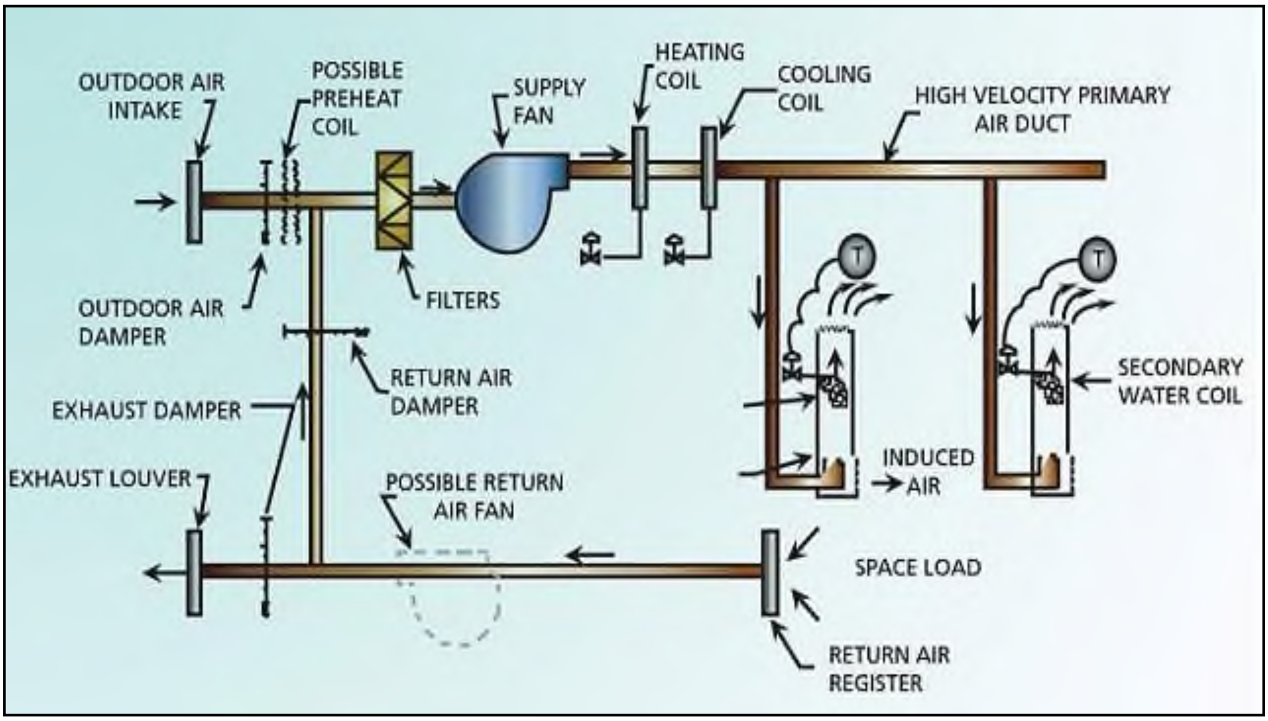


Fig.(6): Typical Constant Volume Induction System

3. All water systems:

In all water systems the fluid used in the thermal distribution system is water, i.e., water transports energy between the conditioned space and the air conditioning plant. When cooling is required in the conditioned space then cold water is circulated between the conditioned space and the plant, while hot water is circulated through the distribution system when heating is required. Since only water is transported to the conditioned space, provision must be there for supplying required amount of treated, outdoor air to the conditioned space for ventilation purposes. Depending upon the number of pipes used, the all water systems can be classified into a 2-pipe system or a 4-pipe system.

A 2-pipe system is used for either cooling only or heating only application, but cannot be used for simultaneous cooling and heating. Figure (7) shows the schematic of a 2-pipe, all water system. As shown in the figure and as the name implies, a 2-pipe system consists of two pipes – one for supply of cold/hot water to the conditioned space and the other for the return water. A cooling or heating coil provides the required cold or hot water. As the supply water flows through the conditioned space, required heat transfer between the water and conditioned space takes place, and the return water flows back to the cooling or heating coil. A flow control valve controls the flow rate of hot or cold water to the conditioned space and thereby meets the required building heating or cooling load. The flow control valve is controlled by the zone thermostat. As already mentioned, a separate arrangement must be made for providing the required amount of ventilation air to the conditioned space. A pressure relief valve (PRV) is installed in the water line for maintaining balanced flow rate. A 4-pipe system consists of two supply pipelines – one for cold water and one for hot water; and two return water pipelines. The cold and hot water are mixed in a required proportion depending upon the zone load, and the mixed water is supplied to the conditioned space. The return water is split into two streams, one stream flows to the heating coil while the other flows to the cooling coil.

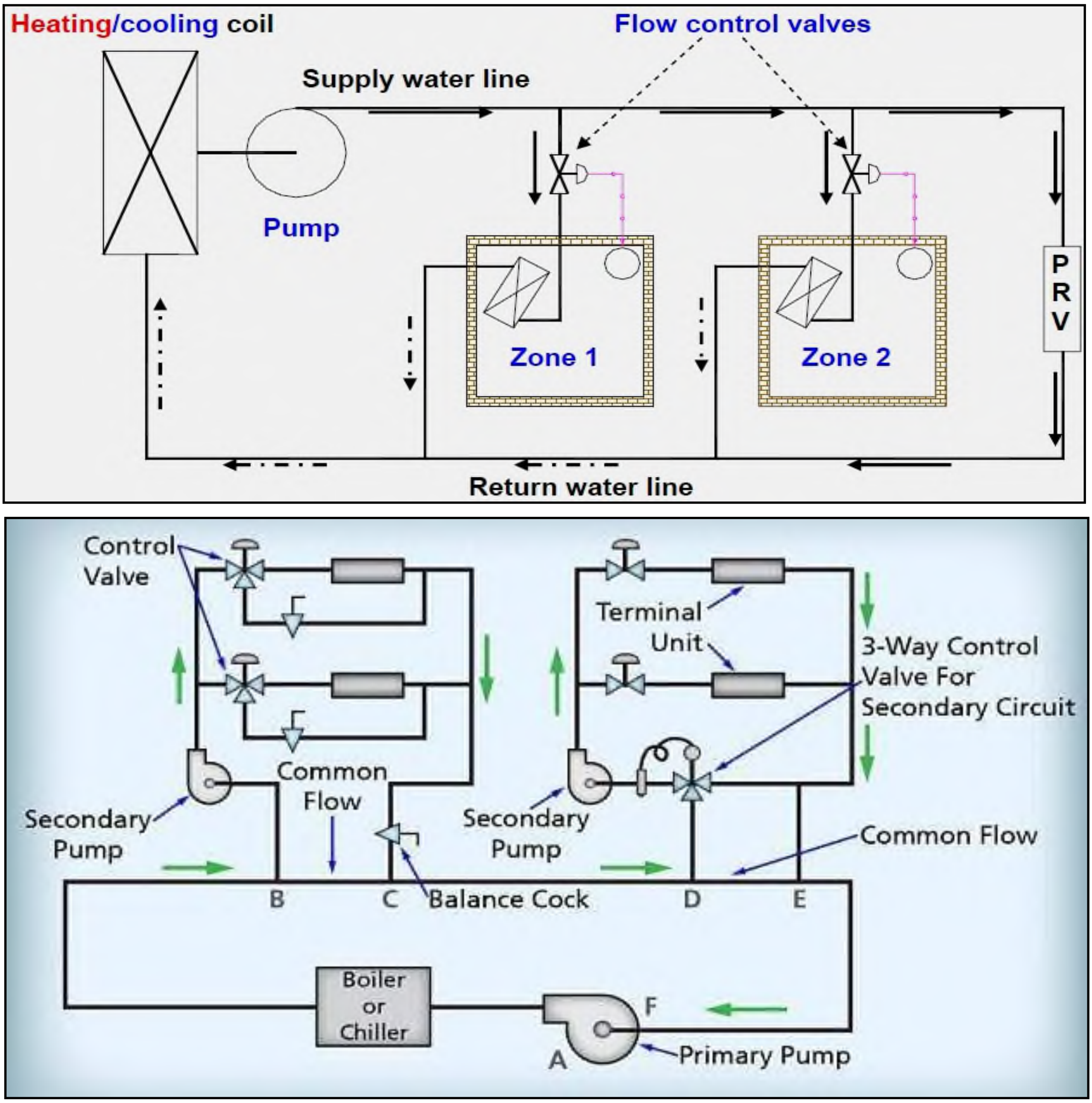


Fig. (7): Two and Three Pipes , All Water System

Heat transfer between the cold/hot water and the conditioned space takes place either by convection, conduction or radiation or a combination of these. The cold/hot water may flow through bare pipes located in the conditioned space or one of the following equipment can be used for transferring heat:

1. Fan coil units
2. Convectors
3. Radiators .

A fan coil unit is located inside the conditioned space and consists of a heating and/or cooling coil, a fan, air filter, drain tray and controls. Figure (8) shows the schematic of a fan coil unit used for cooling applications. As shown in the figure, the basic components of a fan coil unit are: finned tube cooling coil, fan, air filter, insulated drain tray with provision for draining condensate water and connections for cold water lines. The cold water circulates through the finned tube coil while the blower draws warm air from the conditioned space and blows it over the cooling coil.

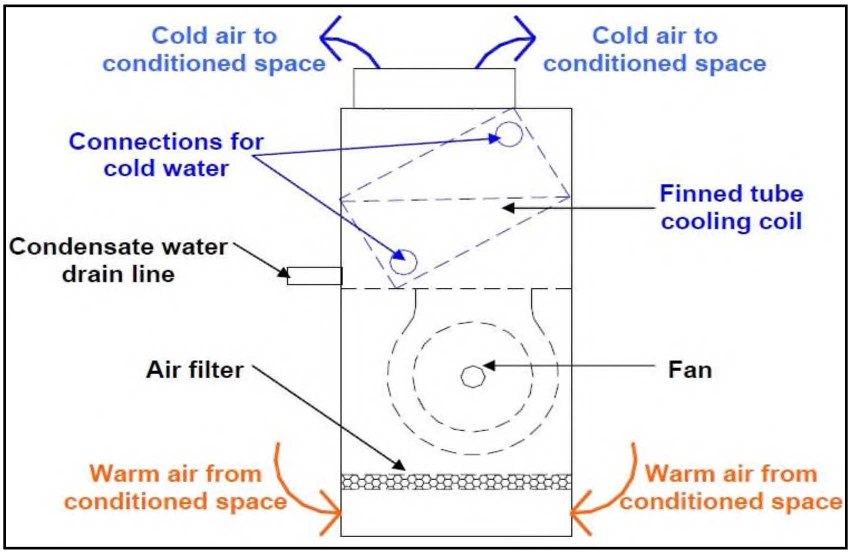
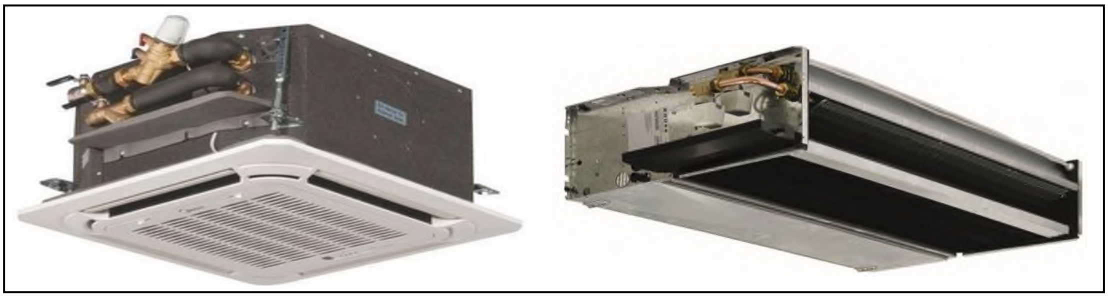


Fig. (8): Fan Coil Unit (FCU)



These are room air conditioners but use chilled water instead of refrigerant. Units can be floor or ceiling mounted. The chilled water is piped to a finned heat exchanger as in a fan convector.
A fan blows room air across the heat exchanger and cool air is emitted into the room, as shown below.

Fan coil units may be looked upon as being small air handling units located in rooms and they can be piped with chilled water for cooling and low temperature hot water (LTHW) for heating if necessary.

In a radiator shown in Fig. below, the heat transfer between the coil and the surrounding air is primarily by radiation. Some amount of heat is also transferred by natural convection. Radiators are widely used for heating applications.

Advantages of all water systems:

1. The thermal distribution system requires very less space compared to all air.
2. Individual room control is possible, and at the same time the system offers all the benefits of a large central system.
3. Since the temperature of hot water required for space heating is small, it is possible to use solar or waste heat for winter heating.
4. It can be used for new as well existing buildings (retrofitting).
5. Simultaneous cooling and heating is possible with 4-pipe systems.

Disadvantages of all water systems:

1. Requires higher maintenance compared to all air systems, particularly in the conditioned space.

2. Draining of condensate water can be messy and may also create health problems if water stagnates in the drain tray. This problem can be eliminated, if dehumidification is provided by a central ventilation system, and the cooling coil is used only for sensible cooling of room air.

3. If ventilation is provided by opening windows or wall apertures, then, it is difficult to ensure positive ventilation under all circumstances, as this depends on wind and stack effects.

4. Control of humidity, particularly during summer is difficult using chilled water control valves.

Applications of all water systems:

All water systems using fan coil units are most suitable in buildings requiring individual room control, such as hotels, apartment buildings and office buildings.

4. Variable Refrigerant Flow/Volume (VRF or VRV) :

Variable Refrigerant Flow (VRF) also known as variable refrigerant volume (VRV) is a flexible method of modern air conditioning system.

The flow of refrigerant can be varied to match the cooling load as heat gains in a room fluctuate, also if reversible heat pumps are used, the heating output can be varied to match the varying heat loss in a room.

An expansion valve or control valve can reduce or stop the flow of refrigerant to each indoor unit, thus controlling its output to the room.

This type of system consists of a number of indoor units (up to 40) connected to one or more external condensing units. The overall refrigerant flow is varied using either an inverter controlled variable speed compressor, or multiple compressors of varying capacity in response to changes in the cooling or heating requirement within the air conditioned space. A control system enables switching between the heating and cooling modes if necessary. In more sophisticated versions, the indoor units may operate in heating or cooling mode independently of others.

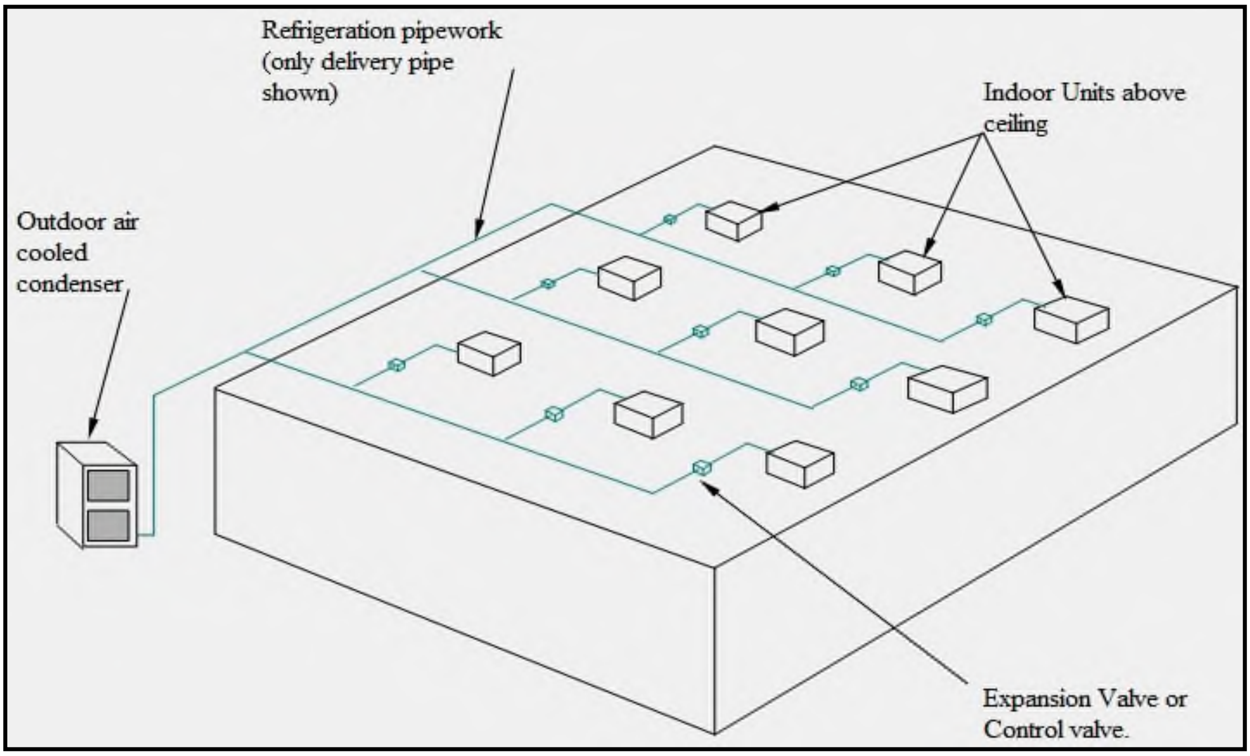
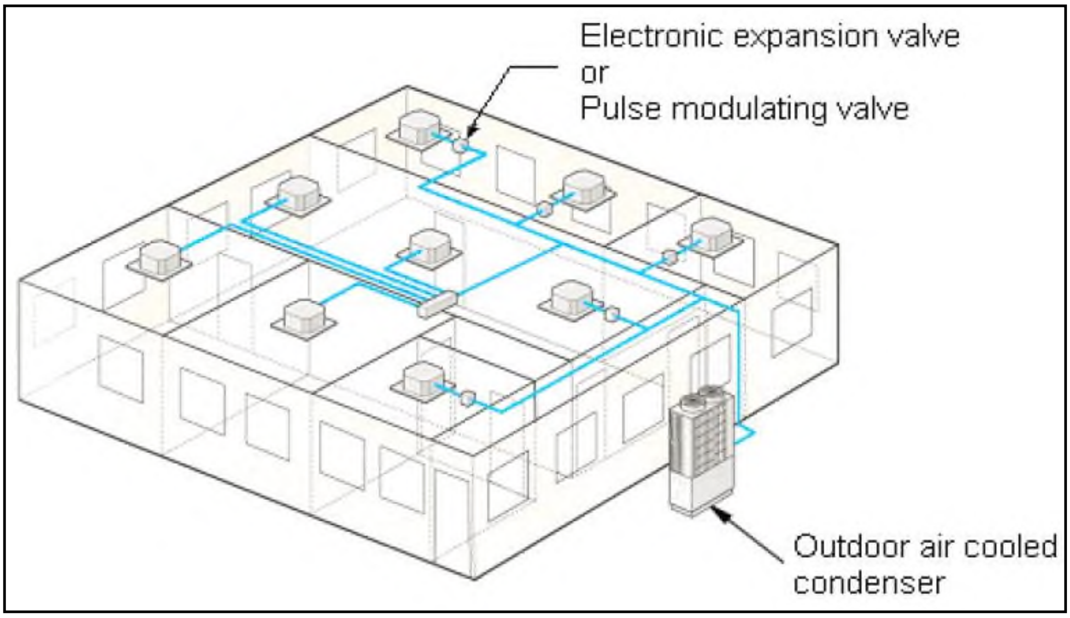
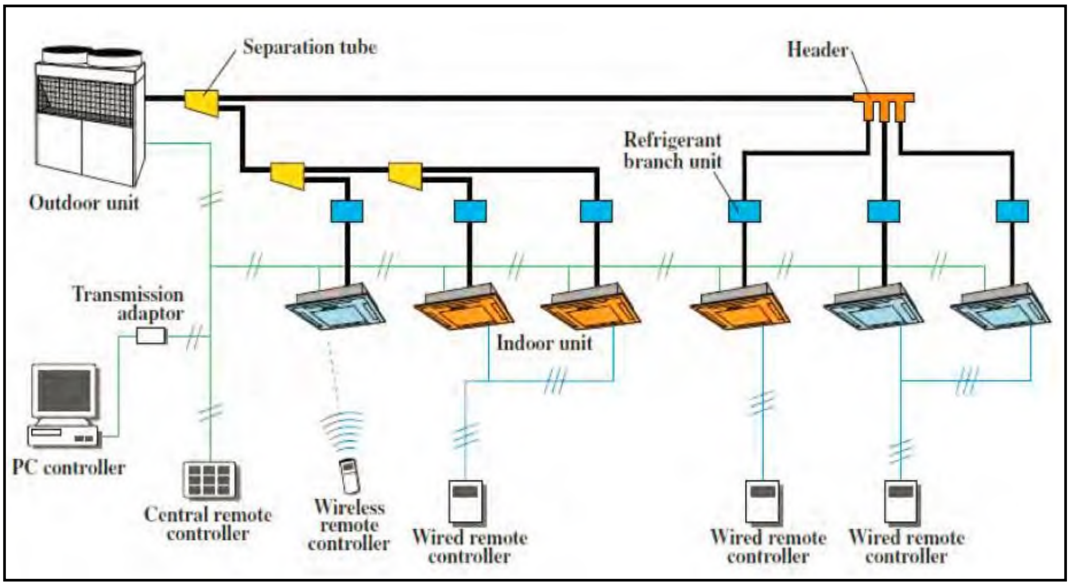


Fig. (9): Basic of Variable Refrigerant Flow (VRF)


Electronic expansion valve
or
Pulse modulating valve
Outdoor air cooled
condenser


Separation tube
Header
Refrigerant
branch unit
Outdoor unit
Transmission
adaptor
Indoor unit
PC controller
Central remote
controller
Wireless
remote
controller
Wired remote
controller
Wired remote
controller
Wired remote
controller


Wall-Mounted
Floor Mounted
4-Way Ceiling
Cassette
2-Way Ceiling
Cassette
Ducted Ceiling Unit

Inverter Drive

An electrical inverter is used to vary the frequency of the power supply from a normal 50Hz enabling fine step speed control of motors (compressors) this in turn varies the flow rate of refrigerant delivered and hence varies the cooling or heating capacity of the indoor units. A typical system is shown above; a Variable Refrigerant Flow (VRF) system has the advantage that it is energy efficient and flexible when compared to constant refrigeration flow systems.

Design Points:

- Refrigerant flow rate is constantly adjusted by an electronic expansion valve in response to load variations as rooms require more or less cooling.
- The electronic expansion valves are situated in the rooms often above the ceiling or in a secure box at low level.
- The units can be either; cooling only, cooling and heating or cooling and heating with heat recovery.
- Scroll compressors (inverter or digital) are often used since they are efficient and quiet, these are usually hermetically sealed.
- Manufacturers produce systems in which 16 indoor units can be connected to a single outdoor air cooled condenser.
- HFC refrigerants are used typically R410A.
- Typical cooling capacity of small indoor units is from 14 kW to 28 kW.
- COP’s (Coefficient of Performance) may be as high.
- Refrigerant liquid lines tend to be about 9.5mm diameter and gas lines about 16mm to 22mm diameter.
- Central control of a VRV system can be achieved by centralized remote controllers BMS control.

Northern Technical University
Technical College of Engineering / Mosul City
Department of Power Mechanics

Fourth Year
Air Conditioning System Design

Chapter One
"Lecture Three"
Types of Air Condition System

Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

❖ Room Air Conditioning Units

These units use refrigerant to transfer cooling effect into rooms. Room A/C units fall into two main categories:

1. Split type
2. Window type.

1. Split Air Conditioners

Split air conditioners have two main parts, the **outdoor unit** is the section which generates the cold refrigerant gas and the **indoor unit** uses this cold refrigerant to cool the air in a space.

The outdoor unit uses a compressor and air cooled condenser to provide cold refrigerant to a **cooling coil** in the indoor unit.

A fan then blows air across the cooling coil and into the room.

The indoor unit types:

a. Wall Mounted
b. Floor Standing
c. Ceiling Cassette
d. Ceiling Concealed Duct

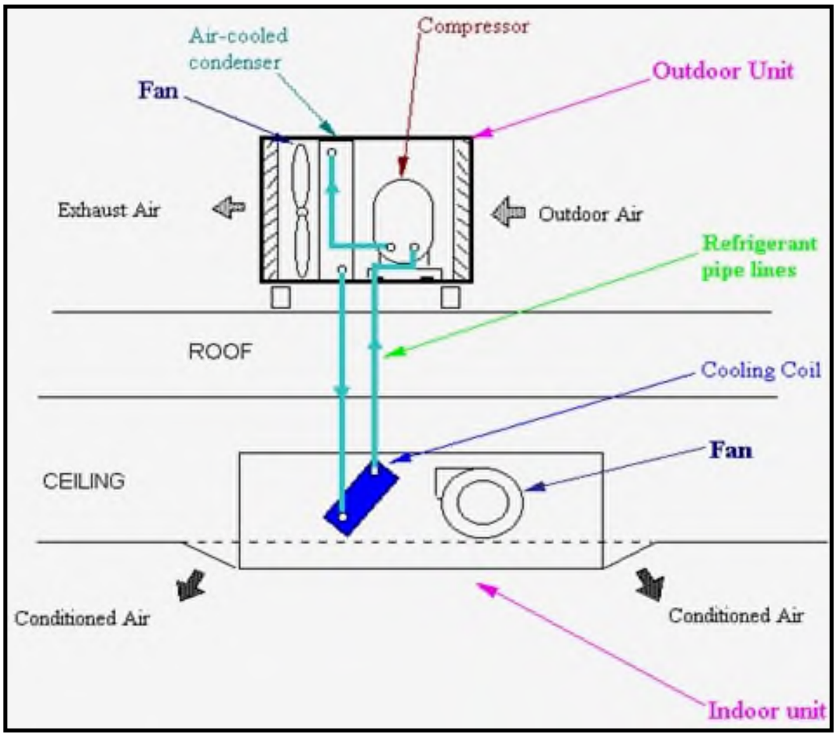


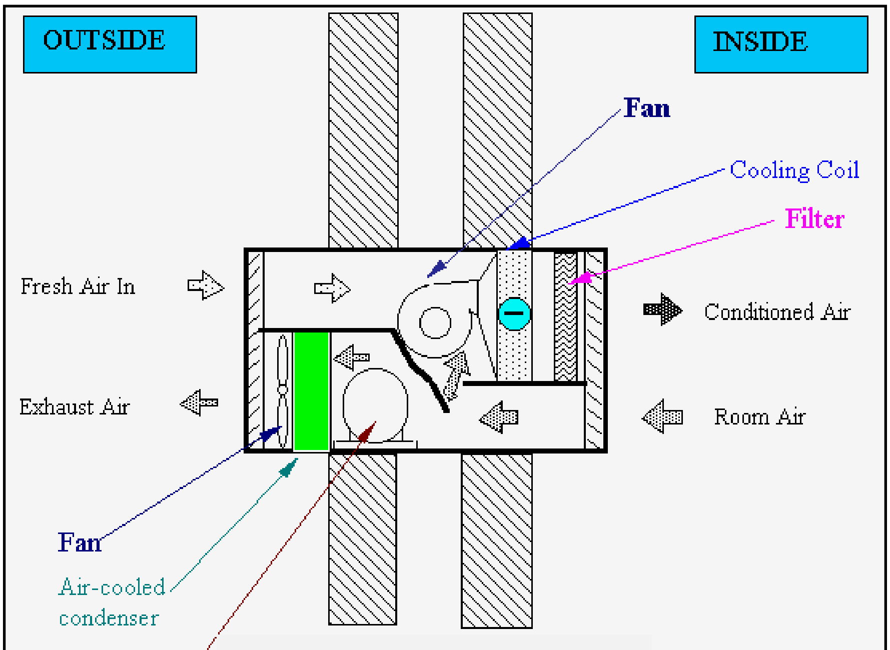
Fig.(11a): Ceiling Cassette Details

Fig.(11b): Types of Indoor Unit

2. Window type:

Window units are more **compact** than split units since all the plant items are contained in one box.

Window units are installed into an appropriate hole in the window and supported from a metal frame.



Window Air Condition Unit

A small **hermetically sealed compressor** is used to provide refrigerant gas at the pressure required to operate the refrigeration cycle.
The condenser is used to condense the refrigerant to a liquid which is then reduced in pressure and piped to the cooling coil.

Choosing an A/C System

Generally central plant systems are used in large **prestigious buildings** where a high quality environment is to be achieved. Cassette units and other split systems can be used together with central plant systems to provide a more **flexible design.**
Each system has its own advantages and the following is a summary of some of the main advantages and disadvantages.

Central Plant Systems Advantages:
1.Noise in rooms is usually reduced if plant room is away from occupied spa
2.The whole building can be controlled from a central control station.
This means that optimum start and stop can be used and a weather compensator can be utilised. Also time clocks can bring air conditioning on and off at appropriate times.
3.Maintenance is centralised in the plant room. Plant is easier to access.

Central Plant Systems - Disadvantages:
1. Expensive to install a complete full comfort air-conditioning system throughout a building.
2. Space is required for plant and to run ductwork both vertically in shafts and horizontally in ceiling spaces.
3. Individual room control is difficult with central plant.
Many systems have been tried such as Variable Air Volume (VAV), dual duct systems and zone re-heaters.

Room Air Conditioning Units - Advantages:

1.Cheaper to install.
2. Individual room control.
3.Works well where rooms have individual requirements.
4.No long runs of ductwork.
5.Can be used to heat as well as cool if a reversing valve is fitted.

Room Air Conditioning Units Disadvantages:

1.Sometimes the indoor unit fan becomes noisy.
2.Noisy compressor in outdoor unit.
3.Each unit or group of units has a filter, compressor and refrigeration pipework that needs periodic maintenance and possible re-charging.
4.The installation may require long runs of refrigerant pipework which, if it leaks into the building, can be difficult to remedy.
5.Not at robust as central plant.
6.The majority of room air conditioners just recirculate air in a room with no fresh air supply although most manufacturers make units with fresh air capability.
7.Cooling output is limited to about 9 kW maximum per unit;
therefore many units would be required to cool rooms with high heat gains.

Fan coil units are similar is some respects to Room Air Conditioners:
Fan Coil Units - Advantages:

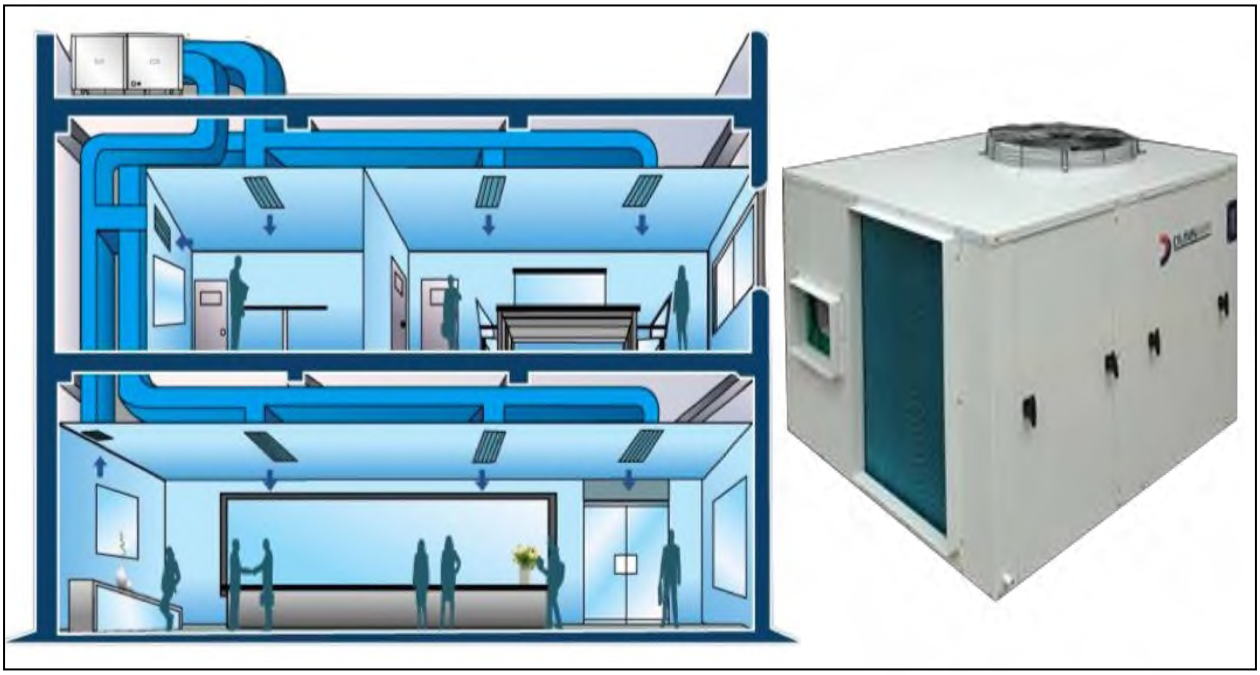
1.Cheaper to install than all air central plant system.
2. Individual room control.
3.Works well where rooms have individual requirements.
4.No long runs of ductwork.
5.Can be used to heat as well as cool if 3 or 4-pipe system is used.

Fan Coil Units Disadvantages:

1. Sometimes the indoor unit fan becomes noisy, especially when the speed is changing with in-built controls.
2. Each unit requires maintenance.
3. Long runs of pipework are required.
4. A chiller is still required to produce chilled water therefore they do not save as much in plant and plant room space as room air conditioners. Also boilers will be required if heating mode is installed.
5. Fresh air facility may not be installed.
6. Cooling output is limited to about 5 kW.

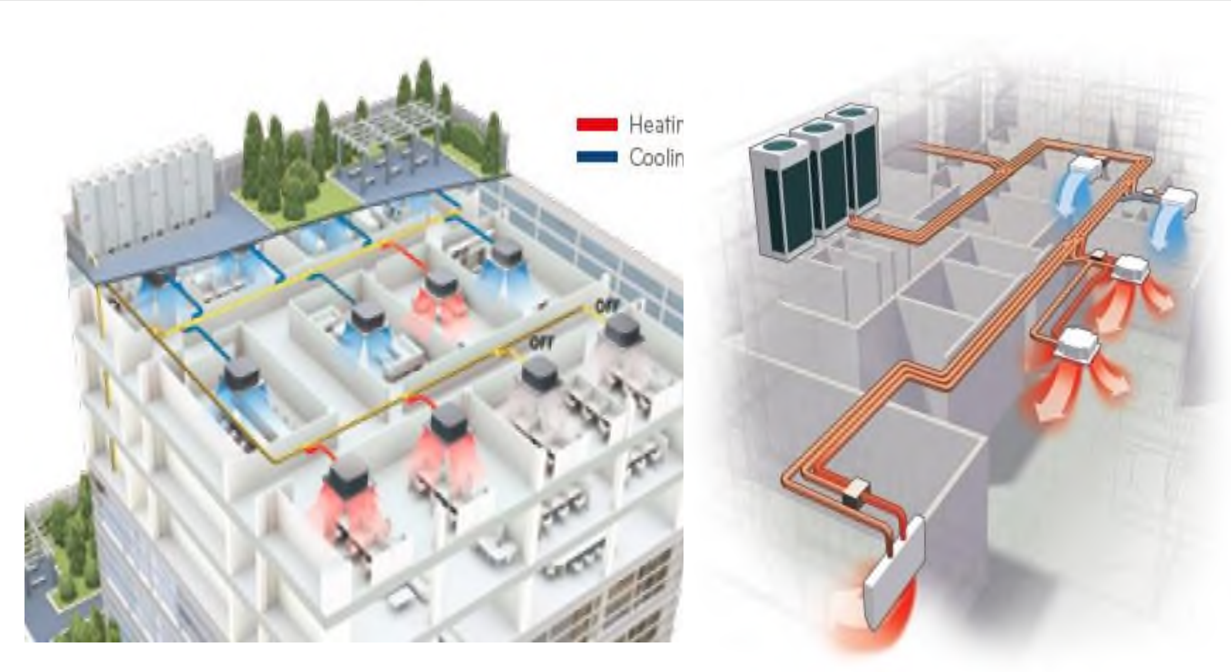
Some Useful Picture:

All Air System (Package Air conditioner units) (Rooftop Units)

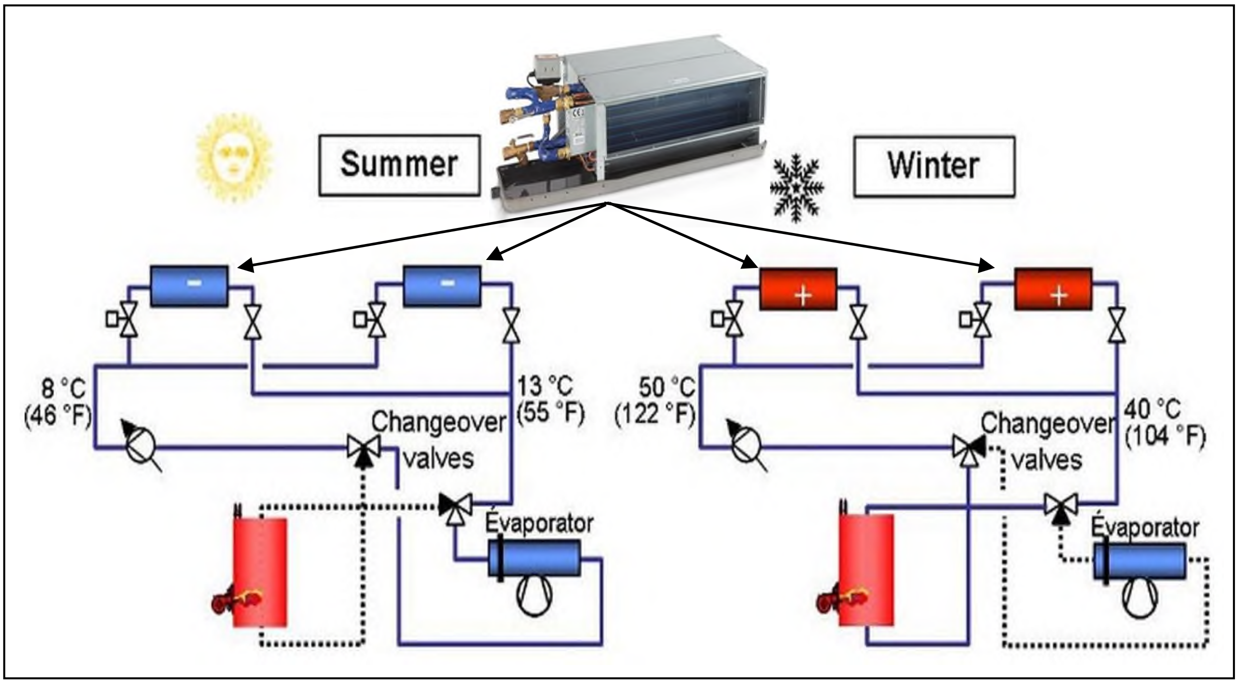


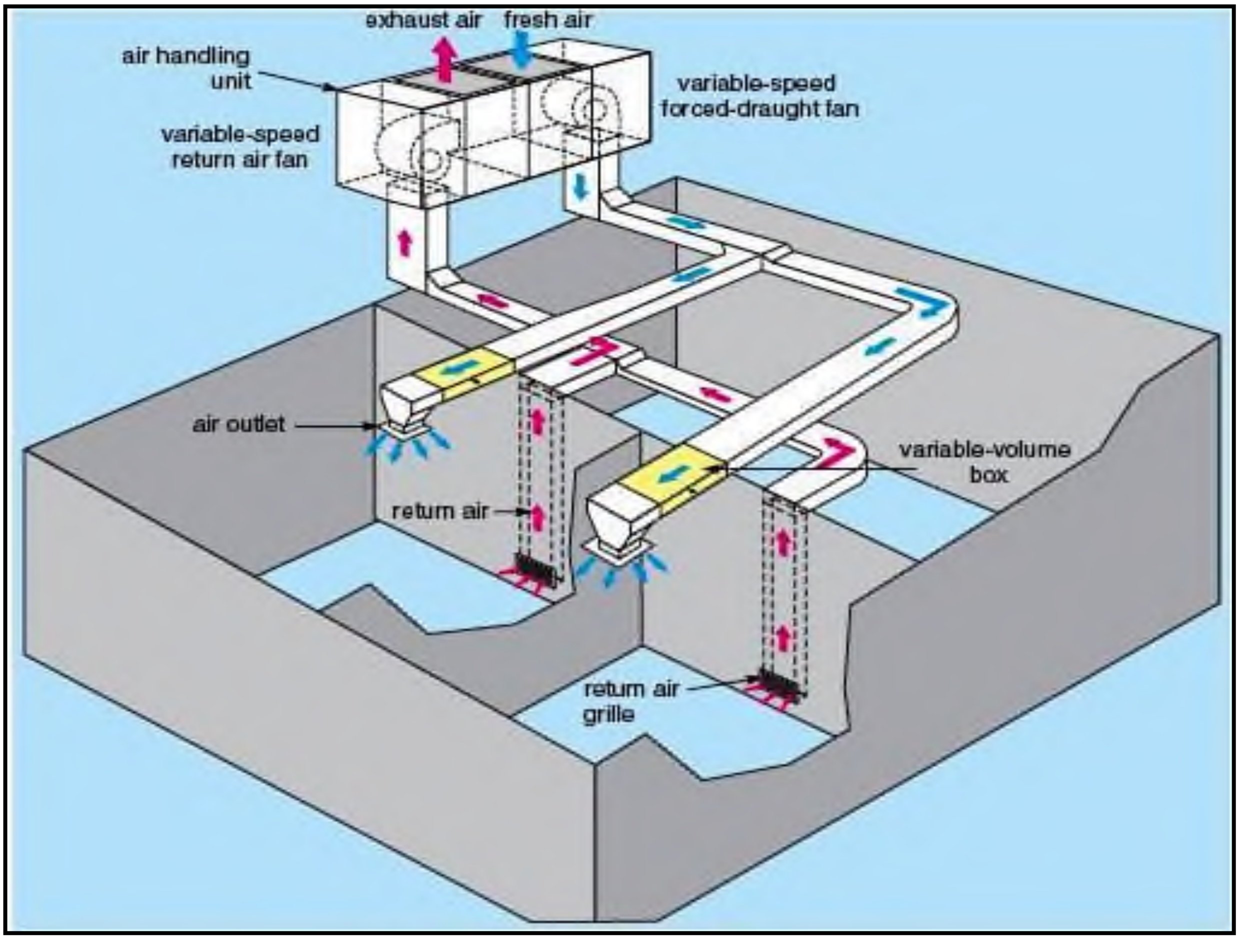
Air –Water System (FAHU, AHU)

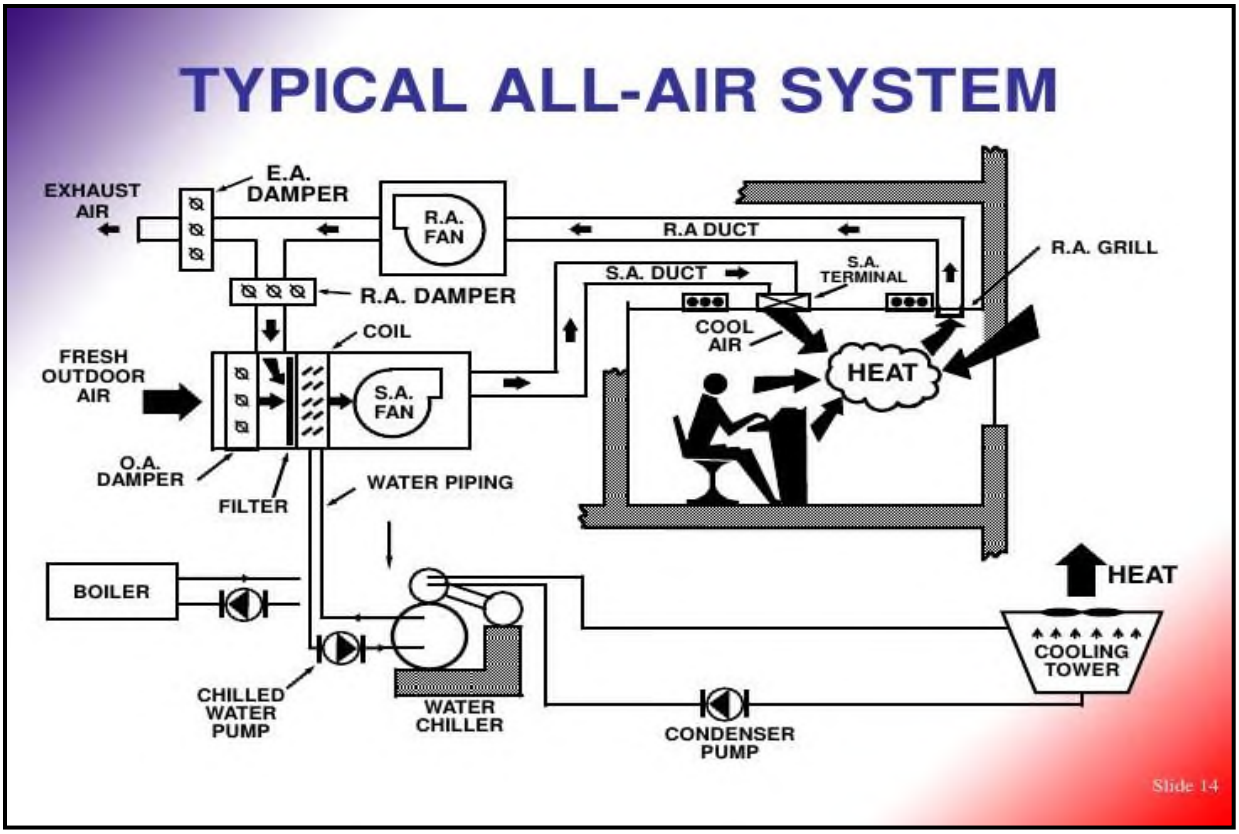
Variable Refrigerant Flow (VRF)

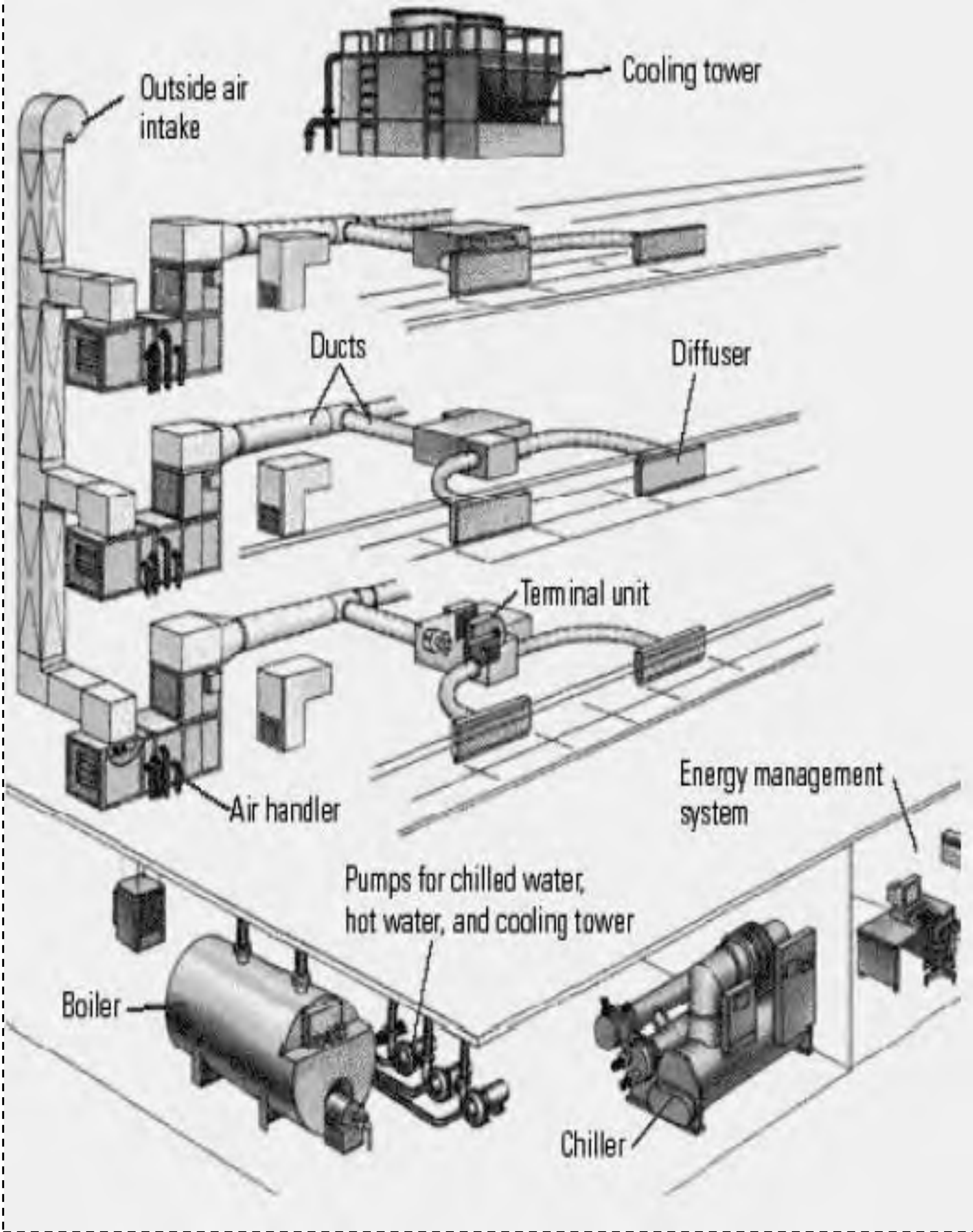


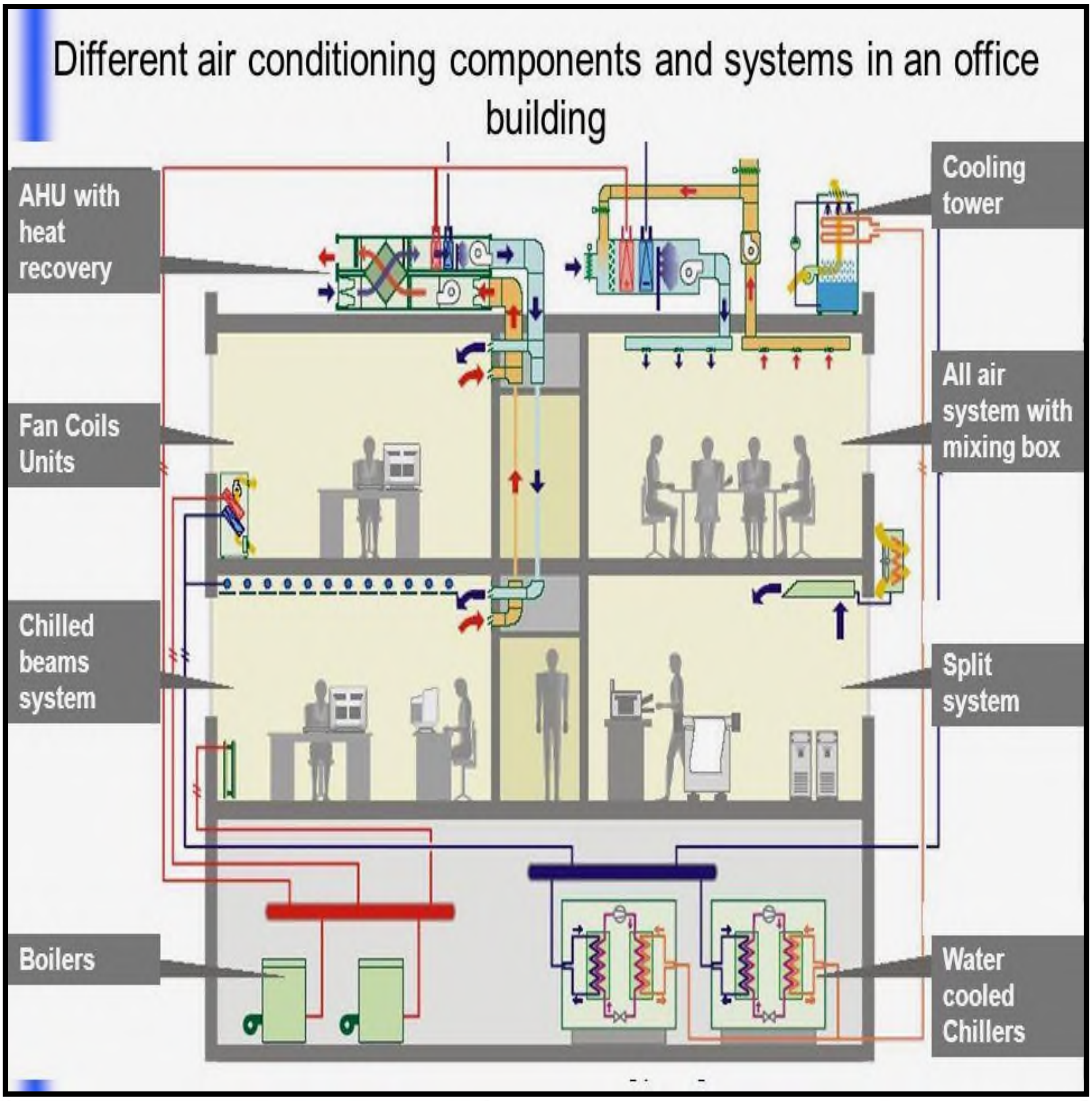
All Water System (FCU)

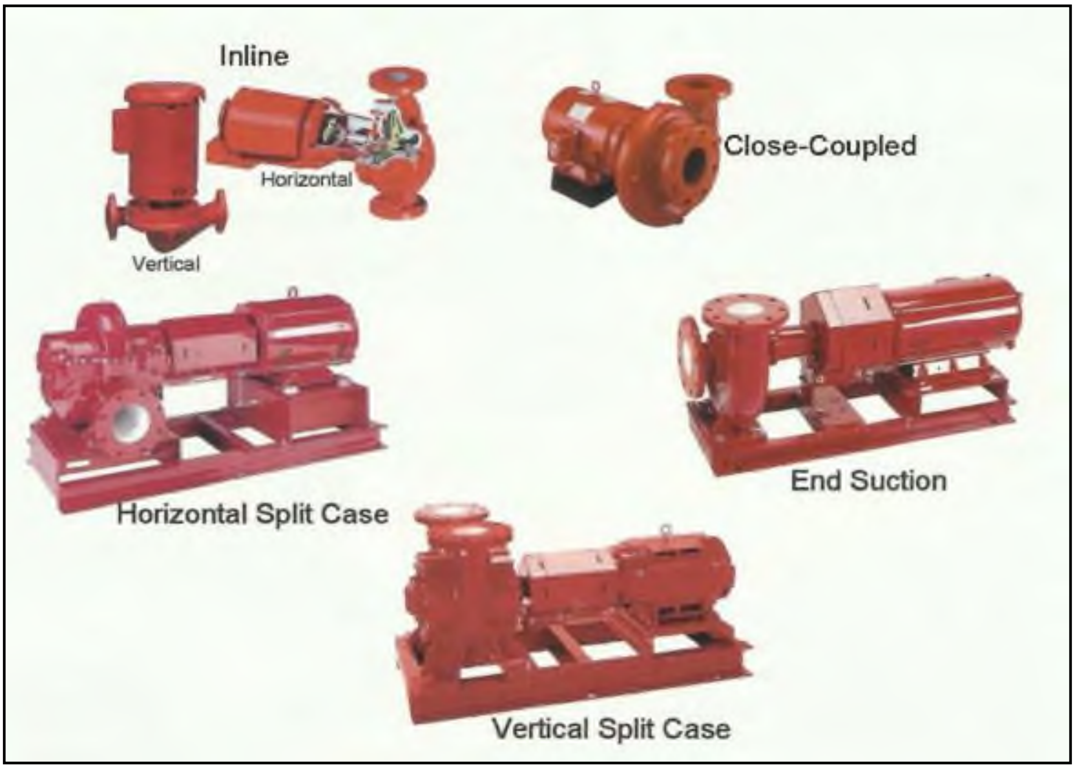


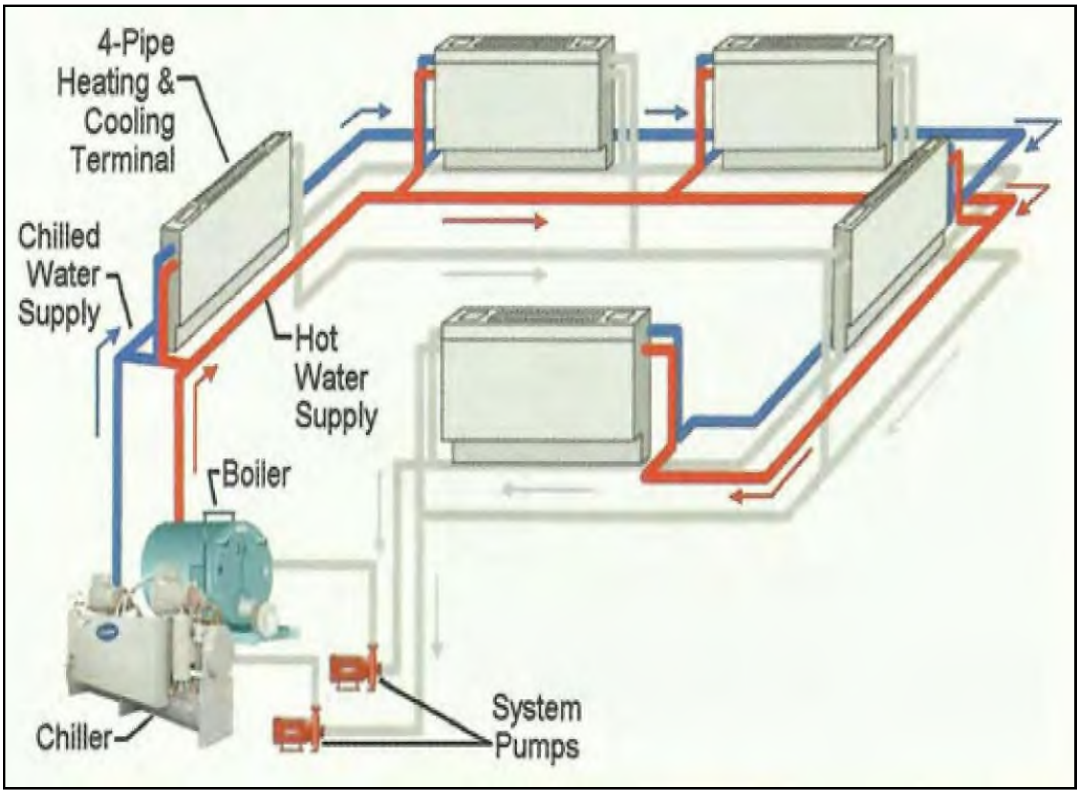

exhaust air
fresh air
air handling unit
variable-speed forced-draught fan
variable-speed return air fan
air outlet
return air
variable-volume box
return air grille

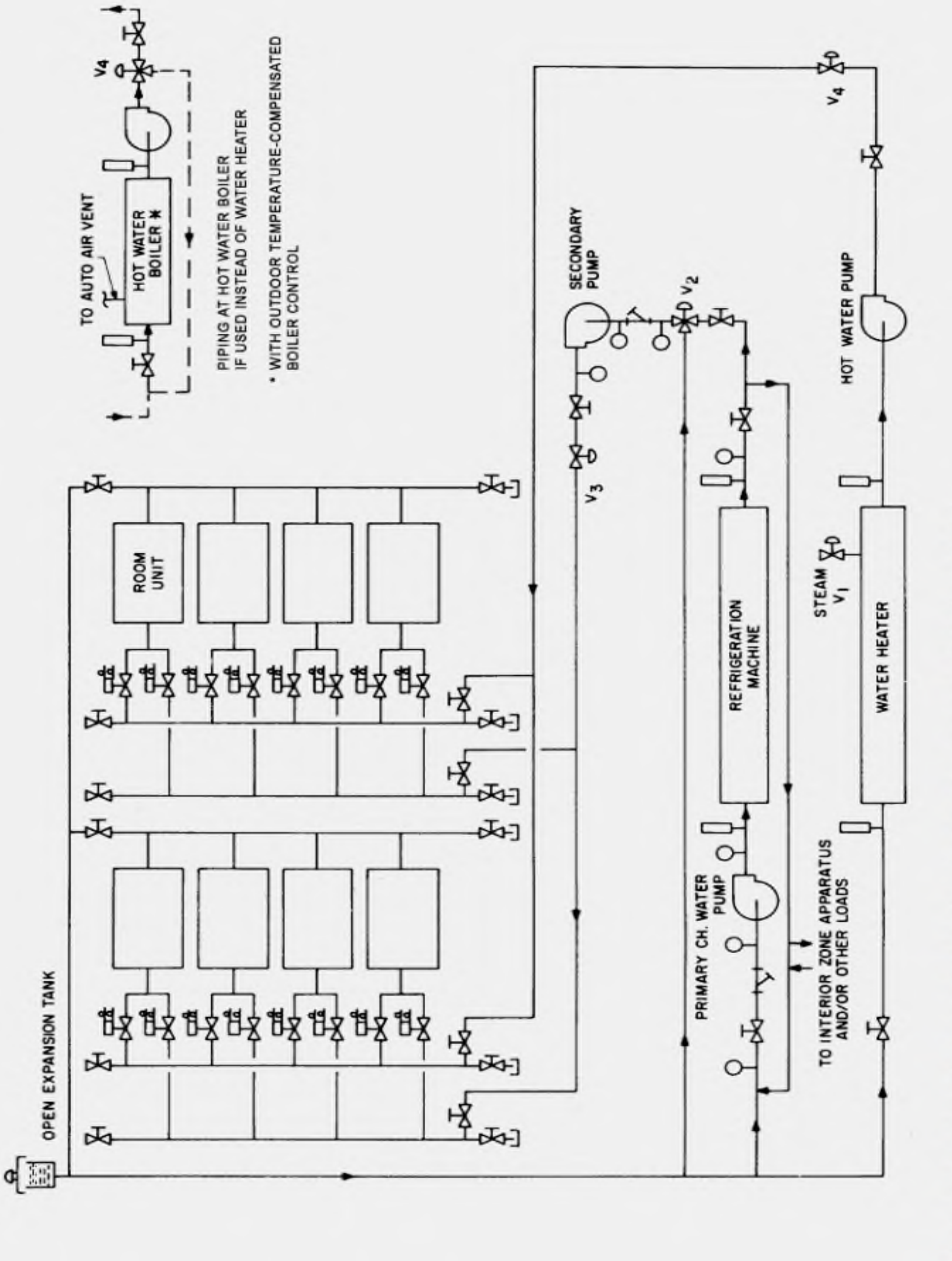

TYPICAL ALL-AIR SYSTEM
EXHAUST AIR
E.A. DAMPER
R.A. FAN
R.A DUCT
S.A. DUCT
S.A. TERMINAL
R.A. GRILL
R.A. DAMPER
COIL
COOL AIR
HEAT
FRESH OUTDOOR AIR
S.A. FAN
O.A. DAMPER
FILTER
WATER PIPING
BOILER
HEAT
COOLING TOWER
CHILLED WATER PUMP
WATER CHILLER
CONDENSER PUMP
Slide 14


Cooling tower
Outside air intake
Ducts
Diffuser
Terminal unit
Air handler
Energy management system
Pumps for chilled water, hot water, and cooling tower
Boiler
Chiller


Different air conditioning components and systems in an office building
AHU with heat recovery
Fan Coils Units
Chilled beams system
Boilers
Cooling tower
All air system with mixing box
Split system
Water cooled Chillers


Inline
Horizontal
Vertical
Close-Coupled
Horizontal Split Case
End Suction
Vertical Split Case


4-Pipe Heating & Cooling Terminal
Chilled Water Supply
Hot Water Supply
Boiler
Chiller
System Pumps



Piping schematic for a four-pipe fan-coil system (Carrier).

Problems:

State the suitable A/C system for the project as mention below:

a- Shopping Mall.

b- The chicken coop.

Report:

State & Select appropriate Air Conditioning (A/C) system for residential, commercial building and industrial application as show below with mention cause of your selection:

Note: The student must deliver the report after one a week only without any delay.

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Northern Technical University
Technical College of Engineering
Department of Power Mechanics Techniques

Fourth Year

Air Conditioning System Design

Chapter Two
"Lecture One"
Advanced Air Duct Design

Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

Chapter Two
Advanced Air Duct Design

1. **Class** : Fourth Year
2. **Subject**: Advanced Air Duct Design
3. **Number of weeks:** Thre weeks + One week Tutorial

4. Central idea: Study the methods of air duct design, when use each method, how to distribution the air within zone and how to calculate the friction loss in the straight and fitting duct

5. **The Test & Problems** :

Advanced Air Duct Design

Introduction:

Correct air diffusion, as well as the proper quantity of conditional air conditioned, is essential for comfortable conditions in forced systems. A well designed air duct system, either commercial or industrial, must consider most of the following system design factors: (1) space availability; (2) space air diffusion; (3) noise levels; (4) duct leakage; (5) duct heat gain and losses; (6) balancing; (7) fire and smoke control; (8) initial investment cost; (9) system operating cost.

Any deficiency in duct design may result in a system that does not operate properly. These deficiencies include system, which are excessively expensive to own and / or operate. Poor air distribution can cause discomfort, and lack sound attenuators may result in objectionable noise levels. Poor duct construction or lack of duct sealing can cause inadequate airflow rates at the terminal units. Inadequate airflow is also caused by excessive heat gains/losses, which can be avoided with proper duct insulation. Poor design of the branches concerning main ducts may result in unbalanced systems. As a part of our course, we redesigned the duct system in the building. Moreover, we resized all the ducts depending on the actual data that we have calculated.

Duct Design Methods

The most common methods of air duct system design are: (1) equal friction, velocity reduction, static regain and variations such as total pressure, and constant velocity. The choice of design method is the designer's and the system design with the minimum owning and operating cost depends on both the application and ingenuity of the designer. No single duct design method will automatically produce the most economical duct system for all conditions. Air-conditioning and ventilation systems, and exhaust systems conveying vapors, gases, and smoke are generally designed by the equal friction method. Exhaust systems conveying particulates are designed with a minimum constant velocity.

Equal Friction Method:

The principle of this method is to size a system's ductwork for a constant pressure loss per unit length of duct. At the higher air flow rates, however, it may be necessary to limit the velocity so as not to generate objectionable noises. Once the system is sized, the total pressure losses for the main and branch sections from junction-to-junction /fan/terminal may be calculated and the total pressure grade line plotted.

After the system has been designed and the total pressure grade line plotted, sections of ductwork may be redesigned to achieve an approximate balance at the junctions without relying entirely on balancing dampers. If the pressure available for the duct system is known, as it is for packaged equipment, this pressure can be divided by the total equivalent length of the run with the apparent highest resistance, to obtain a design friction loss value per unit length. After the system is sized, the system total pressure requirements can be compared to that available, and if there is a considerable difference, a redesign and recalculation are necessary.

Velocity Reduction Method:

This method consists of selecting the velocity at the fan discharge, and designing for progressively lower velocities in the main of each junction or branch duct. The return air ductwork is sized similarly, starting with the highest velocity at the fan suction and decreasing progressively in the direction of the return intakes. With the ducts sized and the fittings known, the total pressure losses can be calculated, the pressure gradients plotted, and the minimum pressure loss or critical path of the system established.

A refinement of this method involves sizing the branch ducts to dissipate the pressure available at the entrance to each. The pressure loss of the ductwork between the fan and first branch take-off is subtracted from the total fan pressure to obtain the available pressure at the first junction. Through trial, a branch velocity is found that results in the branch pressure loss being equal to or less than the pressure available. The procedure is repeated for each branch.

Static Regain Method:

The static regain method is design procedure in which the ducts are sized so that the increase in static pressure (static regain) at each take-off offsets the pressure loss of the succeeding section of ductwork. This method is especially suited for high velocity installations having long runs with many take-offs or terminal units. With this design procedure, approximately the same static pressure exists at the entrance to each branch, which simplifies outlet or terminal unit selection and system balancing. With the ductwork sized by this method, the system's total pressure losses can be calculated. The major disadvantage of this method, however, is that excessively large ducts (low velocities) result at the end of long duct runs.

The total pressure design method is adaptation of the static regain method. This method is advantageous since a designer has knowledge of the intermediate system pressures and control of duct sizes and velocities.

Constant Velocity Method

Since the constant velocity design method is generally applied to exhaust systems conveying particulates, and since these systems are usually round, this method is applied for round ducts only.

Duct Design Procedures

The general procedure for duct design is as follows:

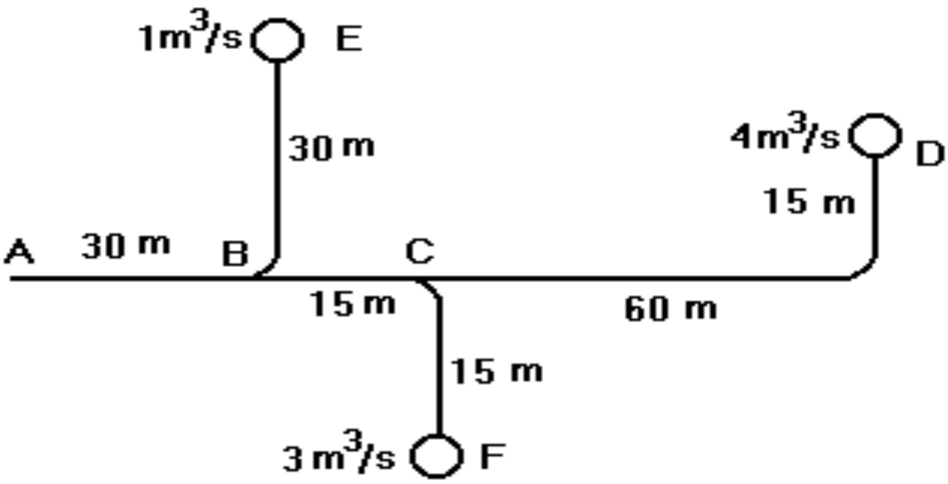
1. Study the plans of the building and arrange the supply and return outlets to provide proper distribution of air within each space. Adjust calculated actual air quantities for duct heat gains or losses and duct leakage. Also, adjust the supply, return, and/or exhaust air quantities to meet space pressurization requirements.
2. Select outlet sizes from manufacturers’ data.
3. Sketch the duct system, connecting the supply outlets and return intakes with the central station apparatus, taking recognizance of the building construction, and avoiding all structural obstructions and equipment. The space allocated for the supply and return ducts often dictates the system layout and the shape of the ductwork.
4. Determine the size of main and all branches by the selected design method.
5. Calculate the total pressure requirements of all duct sections, both supply and return, and then plot the total pressure grade line.
6. To design a system with the minimum owning and operating costs, repeat steps 4 and 5 with different duct sizes. It is necessary to estimate the cost of the initial design and the incremental cost variations due to the redesigns.
7. Layout the system in detail. If significant duct routing and fitting variations have occurred from the original design, recalculate the pressure losses.
8. Redesign the duct branches to minimize the balancing necessary by dampers.
9. Analyze the design for objectionable noise levels and specify sound attenuators as necessary.
10. Select the fan.

Equal Friction Method: **(Review Lecture)**

This method is used to determine the diameter of air duct, so that the duct friction loss per unit length at various duct section always remain constant. The final dimensions of sized ducts should be rounded to standard size. The procedure of this method is as follows:

1. Select a suitable velocity in the main duct from sound level considerations as given in the table.
2. Knowing the air flow rate from the load estimation.
3. The sized of the main duct and friction loss are determined.
4. The remaining ducts are then sized respectively.

Example:



The system shown below, find the size of the main duct and branches.

First we will use the Equal friction method.

The main duct A-B.

The total flow rate is,

$$Q_t = Q_1 + Q_2 + Q_2$$

$$Q_t = 4 + 3 + 1 = 8 \quad m^3/s$$

We assume the velocity in the main duct A – B and size the duct

$$V = 8 \quad m/s$$

$$Q_t = \frac{\pi}{4} d^2 V$$

$$d = \sqrt{\frac{4 \times 8}{\pi \times 8}} = 1.128 \quad m$$

Friction losses in the main duct A-B

$$\Delta P = \rho \frac{fL}{d} \frac{V^2}{2}$$

Assume the roughness of the surface from the table and calculate the value,

$$\frac{\varepsilon}{d} = \frac{0.00015}{1.128} = 0.000133$$

We can calculate the Reynolds number for air in the main duct after finding the viscosity and density of the air from the table.

The properties of the air is at 25 oC.

$$\text{Re} = \frac{\rho V d}{\mu} = \frac{1.184 \times 8 \times 1.128}{18.413 \times 10^{-6}} = 5.80 \times 10^5$$

From Moody chart, we can find the fraction factor, f

$$f = 0.0145$$

$$\Delta P = 1.184 \times \frac{0.0145 \times 30}{1.128} \times \frac{8^2}{2} = 14.61 \quad Pa$$

$$\frac{\Delta P}{L} = 0.487 \quad Pa/m$$

The branch B-E.

$$Q = AV$$

$$V = \frac{4Q}{\pi d^2}, \quad \frac{V^2}{2} = \frac{8Q^2}{\pi^2 d^4}$$

$$\frac{\Delta P}{L} = \rho \frac{f}{d} \frac{8Q^2}{\pi^2 d^4}$$

$$d = \sqrt[5]{\frac{8\rho f Q^2}{\pi^2 \frac{\Delta P}{L}}} = \sqrt[5]{\frac{8 \times 1.184 \times 0.0145 \times 1}{\pi^2 \times 0.487}} = 0.491 \quad m$$

$$V = \frac{4Q}{\pi d^2} = 5.281 \quad m/s$$

By using the value of d and V, we can calculate the Reynolds number again and modify the value of d and V if possible as follows,

The first modification of d and V gives,

$$\mathrm{Re} = \frac{\rho V d}{\mu} = \frac{1.184 \times 5.281 \times 0.491}{18.413 \times 10^{-6}} = 1.66 \times 10^5$$

$$\frac{\varepsilon}{d} = \frac{0.00015}{0.491} = 0.000305$$

$$f = 0.016$$

$$d = 0.501 \quad m$$

$$V = 5.073 \quad m/s$$

The second modification of d and V gives,

$$\mathrm{Re} = \frac{\rho V d}{\mu} = \frac{1.184 \times 5.073 \times 0.501}{18.413 \times 10^{-6}} = 1.63 \times 10^5$$

$$\frac{\varepsilon}{d} = \frac{0.00015}{0.513} = 0.000299$$

$$f = 0.016$$

The same fraction factor, so the value of d and V does not change.

$$d = 0.501 \quad m$$

$$V = 5.073 \quad m/s$$

We can check the volume flow rate is less or higher the design value,

$$Q_{cal} = AV = \frac{\pi}{4} d^2 V = \frac{\pi}{4} \times 0.501^2 \times 5.073 = 1.000069 \quad m^3/s$$

This is acceptable value.

The branch B-C.

$$d = \sqrt[5]{\frac{8\rho f Q^2}{\pi^2 \frac{\Delta P}{L}}} = \sqrt[5]{\frac{8 \times 1.184 \times 0.016 \times 7^2}{\pi^2 \times 0.487}} = 1.091 \quad m$$

$$V = \frac{4Q}{\pi d^2} = \frac{4 \times 7}{\pi \times 1.091^2} = 7.489 \quad m/s$$

The first modification of d and V gives,

$$\text{Re} = \frac{\rho V d}{\mu} = \frac{1.184 \times 7.79 \times 1.0696}{18.413 \times 10^{-6}} = 5.25 \times 10^5$$

$$\frac{\varepsilon}{d} = \frac{0.00015}{1.091} = 0.000137$$

$$f = 0.0146$$

The same fraction factor we used, so the value of d and V does not change.

$$d = 1.071 \quad m$$

$$V = 7.768 \quad m/s$$

The second modification of d and V gives,

$$Re = \frac{\rho V d}{\mu} = \frac{1.184 \times 7.768 \times 1.071}{18.413 \times 10^{-6}} = 5.35 \times 10^{5}$$

$$\frac{\varepsilon}{d} = \frac{0.00015}{1.071} = 0.00014$$

$$f = 0.0146$$

The same fraction factor we used, so the value of d and V does not change.

$$d = 1.071 \quad m$$

$$V = 7.768 \quad m/s$$

We can check the volume flow rate is less or higher the design value,

$$Q_{cal} = AV = \frac{\pi}{4} d^2 V = \frac{\pi}{4} \times 1.071^2 \times 7.768 = 6.998 \quad m^3/s$$

This is acceptable value.

The branch C-F.

$$d = \sqrt[5]{\frac{8\rho f Q^2}{\pi^2 \frac{\Delta P}{L}}} = \sqrt[5]{\frac{8 \times 1.184 \times 0.0146 \times 3^2}{\pi^2 \times 0.487}} = 0.7632 \quad m$$

$$V = \frac{4Q}{\pi d^2} = \frac{4 \times 3}{\pi \times 0.7621^2} = 6.557 \quad m/s$$

The first modification of d and V gives,

$$Re = \frac{\rho V d}{\mu} = \frac{1.184 \times 6.557 \times 0.7632}{18.413 \times 10^{-6}} = 3.22 \times 10^{5}$$

$$\frac{\varepsilon}{d} = \frac{0.00015}{0.7632} = 0.000197$$

$$f = 0.0163$$

$$d = 0.780 \quad m$$

$$V = 6.275 \quad m/s$$

The second modification of d and V gives,

$$\text{Re} = \frac{\rho V d}{\mu} = \frac{1.184 \times 6.275 \times 0.780}{18.413 \times 10^{-6}} = 3.15 \times 10^{5}$$

$$\frac{\varepsilon}{d} = \frac{0.00015}{0.780} = 0.000192$$

$$f = 0.0164$$

The same fraction factor we used, so the value of d and V does not change.

$$d = 0.780 \quad m$$

$$V = 6.275 \quad m/s$$

We can check the volume flow rate is less or higher the design value,

$$Q_{cal} = AV = \frac{\pi}{4} d^{2} V = \frac{\pi}{4} \times 0.78^{2} \times 6.275 = 2.9984 \quad m^{3}/s$$

This is acceptable value.

The branch C-D.

$$d = \sqrt[5]{\frac{8 \rho f Q^{2}}{\pi^{2} \frac{\Delta P}{L}}} = \sqrt[5]{\frac{8 \times 1.184 \times 0.0164 \times 4^{2}}{\pi^{2} \times 0.487}} = 0.8764 \quad m$$

$$V = \frac{4Q}{\pi d^{2}} = \frac{4 \times 4}{\pi \times 0.8551^{2}} = 6.630 \quad m/s$$

The first modification of d and V gives,

$$\text{Re} = \frac{\rho V d}{\mu} = \frac{1.184 \times 6.630 \times 0.8764}{18.413 \times 10^{-6}} = 3.74 \times 10^{5}$$

$$\frac{\varepsilon}{d} = \frac{0.00015}{0.8764} = 0.000171$$

$$f = 0.0157$$

$$d = 0.869 \quad m$$

$$V = 6.747 \quad m/s$$

The second modification of d and V gives,

$$\mathrm{Re} = \frac{\rho V d}{\mu} = \frac{1.184 \times 6.747 \times 0.869}{18.413 \times 10^{-6}} = 3.77 \times 10^{5}$$

$$\frac{\varepsilon}{d} = \frac{0.00015}{0.869} = 0.000173$$

$$f = 0.0159$$

$$d = 0.869 \quad m$$

$$V = 6.747 \quad m/s$$

The difference between second and first modification is not so much, so the value of d and V does not change.

We can check the volume flow rate is less or higher the design value,

$$Q_{cal} = AV = \frac{\pi}{4} d^2 V = \frac{\pi}{4} \times 0.869^2 \times 6.747 = 4.002 \quad m^3/s$$

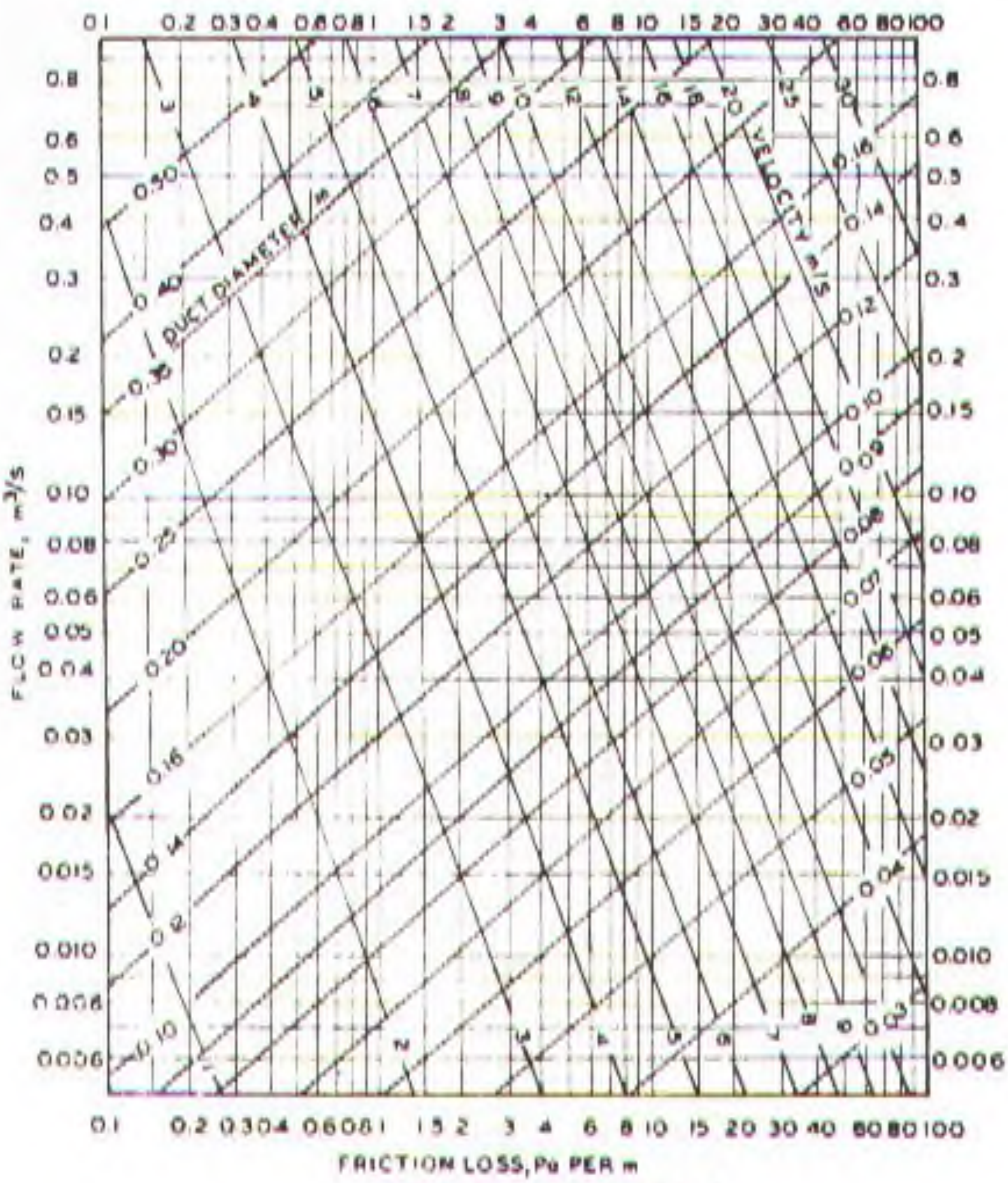
The results of calculation must be illustrated in a table to use it in the calculation of air fan power.

Results

Section	L (m)	Q (m3/s)	V (m/s	d (m)	Qcal
A-B	30	8	8.00	1.128	8.000
B-C	15	7	7.77	1.071	6.998
C-D	75	4	6.75	0.869	4.002
B-E	30	1	5.07	0.501	1.000
C-F	15	3	6.275	0.780	2.998

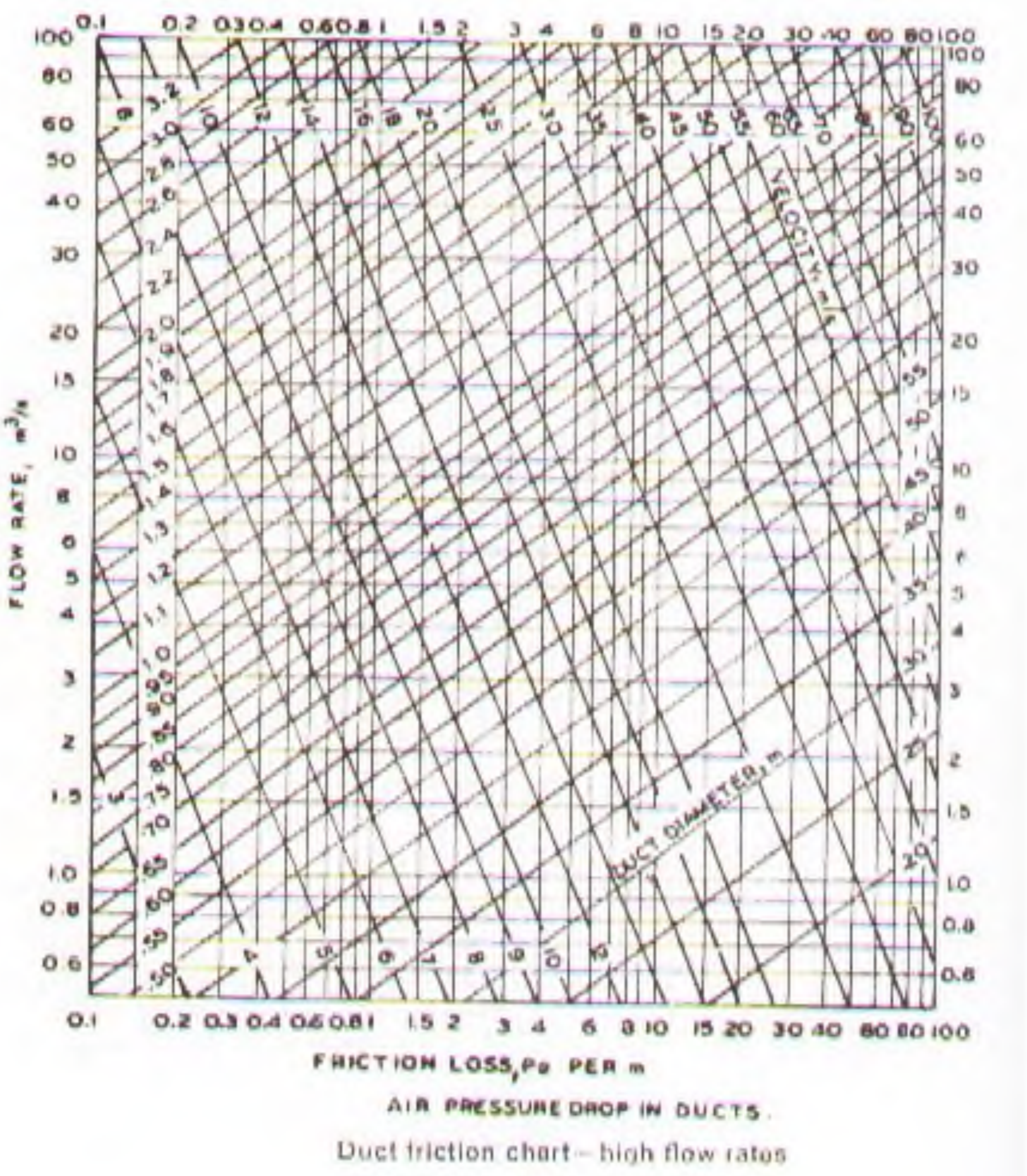
For galvanized steel air duct and air properties at 20 oC, the following charts could be used for estimate the duct size and velocity at a given pressure drop per meter and volume flow rate.

Duct friction chart-low flow rate.



Air Pressure Drop in Ducts

Duct friction chart—low flow rates



Duct friction chart-high flow rate.

The above two charts recommended only for air and the duct which made from galvanized steel with ε = 0.00015 m and rounded section. But if another duct material it should be use correction factor.

We now recalculate the given example by using the duct chart.

The main duct A-B.

The total flow rate is,

$$Q_t = Q_1 + Q_2 + Q_2$$

$$Q_t = 4 + 3 + 1 = 8 \quad m^3/s$$

We assume the velocity in the main duct A – B and size the duct

$$V = 8 \quad m/s$$

From chart at Q = 8 m3/s and V = 8 m/s, the equivalent diameter and pressure loss are,

$$d = 1.135 \quad m$$

$$\Delta P = 0.5 \quad Pa/m$$

We use the value of ΔP=0.5 Pa/m is constant through all branches and determine the velocity and diameter from chart and tabulated the results as follows,

Resluts

Section	L (m)	Q (m3/s)	V (m/s	d (m)	Qcal
A-B	30	8	8.00	1.135	8.094
B-C	15	7	7.8	1.080	7.145
C-D	75	4	6.9	0.875	4.149
B-E	30	1	4.80	0.515	0.999
C-F	15	3	6.30	0.780	3.010

Velocity Reduction Method

In this method the main duct is designed in the same manner as in the equal friction method. Thereafter, arbitrary reductions are made in the air velocity as we go down the duct run. Equivalent diameters are found, as before from the friction chart. We now recalculate the given example by using the velocity reduction method and using the chart.

The main duct A-B.

The total flow rate is,

$$Q_t = Q_1 + Q_2 + Q_2$$

$$Q_t = 4 + 3 + 1 = 8 \quad m^3 / s$$

We assume the velocity in the main duct A – B and size the duct

$$V = 8 \quad m / s$$

From chart at Q = 8 m3/s and V = 8 m/s, the equivalent diameter and pressure loss are,

$$d = 1.135 \quad m$$

$$\Delta P = 0.5 \quad Pa / m$$

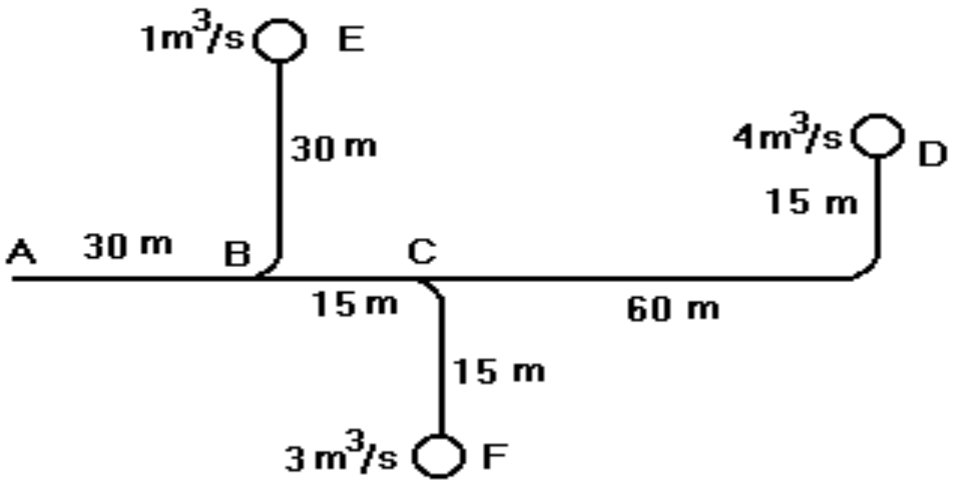
We assume the velocity as follows,

B-C, V = 7 m/s

B-E, V = 7 m/s, C-D, C-F, V = 6 m/s.

After that, we determine the duct diameter and friction loss from the chart and put the results in table as follows,

Results



Section	L (m)	Q (m3/s)	V (m/s	d (m)	Qcal
A-B	30	8	8.00	1.135	8.094
B-C	15	7	7.00	1.130	7.020
C-D	75	4	6.00	0.925	4.032
B-E	30	1	7.00	0.430	1.017
C-F	15	3	6.00	0.800	3.016

Advanced Air Duct Design

Ducts are tubes, which carry air from one place to another or to distribute air in different zones. Also they are used to extract (exhaust) air form different spaces and deliver it to the proper place.

Duct Applications:

- Ventilating single or multi zones.
- Supply of fresh air or conditioned (Hot or Cold) air.
- Exhausting air or gases from spaces.
- Transfer air from one zone to another.

Duct Classification:

Acc. To Velocity:

1- Low Velocity: Between 6 m/sec to 11 m/sec for Commercial Usage & Between 11 m/sec to 13 m/sec for Factory Usage.

2- High Velocity: above 13 m/sec for Commercial Usage & Between 13 m/sec to 25 m/sec for Factory Usage.

Acc. To Pressure:

1- Low Pressure (Class I) : up to 3.75 in.wg.

2- Medium Pressure (Class II) : Between 3.75 in.wg. to 6.75 in.wg.

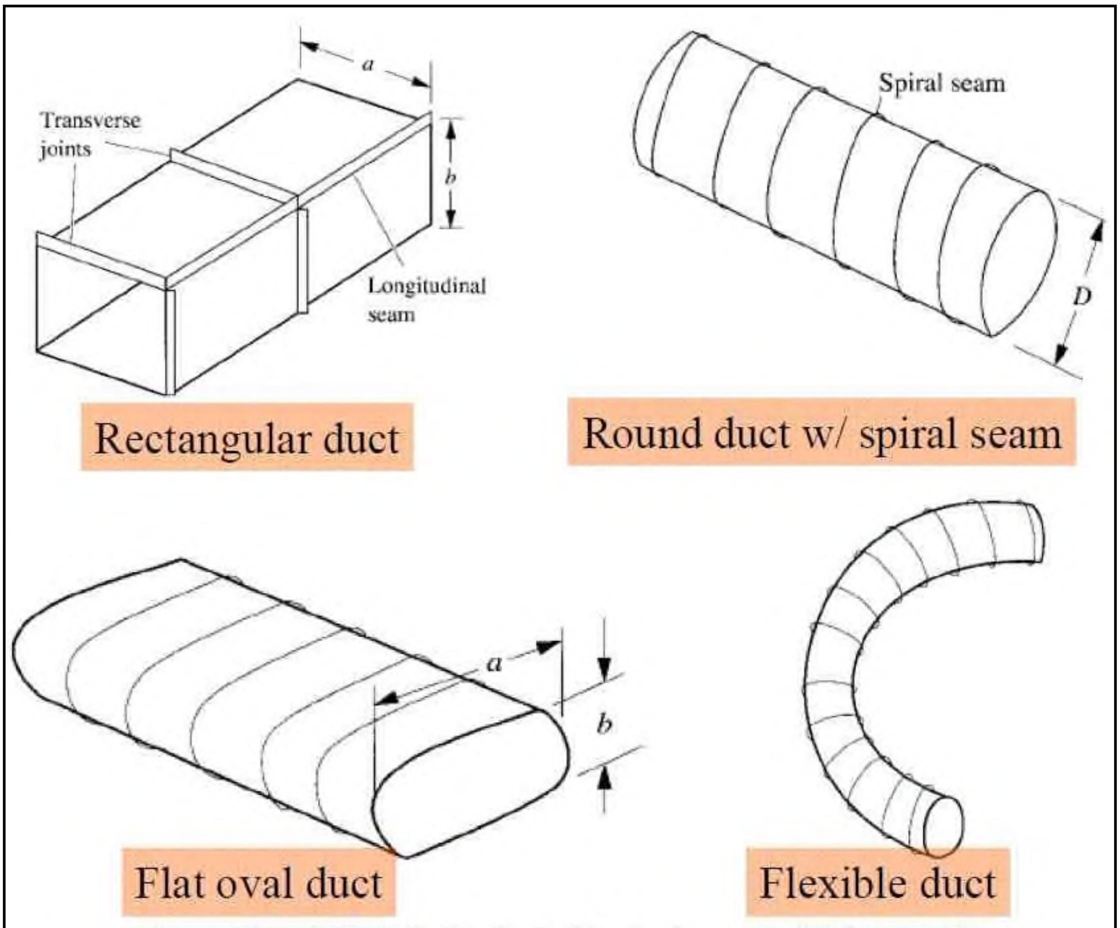
3- High Pressure (Class III) : Between 6.75 in.wg. to 12.25 in.wg.

Design Criteria:

The following Criteria & their factors should be considered when designing an Air Duct System;

- The available Space.
- Architectural Appearance.
- The permitted Sound Level.
- The First Cost & the Operating Cost (Heat Gain or Loss, Aspect Ratio, Friction Rate & Type of Fittings).

Type of Air Duct:



(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

Zoning & Space :

Zoning is a practice of dividing a building into smaller areas (zones), thereby providing the opportunity to control comfort levels in each zone. Zoning influence the way ducting is routed and often require multiple ducts, each feeding a respective zone. For example, in single story residential it is normal for the system to be a single zone. In some instances, two story dwellings have single HVAC zones but it is difficult to maintain optimum comfort from the first floor to the second floor for obvious reasons.

A two story dwelling will keep each floor comfortable by HVAC zoning the systems or by having two separate systems, one for upstairs and one for downstairs. After determining the zones for the building, a preliminary layout of the ductwork is drawn. Preliminary duct layout can be drawn either in single-line (non-detailed) or double line technique.

Proper zoning provides greater comfort, reduces energy use due to over-conditioning, and reduces equipment wear.

Aspect Ratio:

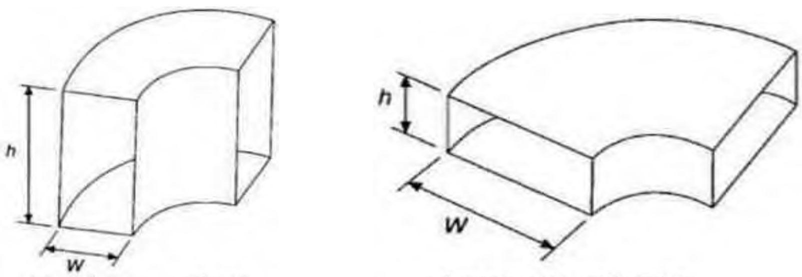
The aspect ratio is the ratio of the long side (Width) to the short side (Height) of a duct. This ratio is an important factor to be considered in the initial design. Increasing the aspect ratio increases both the installed cost and the operating cost of the system. A rectangular duct with an aspect ratio closer to ONE has lower frictional resistance and will use lowest sheet metal. A.R. =W/H

Ex.(1) : Say the main trunk of the duct requires cross-sectional area of 4 sq-ft and is 100 ft long. The duct can be fabricated as 2' x 2' or 1' x 4' dimensions.

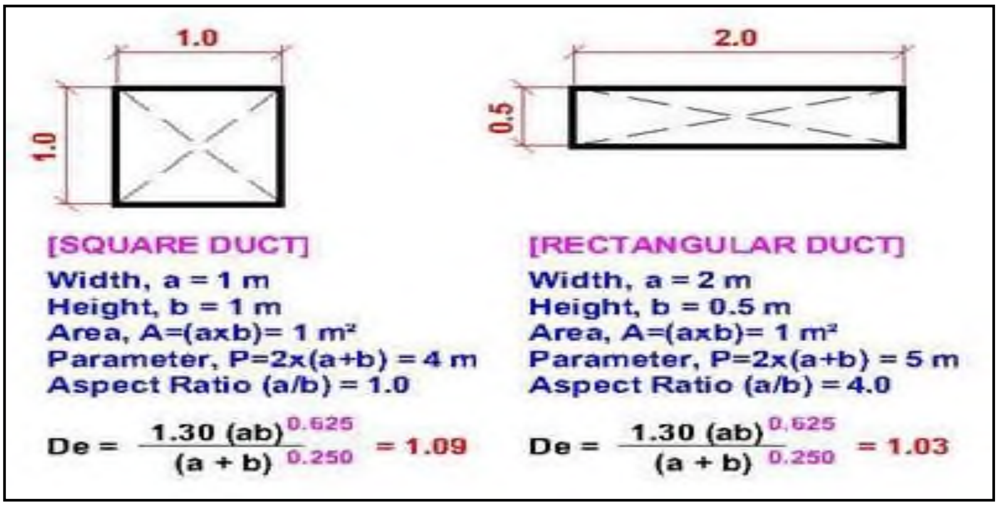
In first case 2 'x 2', the perimeter = 8 ft and total sheet metal required is 8 x 100 = 800 sq-ft

In second case 1' x 4', the perimeter = 10 ft and total sheet metal required is 10 x 100 = 1000 sq-ft

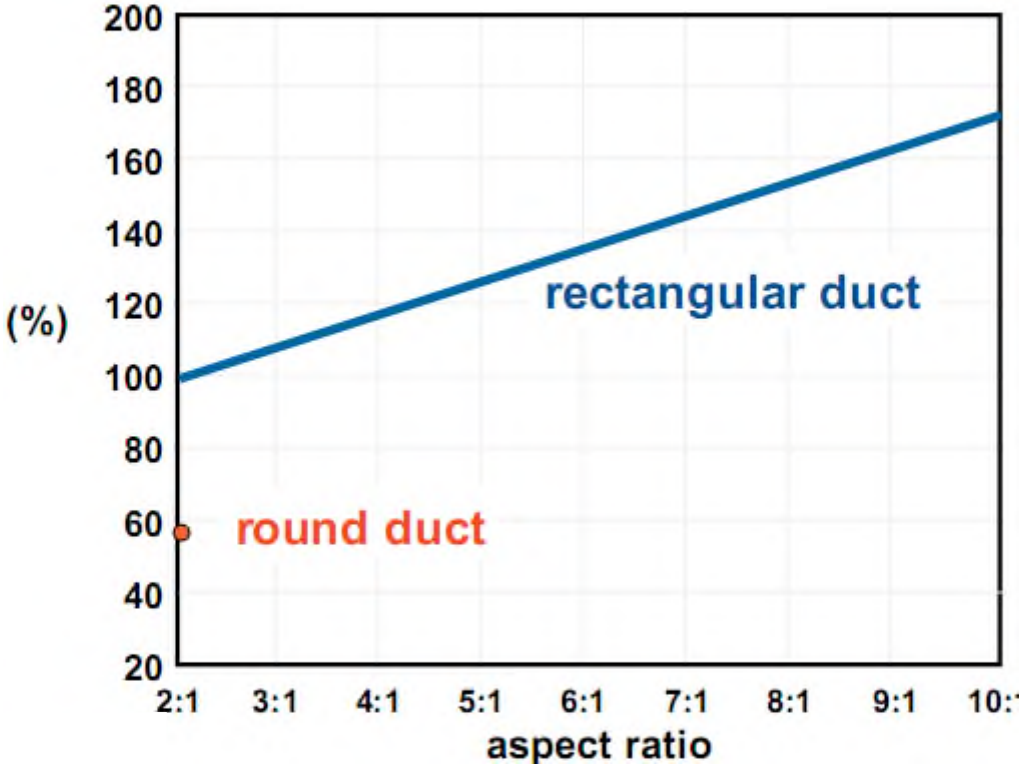
As the aspect ratio increases from 1: 1 to 1: 4, the surface area and insulation requirements increase 25% percent. Other benefits of low aspect ratio include low friction drop, low weight of metal, lower insulation and installation costs.



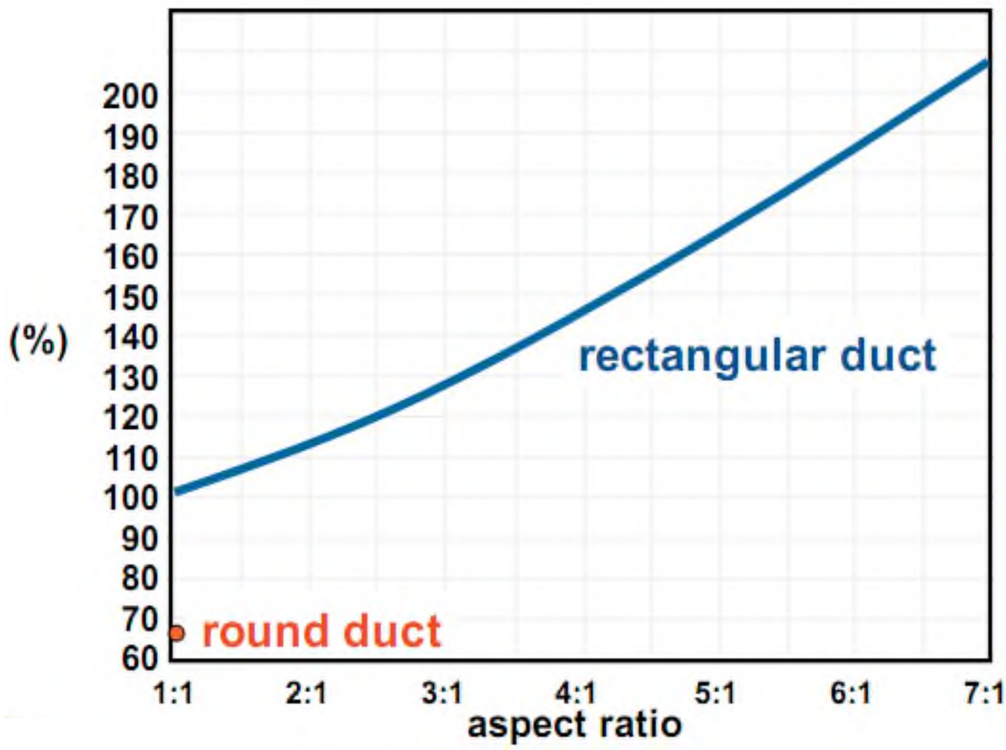
Small Aspect Ratio   Large Aspect Ratio



Duct Heat Gain vs. Aspect Ratio



Relative Installed Cost vs. Aspect Ratio



Northern Technical University
Technical College of Engineering
Department of Power Mechanics Techniques

Fourth Year

Air Conditioning System Design

Chapter Two
“Lecture Two”
Advanced Air Duct Design

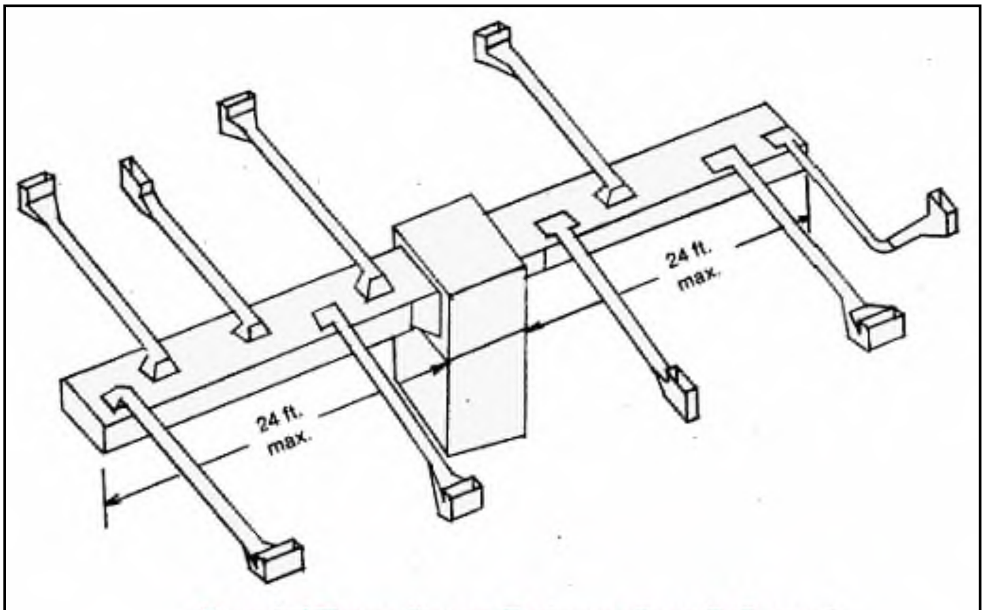
Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

SUPPLY DUCT CONFIGURATIONS:

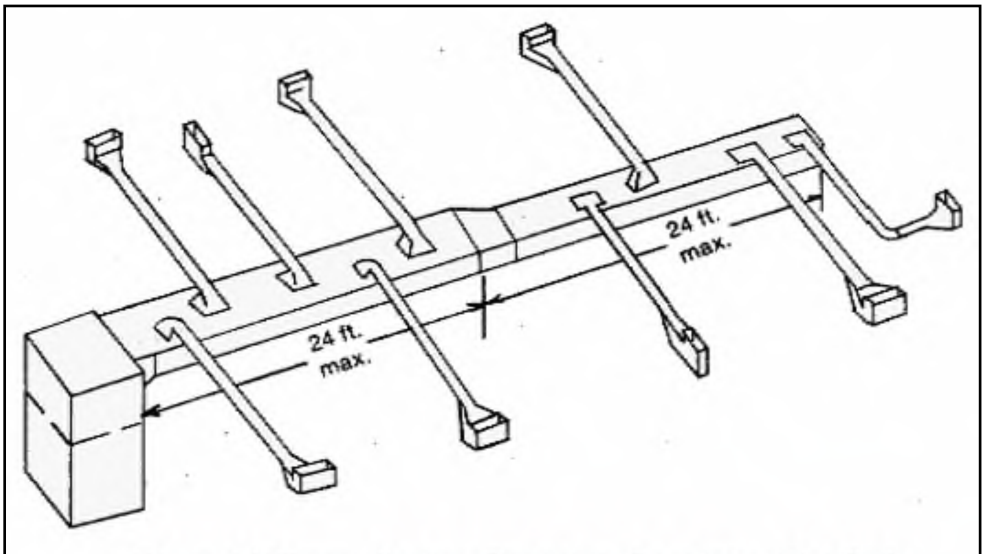
The configuration of a duct system is often like a tree with branches connected to the terminal units and a fan located at the root. The configuration of duct options depending on space type and other design considerations :

1.Extended Plenum Systems

In the extended plenum systems, a large main supply trunk is connected directly to the air handler or its supply plenum. Smaller branch ducts and run outs are connected to the trunk.



Extended Plenum System (Equipment Centrally Located)

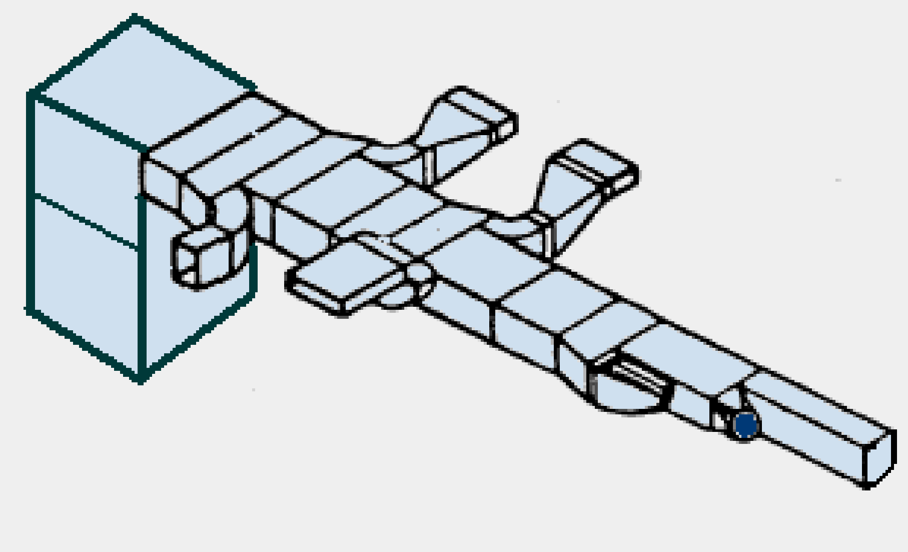


Extended Plenum System (Equipment Located at One End)

2.Reducing Trunk System:

A reducing plenum system uses a trunk reduction periodically to maintain a more uniform pressure and air velocity in the trunk, which improves air flow in branches and run outs closer to the air handler. Similarly, a reducing trunk system reduces the cross-sectional area of the trunk after every branch duct or run out, but it is the most complex system to design. A properly designed reducing trunk system represents the ultimate in an engineered duct system with each portion of trunk duct specially sized so that the trunk is proportionately reduced after each branch takeoff. The system is well-balanced since each branch is specifically engineered but is more costly than other standard duct systems because of custom nature of design, ductwork and installation. Note this is not to be confused with the reduced extended-plenum system described above.

Figure below illustrates that the main trunk duct becomes smaller after each takeoff, ultimately reducing to a single branch duct at the last takeoff.

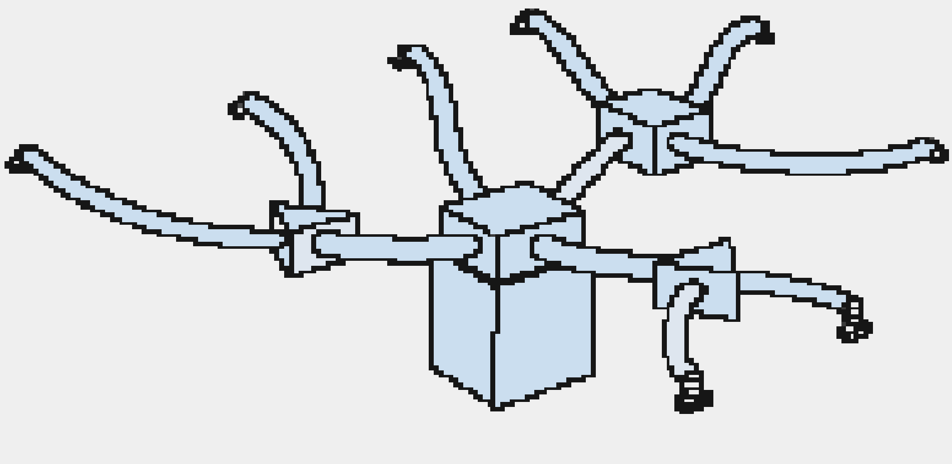


Reducing Trunk Duct System

Since air delivery requirements in a reducing trunk system are predetermined by design, grilles are sometimes used in place of registers to avoid tampering at individual outlets. Proper design of a reducing trunk system requires a well-qualified HVAC contractor or engineer.

3. **Spider System** :

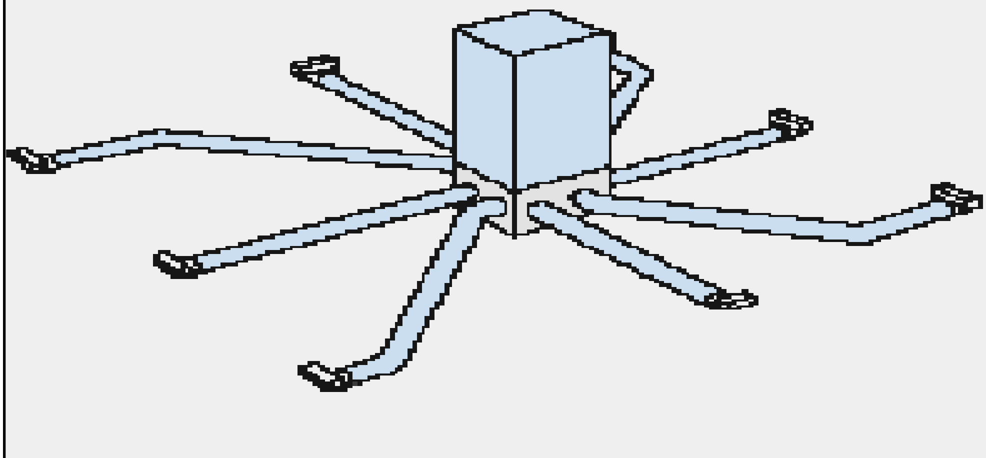
A spider system is a more distinct variation of the trunk and branch system. Large supply trunks (usually large-diameter flexible ducts) connect remote mixing boxes to a small, central supply plenum. Smaller branch ducts or run outs take air from the remote mixing boxes to the individual supply outlets. The figure below illustrates this concept.



Spider Duct System

4. **Radial System:**

In a radial system, there is no trunk duct; branch ducts or run outs; rather individual supply outlets are essentially connected directly to the air handler, usually using a small supply plenum. The short, direct duct runs maximize air flow. The radial system is most adaptable to single-story homes. Traditionally, this system is associated with an air handler that is centrally located so that ducts are arranged in a radial pattern. However, symmetry is not mandatory, and designs using parallel run outs can be designed so that duct runs remain in the conditioned space (e.g., installed above a dropped ceiling). Radial systems typically are used where it is not necessary to conceal ductwork and where the equipment could be centrally located to take best advantage of the system.

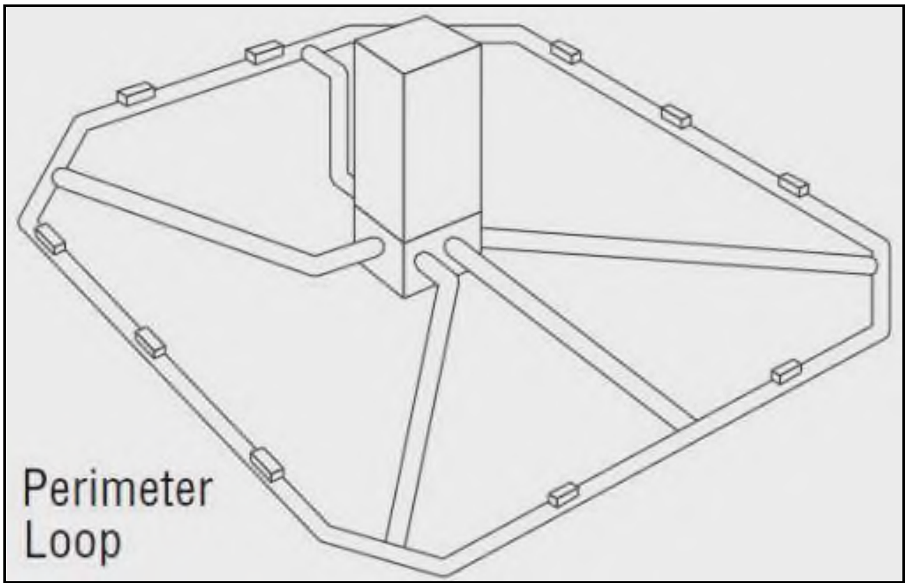


Radial Duct System

This system is practical where the piping runs are located in an attic or crawl space. The radial system is most economical and easiest to install, but is not practical if the air handling unit or furnace cannot be centrally located.

5. Perimeter Loop System

A perimeter loop system uses a perimeter duct fed from a central supply plenum using several feeder ducts. This system is typically limited to facilities built on slab in cold climates.



DUCT MATERIALS:

Ducting may be categorized according to the materials of construction and are either metallic or non-metallic ducts. The majority of ducts are constructed of metal and installed by tradesmen called sheet metal workers. In fact, sheet metal use in HVAC is greater than all other materials combined. The steel and aluminum used for ductwork is a "high achiever" in the 21st-century move toward sustainable buildings because of the high recycling rates and cleanliness.

Metallic Ducts:

A great majority of metallic ducts is made of galvanized steel. Next in popularity in metal ducts is aluminum. Aluminum ducts are light in weight, but basic cost per pound is higher than galvanized steel. Other metals used under special circumstances are copper and stainless steel and non-metallic ducts may include glass fiber, compressed paper, plastic, cement-asbestos, vitrified clay, and concrete.

Each material has characteristics that may favor its use in specialized applications. Sheet metal has a number of advantages: It is made from recycled materials; it is non-combustible; it is the sturdiest material; and it is the easiest to clean. Following is a list of key characteristic of duct materials:

1. Galvanized Steel - Widely used as a duct material for most air handling systems; not recommended for corrosive product handling or temperatures above 400ºF. Advantages include high strength, rigidity, durability, rust resistance, availability, non-porosity, workability, and weldability.

2. Carbon Steel (Black Iron) - Applications include flues, stacks, hoods, other high temperature duct systems, and ducts requiring paint or special coating. Advantages include high strength, rigidity, durability, availability, weldability, and non-porosity. Some limiting characteristics are corrosion resistance and weight.

3. Aluminium : Aluminium ducting is most commonly used for clean room applications. These are also preferred systems for moisture laden air, special exhaust systems and ornamental duct systems. Some advantages include weight and resistance to moisture corrosion. Limiting characteristics include low strength, material cost, weldability, and thermal expansion.

4. Stainless Steel : Used in duct systems for kitchen exhaust, moisture laden air, and fume exhaust. Advantages include high resistance to corrosion from moisture and most chemicals and the ability to take a high polish. Limiting characteristics include labour and material costs, workability, and availability.

5. Copper : Copper applications include duct systems exposed to outside elements and moisture laden air, certain chemical exhaust, and ornamental ductwork. Advantages are durability and corrosion resistance and that it accepts solder readily and is nonmagnetic. Limiting characteristics are cost, ductility, electrolysis, thermal expansion, and stains

Non Metallic Ducts:

1. Fibreglass Reinforced Plastic (FRP): Applications include chemical exhaust, scrubbers, and underground duct systems. Limiting characteristics include cost, weight, range of chemical and physical properties, brittleness, fabrication (necessity of moulds and expertise in mixing basic materials), and code acceptance. Fibreglass duct board is insulated and sealed as part of its construction. Fibreglass duct board provides excellent sound attenuation, but its longevity is highly dependent on its closure and fastening systems. Resistance to corrosion and ease of modification are advantages of FRP. It is usually used to form rectangular supply and return trunks, branches, and plenums, although it can be used for run outs as well.

2. Polyvinyl Chloride (PVC): Applications are exhaust systems for chemical fumes and underground duct systems. Advantages include resistance to corrosion, weight, weldability, and ease of modification. Limiting characteristics include cost, fabrication, code acceptance, thermal shock, and weight.

3. Polyvinyl Steel (PVS): Applications include underground duct systems, moisture laden air, and corrosive air systems. Some advantages are resistance to corrosion, weight workability, fabrication, and rigidity. Some limiting characteristics include temperature limitations (250ºF maximum), weldability, code acceptance, and susceptibility to coating damage.

4. Flexible Nonmetallic Duct: Flexible or flex duct consists of a duct inner liner supported on the inside by a helix wire coil and covered by blanket insulation with a flexible vapor-barrier jacket on the outside. Flex duct is often used for run outs, with metal collars used to connect the flexible duct to supply plenums, trunks, and branches constructed from sheet metal or duct board. Flex duct is also commonly used as a return duct. Flex duct is factory-insulated and has fewer duct connections and joints. However, these connections and joints must be mechanically fastened using straps and sealed using mastic. Flex duct is easily torn, crushed, pinched, or damaged during installation. It has the highest resistance to air flow. Consequently, if used, it must be properly specified and installed.

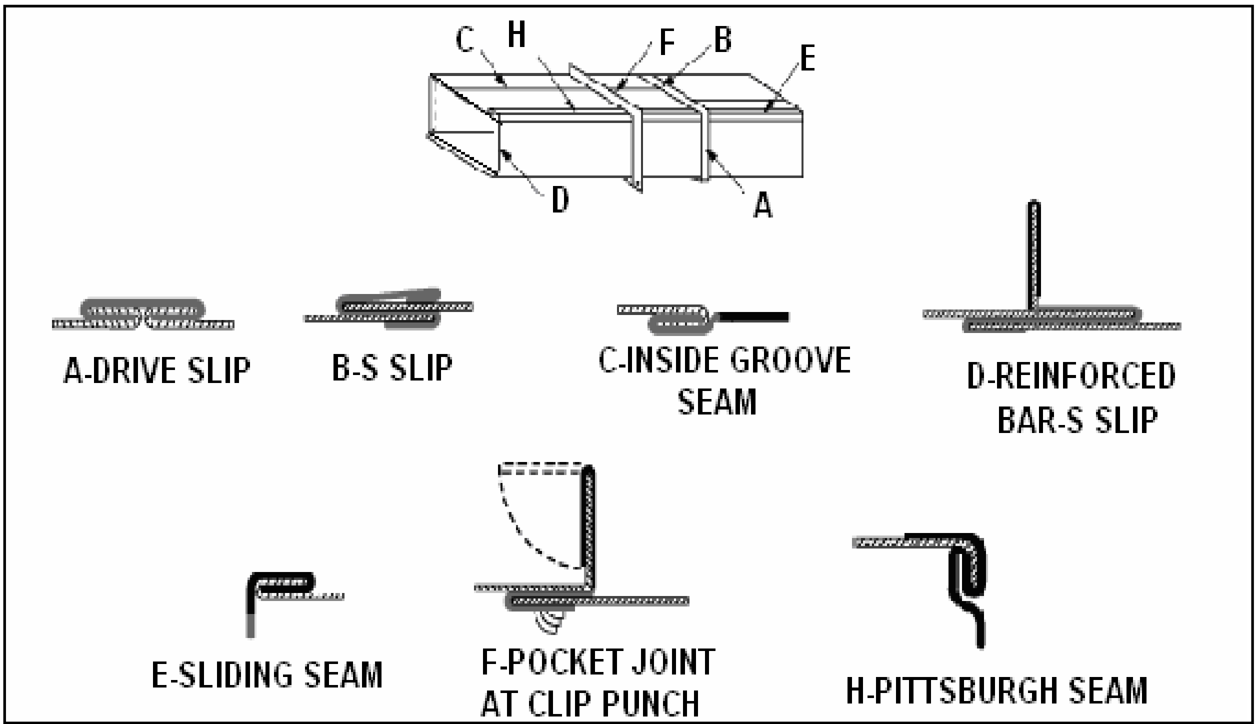
Flex duct, which is used extensively in commercial construction, has more than 60% higher pressure drop than galvanized metal duct of the same diameter. Flex duct runs should be limited to six feet or less. When longer runs must be used, make sure the duct is well supported at five foot intervals to minimize sag. Flex duct should be fully extended to minimize pressure drop.

5. **Concrete:** Concrete can be used for underground ducts and air shafts. Advantages include compressive strength and corrosion resistance. Cost, weight, porosity, and fabrication (requires forming processes) are some limiting characteristics.

6. **Rigid Fibrous Glass**: Fibrous glass ducts are fabricated from sheets of materials that have been manufactured from resin bonded inert and inorganic glass fibers.

DUCT CONSTRUCTION & REINFORCEMENT:

Duct walls, transverse joints, and reinforcements at or between joints and supports make up the basic elements of duct construction. Each size in a pressure class has a minimum duct wall thickness and a minimum specification for joints, reinforcements, etc. Depending on the duct pressure and type, joints and seams are made in different ways. Figure below shows the various types of slip joints made for a low-pressure rectangular duct system.



Duct Sheet Metal Thickness:

The greater of the duct's dimension is the one that is used to determine the gage of the sheet metal for all sides.

Rectangular Duct			Round Duct		
Greater Dimension	Galvanized Steel (gauge)	Aluminum (gauge)	Diameter	Galvanized Steel (gauge)	Aluminum (gauge)
Up to 30 inch	24	22	Up to 8 inch	24	22
31 – 60 inches	22	20	9 – 24 inches	22	20
61 – 90 inches	20	18	25 – 48	20	18
91inches and above	18	16	49 – 72 inches	18	16

Duct Hanger Spacing:

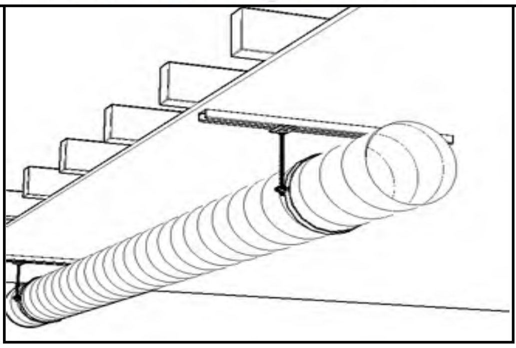
Maximum ductwork hanger spacing:

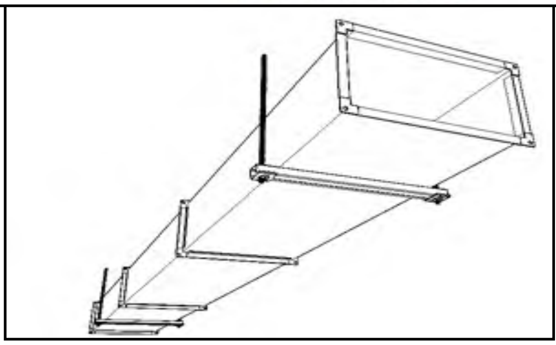
SMACNA Minimum Requirements:

- Horizontal: 8 feet maximum
- Vertical: 16 feet and at each floor

Good Engineering Practices:

- Horizontal Ducts less than 4 square feet: 8 feet maximum
- Horizontal Ducts 4 to 10 square feet: 6 feet maximum
- Horizontal Ducts greater than 10 square feet: 4 feet maximum
- Vertical Round Ducts: 12 feet maximum
- Vertical Rectangular Ducts: 10 feet maximum





Ductwork Air Leakage:

Duct leakage is always uncontrolled, so it should be avoided. Although leakage may not cause an air distribution system to perform improperly, it drives up operating costs. Even when supply ducts are inside a building's envelope and air leakage goes into a plenum space, leakage diminishes the supply air's effect on control sensors, thus increasing system operation.
The duct leakage essentially depends on the method of duct fabrication and of sealing as well as on workmanship and static pressure differential.
Duct leakage can be determined as :

Leakage = (Leakage class) * (Static pressure) * 0.65

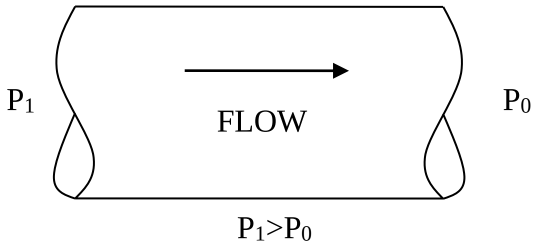
Because the amount of duct leakage depends on internal static pressure, lower pressure in a system reduces leakage. For a single straight duct static pressure changes uniformly. However, local resistance causes sudden changes of static pressure. Therefore, in general, static pressure and duct leakage are not equally distributed through a duct's length and should be calculated locally between fittings. The leakage class reflects the quality of duct construction and sealing method.
Using welded or flanged and casketed duct construction in critical exhaust systems will make ductwork virtually leak free. Leakage Class 3 is achievable by most contractors with some practice and guidance in duct construction and sealing techniques.
Leakage occurs at transverse and longitudinal joints and at connections, e.g. at tees, at Variable Air Volume (VAV) boxes, and at flexible terminal sections. Sealing the duct joints, usually with silicone-based sealant, is a basic method for avoiding the leaks.

Optimal Air Duct Design:

- Optimal duct system layout, space available
- Satisfactory system balance.
- Acceptable sound level.
- Optimum energy loss and initial cost
- Install only necessary balancing devices (dampers)
- Fire codes, duct construction & insulation
- Require comprehensive analysis & care for different transport functions.

Air Flow

Flow of air or any other fluid is caused by a pressure differential between two points. Flow will originate from an area of high energy, or pressure, and proceed to area(s) of lower energy or pressure.



Duct air moves according to three fundamental laws of physics: conservation of mass, conservation of energy, and conservation of momentum.

Conservation of mass simply states that an air mass is neither created nor destroyed. From this principle it follows that the amount of air mass coming into a junction in a ductwork system is equal to the amount of air mass leaving the junction, or the sum of air masses at each junction is equal to zero. In most cases the air in a duct is assumed to be incompressible, an assumption that overlooks the change of air density that occurs as a result of pressure loss and flow in the ductwork. In ductwork, the law of conservation of mass means a duct size can be recalculated for a new air velocity using the simple equation:

$V_2 = (V_1 * A_1)/A_2$

Where V is velocity and A is Area

The **law of energy conservation** states that energy cannot disappear; it is only converted from one form to another. This is the basis of one of the main expression of aerodynamics, the **Bernoulli equation**. Bernoulli's equation in its simple form shows that, for an elemental flow stream, the difference in total pressures between any two points in a duct is equal to the pressure loss between these points, or:

(Pressure loss)1-2 = (Total pressure)1 - (Total pressure)2

Conservation of momentum is based on Newton's law that a body will maintain its state of rest or uniform motion unless compelled by another force to change that state. This law is useful to explain flow behavior in a duct system's fitting.

Types of Flow:

Laminar Flow: Flow parallel to a boundary layer. In HVAC system the plenum is a duct.

Turbulent Flow : Flow which is perpendicular and near the center of the duct and parallel near the outer edges of the duct. Most HVAC applications fall in the transition range between laminar and turbulent flow.

Types of Pressure Losses or Resistance to Flow:

Pressure loss is the loss of total pressure in a duct or fitting. There are three important observations that describe the benefits of using total pressure for duct calculation and testing rather than using only static pressure.

Pressure loss in ductwork has three components, frictional losses along duct walls ; dynamic losses in fittings and component pressure losses in duct.

1. **Component Pressure:**

Due to physical items with known pressure drops, such as hoods, filters, louvers or dampers.

2. **Frictional or Static Pressure:**

Friction Losses – occur due to fluid viscosity and turbulence in the flow through the ductwork and occur along the entire length of the ductwork. The moving air is subjected to a certain amount of resistance which inevitably turns into a load loss. This depends on

a. The nature and physical state of the air

b. Average speed

c. Duct dimensions

d. Roughness of the material

e. Length of the duct

Frictional losses in duct sections are result from air viscosity and momentum exchange among particles moving with different velocities. These losses also contribute negligible losses or gains in air systems unless there are extremely long duct runs or there are significant sections using flex duct.

Flow of Air Through Ducts:

The fundamental equation to be used in the analysis of air conditioning ducts is the Bernoulli's equation. Bernoulli's equation is valid between any two points in the flow field when the flow is steady, irrotational, inviscid and incompressible. The equation is valid along a streamline for rotational, steady and incompressible flows. Between any two points 1 and 2 in the flow field for irrotational flows, the Bernoulli's equation is written as:

$$\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{V_2^2}{2g}+z_2=\frac{p_T}{\rho g}=\text{total head}$$

where $\frac{p}{\rho g}$ is the pressure head, $\frac{V^2}{2g}$ is the velocity head and **Z** is the static head, respectively. Each of the heads has units of length as explained before. The above equation can be written in terms of static, velocity, datum and total pressures as:

$$p_1+\frac{\rho V_1^2}{2}+\rho g z_1=p_2+\frac{\rho V_2^2}{2}+\rho g z_2=p_T=\text{total pressure}$$

$$\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{V_2^2}{2g}+z_2+H_l$$

Estimation of pressure loss in ducts:

As air flows through a duct its total pressure drops in the direction of flow. The pressure drop is due to:

1. Fluid friction
2. Momentum change due to change of direction and/or velocity

The pressure drop due to friction is known as frictional pressure drop or friction loss, Δp_f. The pressure drop due to momentum change is known as momentum pressure drop or dynamic loss, Δp_d. Thus the total pressure drop Δp_t is given by:

$$\Delta p_t=\Delta p_f+\Delta p_d$$

Evaluation of frictional pressure drop in ducts :

The Darcy-Weisbach equation is one of the most commonly used equations for estimating frictional pressure drops in internal flows. This equation is given by:

$$\Delta p_f = f\frac{L}{D}\left(\frac{\rho V^2}{2}\right)$$

where f is the dimensionless friction factor, L is the length of the duct and D is the diameter in case of a circular duct and hydraulic diameter in case of a non-circular duct. The friction factor is a function of **Reynolds number**, $Re_D = \left(\frac{\rho V D}{\mu}\right)$ and the relative surface roughness of the pipe or duct surface in contact with the fluid.

For turbulent flow, the friction factor can be evaluated using the empirical correlation suggested by **Colebrook and White** is used, the correlation is given by:

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\frac{k_s}{3.7D} + \frac{2.51}{(Re_D)\sqrt{f}}\right]$$

where ks is the average surface roughness of inner duct expressed in same units as the diameter D. Evaluation of f from the above equation requires iteration since f occurs on both the sides of it. In general in air conditioning ducts, the fluid flow is turbulent. It is seen from the above equation that when the flow is turbulent, the friction factor is a function of Reynolds number, hydraulic diameter and inner surface roughness of the duct material. Table below shows absolute roughness values of some of the materials commonly used in air conditioning:

Average surface roughness of commonly used duct materials

Material	Absolute roughness , ε (m)
Galvanized Iron (GI) sheet	0.00015
Concrete	0.0003 to 0.003
Riveted steel	0.0009 to 0.009
Cast Iron (CI)	0.00026
Commercial steel	0.00046

the GI sheet material is very widely used for air conditioning ducts. Taking **GI as the reference material** and properties of air at 20 ^{o}C and 1 atm. pressure, the frictional pressure drop in a circular duct is given by:

$$\Delta p_f = \frac{0.022243\,\dot{Q}_{air}^{\,1.852}\,L}{D^{4.973}} \quad \text{in } N/m^2$$

where **Qair** is the volumetric flow rate of air in m^3/s , L is the length and D is the inner diameter of the duct in meters, respectively. Using the above equation, friction charts have been created for estimation of frictional pressure drop of standard air through circular ducts made of GI sheets. Figure below shows the standard chart for estimating frictional pressure drop in circular ducts made of GI sheets at standard air conditions.

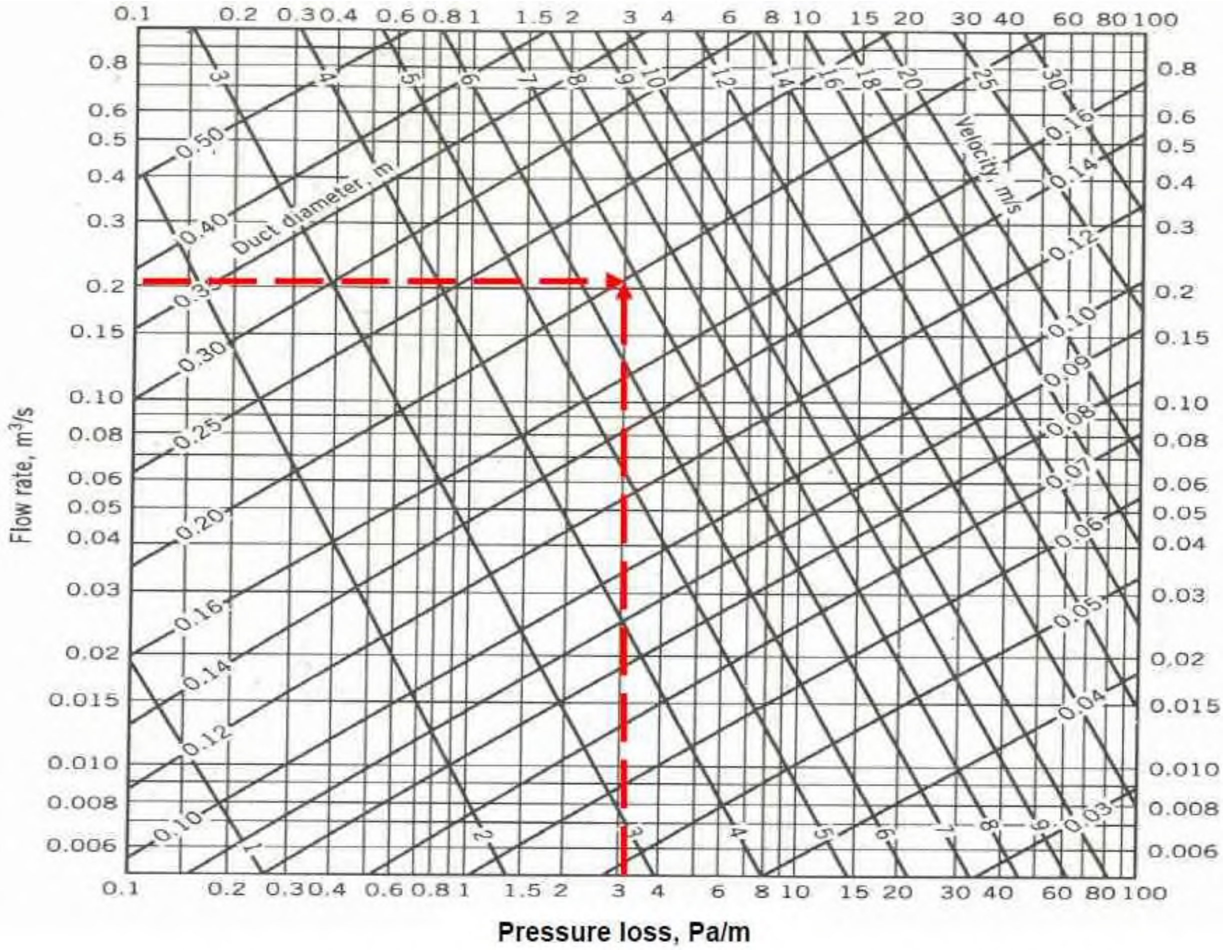


Fig.37.1. Chart for estimating frictional pressure drop in circular GI ducts

It can be seen from the chart that one can estimate frictional pressure drop per unit length if any two parameters out of the three parameters, i.e., flow rate , diameter **D** and velocity **V** are known. Correction factors have to be applied to the pressure drop values for ducts made of other materials and/or for air at other conditions. For small changes in air density (ρ) and temperature (T in K), one can use the following relation to obtain frictional pressure drop from the standard chart.

$$\left(\frac{\Delta p_{f,1}}{\Delta p_{f,2}}\right)=\left(\frac{\rho_1}{\rho_2}\right) \quad \text{and} \quad \left(\frac{\Delta p_{f,1}}{\Delta p_{f,2}}\right)=\left(\frac{T_2}{T_1}\right)^{0.857}$$

The chart shown above is valid only for circular ducts. For other shapes, an equivalent diameter has to be used to estimate the frictional pressure drop.

Rectangular ducts:

Even though circular ducts require the least material for a given flow rate and allowable pressure drop, rectangular ducts are generally preferred in practice as they fit easily into the building construction thus occupying less space, and they are also easy to fabricate. The ratio of the two sides ‘a’ and ‘b’ of the rectangle (a/b) is called as aspect ratio of the duct. Since square ducts with aspect ratio 1.0 come close in performance to a circular duct, it is preferable to use an aspect ratio as close to unity as possible for best performance. One can use equation below

$$\Delta p_f = \frac{0.022243\,\dot{Q}_{air}^{\,1.852}\,L}{D^{4.973}} \qquad \text{in N/m}^2$$

and friction chart for circular ducts for estimating pressure drop through a rectangular duct by using an equivalent diameter. A rectangular duct is said to be equivalent to a circular duct, if the volumetric flow rate and frictional pressure drop per unit length are same for both. Equating these two parameters for a rectangular duct and an equivalent circular duct, it can be shown that the equivalent diameter is given by:

$$D_{eq} = 1.3\,\frac{(ab)^{0.625}}{(a+b)^{0.25}}$$

The above equation is found to be valid for aspect ratio less than or equal to 1:8. Thus from the known values of the two sides of the duct ‘a’ and ‘b’, one can find the equivalent diameter Deq. From the equivalent diameter and the air flow rate, one can estimate the frictional pressure drop per unit length by using either Eq.(37.9) or the friction chart Fig. 37.1. However, when using equivalent diameter and flow rate to find the frictional pressure drop from the chart, the velocity values shown on the chart are not the actual velocities. The actual velocities have to be obtained from the flow rate and the actual cross-sectional area of the rectangular duct. If a rectangular duct has to be designed for a given flow rate and a given frictional pressure drop, then one can first find the equivalent diameter from the friction chart.

3. Dynamic Losses in Air Ducts:

Dynamic pressure loss takes place whenever there is a change in either the velocity or direction of airflow due to the use of a variety of bends and fittings in air conditioning ducts. Some of the commonly used fittings are: **enlargements, contractions, elbows, branches, dampers etc**. Since in general these fittings and bends are rather short in length (< 1 m), the major pressure drop as air flows through these fittings is not because of viscous drag (friction) but due to momentum change. Pressure drop in bends and fittings could be considerable, and hence should be evaluated properly. However, exact analytical evaluation of dynamic pressure drop through actual bends and fittings is quite complex. Hence for almost all the cases, the dynamic losses are determined from experimental data.

How to reduce the dynamic losses?

Reduce dynamic losses of the critical path

a. Maintain optimum air velocity through duct fittings
b. Emphasize reduction of dynamic losses nearer to the fan outlet or inlet (high air velocity)
c. Proper use of splitter vanes
d. Set 2 duct fittings as far apart as possible
e. Air duct leakage
f. Duct leakage classification ANSI, SMACNA, ASHRAE standards

.

In turbulent flows the dynamic loss is proportional to square of velocity. Hence these are expressed as:

$$\Delta p_d = K \frac{\rho V^2}{2}$$

where K is the dynamic loss coefficient, which is normally obtained from experiments.

Evaluation of dynamic pressure loss through various fittings:

A) Turns, bends or elbows: The most common type of bends used in air conditioning ducts are 90o turns shown in Fig.1 below:

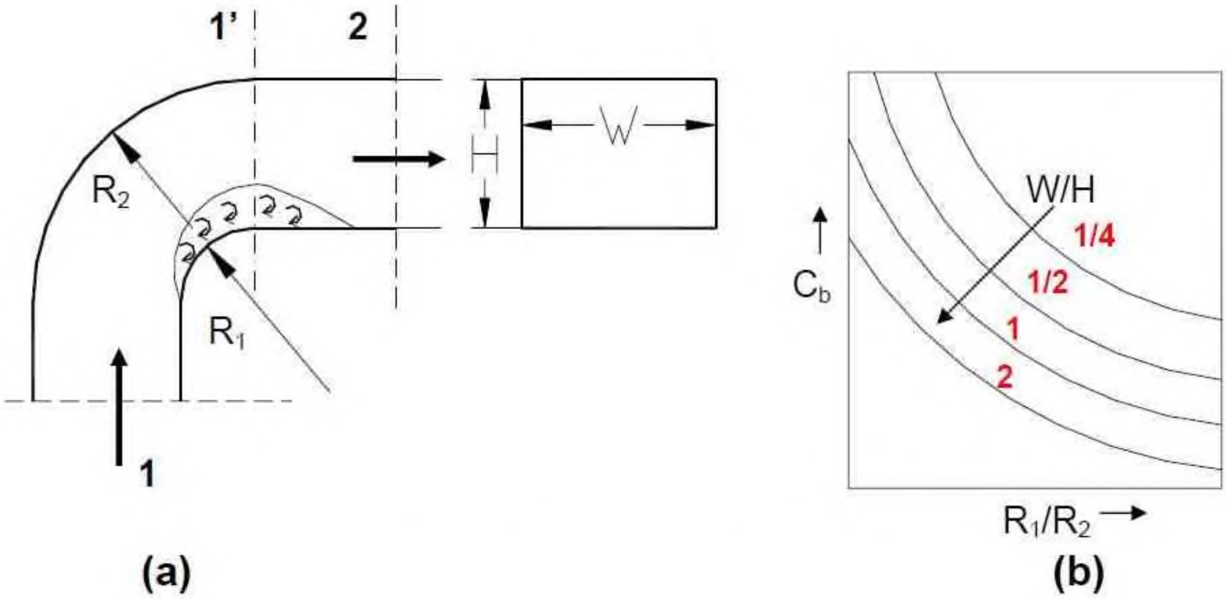


Fig.1: Air Flow through a 90° Bend (a 90° Elbow)

The cross-section of the elbow could be circular or rectangular. Weisbach proposed that the dynamic pressure loss in an elbow is due to the sudden expansion from the vena contracta region (1') to full cross-section 2 as shown in Fig. above . The dynamic pressure drop due to the elbow or 90^{o} turn is found to be a function of the aspect ratio (W/H), inner and outer radii of the turn (R_1 and R_2) and the velocity pressure $\rho V^2/2$, i.e.,

$$\Delta p_{d,b} = C_b\left(\frac{\rho V^2}{2}\right) = f((W/H), R_1, R_2)\left(\frac{\rho V^2}{2}\right)$$

The value of dynamic loss coefficient C_b as a function of aspect ratio (W/H), inner and outer radii of the turn (R_1 and R_2) is available in the form of tables and graphs that the pressure loss increases as (R_1/R_2) decreases and/or the aspect ratio W/H decreases. As a result, installing turning vanes in the bends reduces the dynamic pressure drop as it is equivalent to increasing W/H, as shown below:

Northern Technical University
Technical College of Engineering
Department of Power Mechanics Techniques

Fourth Year
Air Conditioning System Design

Chapter Two
“Lecture Two”
Advanced Air Duct Design

Prepare By Assist Prof.
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2025 - 2026

ANSI: American National Standards Institute.
SMACNA: Sheet Metal and Air Conditioning Contractor National Association.

ASHRAE: **American Society of Heating, Refrigerating and Air - Conditioning Engineers**

B) Losses at Sudden Enlargement:

Consider the flow in the sudden enlargement, shown in figure 2, fluid flows from section 1 to section 2. The velocity must reduce and so the pressure increases (this follows from Bernoulli). At position 1' turbulent eddies occur which give rise to the local head loss.

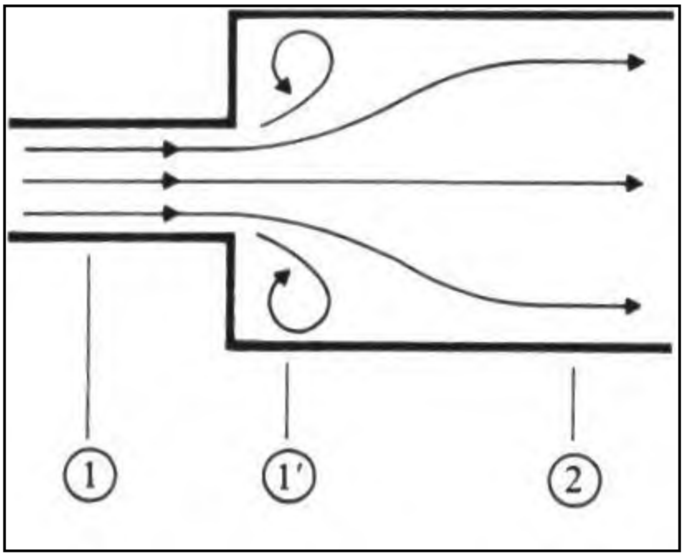


Fig.2:Sudden Enlargement

Apply the momentum equation between positions 1 and 2 to give

$$p_1A_1 - p_2A_2 = \rho Q(u_2 - u_1)$$

Now use the continuity equation to remove Q. (i.e. substitute Q = A2u2)

$$p_1A_1 - p_2A_2 = \rho A_2u_2(u_2 - u_1)$$

Rearranging gives

$$\frac{p_2 - p_1}{\rho g} = \frac{u_2}{g}(u_1 - u_2)$$

Now apply the Bernoulli equation from point 1 to 2, with the head loss term hL

$$\frac{p_1}{\rho g}+\frac{u_1^2}{2g}=\frac{p_2}{\rho g}+\frac{u_2^2}{2g}+h_L$$

And rearranging gives

$$h_L=\frac{u_1^2-u_2^2}{2g}-\frac{p_2-p_1}{\rho g}$$

Combining Equations above:

$$h_L=\frac{u_1^2-u_2^2}{2g}-\frac{u_2}{g}(u_1-u_2)$$

$$h_L=\frac{(u_1-u_2)^2}{2g}$$

Substituting again for the continuity equation to get an expression involving the two areas, (i.e. u2=u1A1/A2) gives

$$h_L=\left(1-\frac{A_1}{A_2}\right)^2\frac{u_1^2}{2g}$$

Comparing this with Equation

$$k_L=\left(1-\frac{A_1}{A_2}\right)^2$$

When a pipe or duct expands in to a large tank A1 << A2 i.e. A1/A2 = 0
so kL = 1. That is, the head loss is equal to the velocity head just before the expansion into the tank

ANSI: American National Standards Institute.
SMACNA: Sheet Metal and Air Conditioning Contractor National Association.

ASHRAE: **American Society of Heating, Refrigerating and Air - Conditioning Engineers**

C) Losses at Converging Duct:

Flow through a converging duct section.

acterizes the geometry of the duct or fitting. Thus,

$$\Delta p = \underbrace{f \frac{L}{D}}_{\text{Geometry}} \frac{V^2 \rho}{2}$$

When air flows frictionlessly through a converging or diverging nozzle the Bernoulli equation

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} = \frac{p_2}{\rho} + \frac{V_2^2}{2}$$

Since

$$\frac{V_2}{V_1} = \frac{A_1}{A_2}$$

$$p_1 - p_2 = \frac{V_1^2 \rho}{2} \underbrace{\left[\left(\frac{A_1}{A_2}\right)^2 - 1\right]}_{\text{Geometry}}$$

D) Losses at Sudden Contraction:

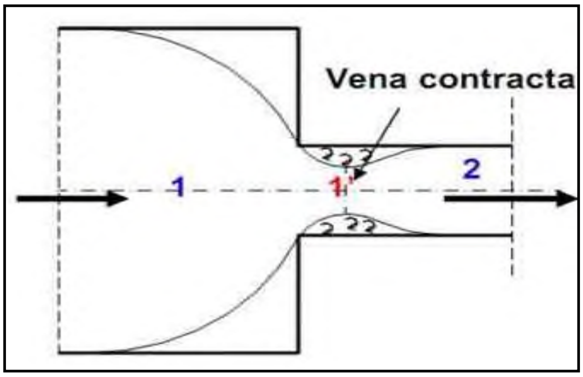


Fig.3: Sudden Contraction

A sudden contraction is shown in Fig.3 Similar to sudden enlargement, the dynamic pressure loss due to sudden contraction ΔPd, can be obtained analytically. This expression is also known as Borda-Carnot equation. It is given by:

$$\Delta p_{d,con} = \left(\frac{\rho V_2^2}{2}\right)\left(\frac{A_2}{A_{1'}} - 1\right)^2 = \left(\frac{\rho V_2^2}{2}\right)\left(\frac{1}{C_c} - 1\right)^2$$

Values of contraction coefficient C_c for different area ratios

$\frac{A_2}{A_1}$	C_c	$\left(\frac{1}{C_c} - 1\right)^2$
0.1	0.624	0.366
0.2	0.632	0.340
0.3	0.643	0.310
0.4	0.659	0.270
0.5	0.681	0.221
0.6	0.712	0.160
0.7	0.755	0.103
0.8	0.813	0.050
0.9	0.892	0.010
1.0	1.000	0.000

where V2 is the velocity in the downstream, and A1' and A2 are the areas at vena contracta and after contraction, respectively. The coefficient Cc is known as contraction coefficient and is seen to be equal to area ratio A1'/A2. The contraction coefficient Cc is found to be a function of the area ratio A2/A1, and the values of Cc as obtained by Weisbach are shown in Table below :

Comparing the expressions of pressure loss for sudden enlargement and sudden contraction, it can be seen that for the same flow rates and area ratios, the pressure drop due to sudden enlargement is higher than that due to sudden contraction.

E) Branch takeoffs When a main duct supplies air to several branch ducts, a takeoff must be provided for each branch, as in Fig **(4)** . From the upstream position u there is a pressure loss both to the downstream position d and into the branch to point b.

Considering first the pressure loss from u to d in the straight section of duct, this loss occurs because the pressure buildup from the higher velocity at u to the lower velocity at d is less than the ideal. The pressure loss in the straight-through section of a branch takeoff is usually small compared with other losses in the system. In many low-velocity designs it is neglected, but an equation[9] that closely approximates tabular data is

$$p_{loss} = \frac{V_d^2 \rho}{2} (0.4) \left(1 - \frac{V_d}{V_u}\right)^2 \quad \text{Pa}$$

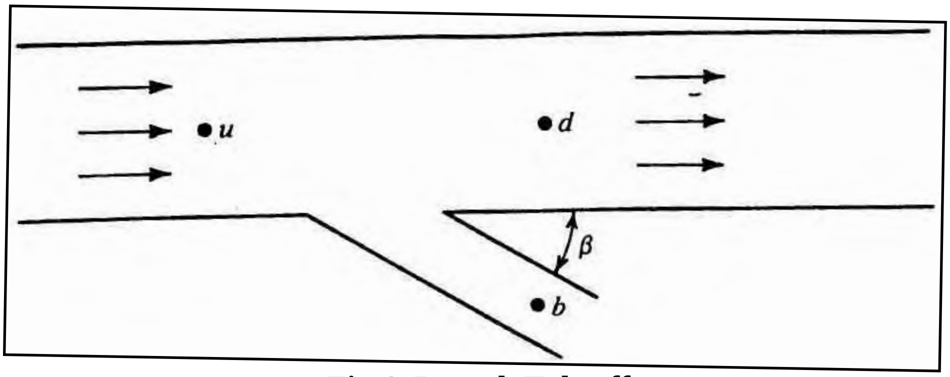
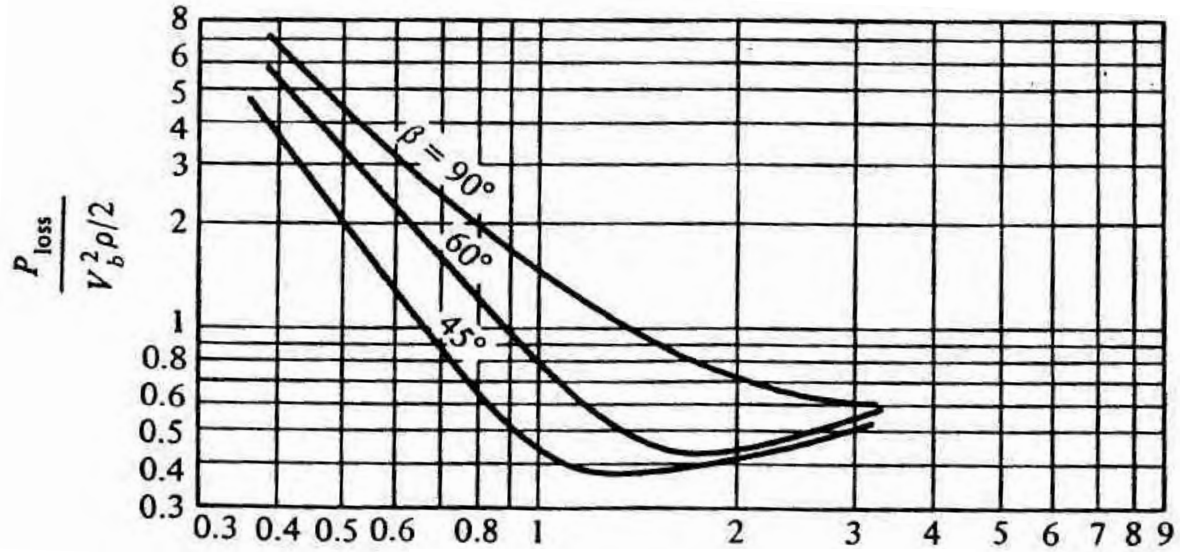


Fig.4: Branch Takeoff



Ratio of branch to upstream velocity

Fig.(5): Pressure Loss from upstream position to the branch duct

Example: A 60°, 30- by 30-cm branch takeoff leaves a 30- by 50-cm trunk duct. The size of the downstream section is also 30 by 50 cm. The upstream flow rate is 1.5 m^3/s, and the branch flow rate is 0.5 m^3/s. The upstream pressure is 500 Pa and the air temperature is 15°C. (*a*) What is the pressure following the straight-through section, and (*b*) what is the pressure in the branch line?

Solution Velocities

$V_u = 10$ m/s $\quad V_d = 6.67$ m/s $\quad V_b = 5.56$ m/s $\quad \rho = 1.225$ kg/m^3

(*a*) From Eq.

$$p_{loss} = \frac{6.67^2(1.225)(0.4)}{2}\left(1 - \frac{6.67}{10}\right)^2 = 1.2 \text{ Pa}$$

Substituting into the revised Bernoulli equation

$$p_2 = \rho\left(\frac{p_1}{\rho} + \frac{V_1^2}{2} - \frac{V_2^2}{2} - \frac{p_{loss}}{\rho}\right)$$

$$p_d = 500 + \frac{10^2(1.225)}{2} - \frac{6.67^2(1.225)}{2} - 1.2 = 533 \text{ Pa}$$

F) Miscellaneous fittings:

The dynamic pressure loss coefficients for other types of fittings, such as suction and discharge openings are also available in the form of tables. These values depend on the design of the fitting/opening. For abrupt suction opening the dynamic loss coefficient (K) is found to be about 0.85, while it is about 0.03 for a formed entrance. For discharge openings where the downstream pressure is atmospheric, all the kinetic energy of the air stream is dissipated at the exit, hence, the dynamic loss coefficient is equal to 1.0 in this case.

Filters, cooling and heating coils, dampers etc.: The pressure drop across air handling unit equipment, such as, air filters, dampers, cooling and heating coils depend on several factors. Hence, normally these values have to be obtained from the manufacturer’s data.

Static regain:

Whenever there is an enlargement in the cross-sectional area of the duct, the velocity of air decreases, and the velocity pressure is converted into static pressure. The increase in static pressure due to a decrease in velocity pressure is known as static regain. In an ideal case, when there are no pressure losses, the increase in static pressure (Δp) is exactly equal to the decrease in velocity pressure (Δp) and e total pressure remains constant as shown in Fig.5(a). Thus for the ideal case:

$$\Delta p_v = p_{v,1} - p_{v,2} = \Delta p_s = p_{s,2} - p_{s,1}$$

$$p_{t,1} = p_{t,2}$$

However, for sudden enlargements or for other non-ideal enlargements, the decrease in velocity pressure will be greater than the increase in static pressure, and the total pressure decreases in the direction flow due to pressure losses as shown in Fig. 5(b). The pressure loss is due to separation of the boundary layer and the formation of eddies as shown in Fig.5 (b). Thus, for sudden or non-ideal enlargement:

$$\Delta p_v = p_{v,1} - p_{v,2} > \Delta p_s = p_{s,2} - p_{s,1}$$

$$p_{t,1} = p_{t,2} + \Delta p_{loss}$$

The pressure loss due to enlargement Δp_{loss} is expressed in terms of a Static Regain Factor, R as:

$$\Delta p_{loss} = (1-R)\Delta p_v = (1-R)(p_{v,1} - p_{v,2})$$

where the static regain factor R is given by:

$$R = \frac{\Delta p_s}{\Delta p_v} = \frac{(p_{s,2} - p_{s,1})}{(p_{v,1} - p_{v,2})}$$

Thus for ideal enlargement the Static Regain Factor R is equal to 1.0, whereas it is less than 1.0 for non-ideal enlargement.

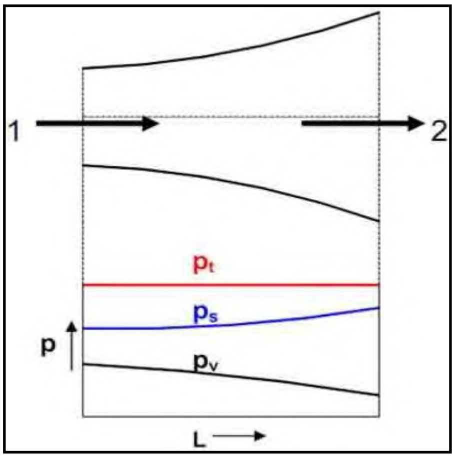


Fig. (5-a): Ideal Enlargement

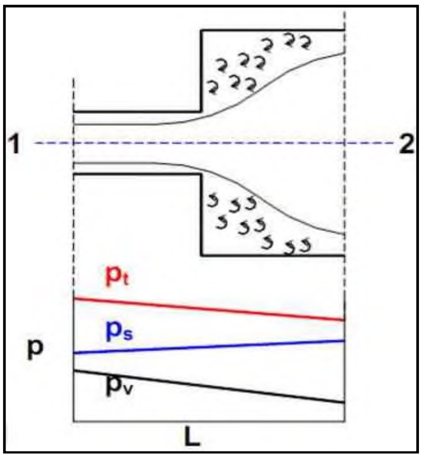
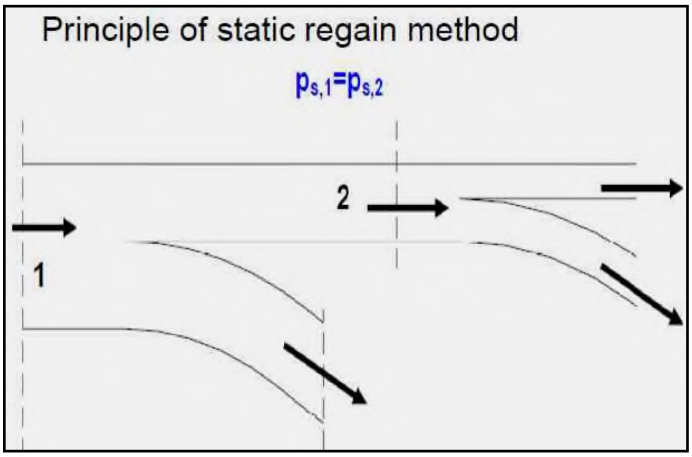
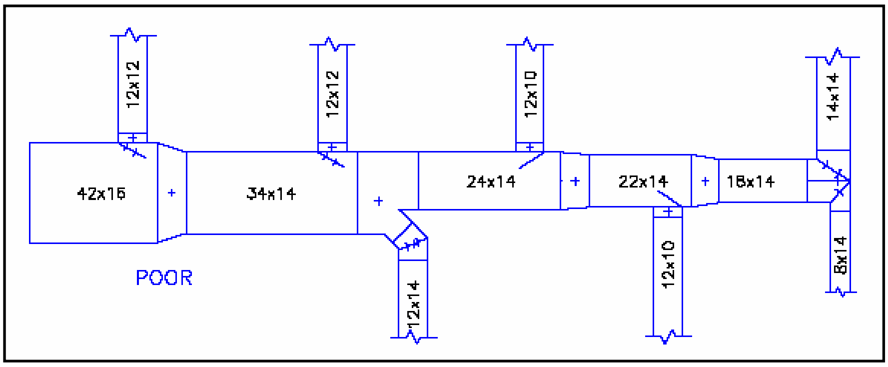
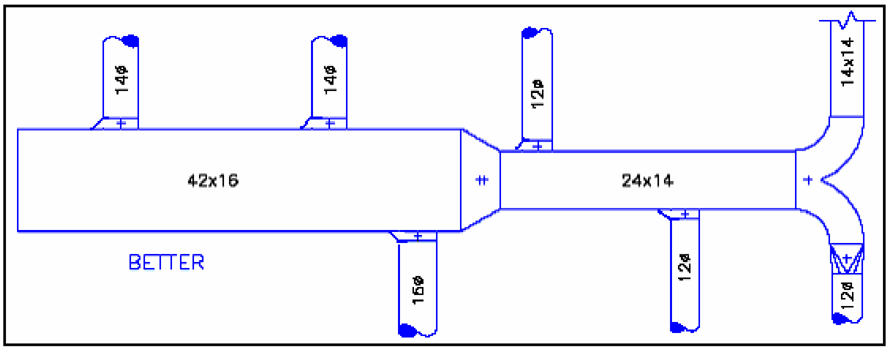


Fig. (5-b): Sudden Enlargement







Examples of Poor and Better Duct Design

What is Cold Air Distribution?

The “conventional approach” to the design of the HVAC system is based on estimating the heat load and computing the air volume for delta temperature (ΔT) between the room set point temperature minus the supply air temperature. For comfort applications, the room set point temperature is 75°F (23.9°C) and the supply air temperature is designed for 55°F (12.8°C); therefore the ΔT is taken as 20°F (11.1°C).

The “cold air systems” distribute air at a temperature much lower than 55°F. The coldest practical air temperature is about 38°F, with most cold air designs using 42-48°F.

Why Use Cold Air Distribution?

For a given air-conditioning load, as the supply air temperature is reduced, the supply air volume is reduced proportionally. Let’s check this for 1 ton of air-conditioning load.

The sensible heat gain equation is Q =1.08×CFM×ΔT **or** ($Q = 1.23 \times \dot{\vartheta} \times \Delta T$)
Where:
Q is sensible heat in Btu/hr. (Note that for 1 ton of refrigeration, Q is equivalent to the heat extraction rate of 12,000 Btus per hour or 3.517kW)
CFM is the air volume required
ΔT is the temperature differential of the space set point minus the supply air temperature
Consider two cases:
Case # 1: The room set point temperature is 75°F and the supply air temperature is 55°F
Case # 2: The room set point temperature is 75°F and the supply air temperature is 45°F

In Case # 1, the ΔT is 20°F and therefore the air volume per ton of air-condition load will be:
CFM = 12000 / (1.08 x 20) or = **555/ton**

In Case # 2, the ΔT is 30°F and therefore the air volume per ton of air-condition load will be:
CFM = 12000 / (1.085 x 30) or = **370/ton**
This shows that by simply lowering the supply-air temperature from the 55°F to 45°F, it reduces the supply-air volume by 33%.

Northern Technical University
Technical College of Engineering
Department of Power Mechanics Techniques

Fourth Year
Air Conditioning System Design

Chapter Two
"Lecture Three"
Advanced Air Duct Design

Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

Fan Total Pressure:

To overcome the fluid friction and the resulting head, a fan is required in air conditioning systems. When a fan is introduced into the duct through which air is flowing, then the static and total pressures at the section where the fan is located rise. This rise is called as Fan Total Pressure (FTP). Then the required power input to the fan is given by:

$$W_{fan} = \frac{\dot{Q}_{air}.FTP}{\eta_{fan}}$$

The FTP should be such that it overcomes the pressure drop of air as it flows through the duct and the air finally enters the conditioned space with sufficient momentum so that a good air distribution can be obtained in the conditioned space. Evaluation of FTP is important in the selection of a suitable fan for a given application. Fan total Pressure is the pressure differential between the inlet and the outlet of the fan. It can be expressed in these terms:

$$P_{t\,fan} = P_{t\,loss} + P_{v\,system\,outlet} + (P_{s\,system\,outlet} + P_{s\,system\,entry} + P_{v\,system\,entry})$$

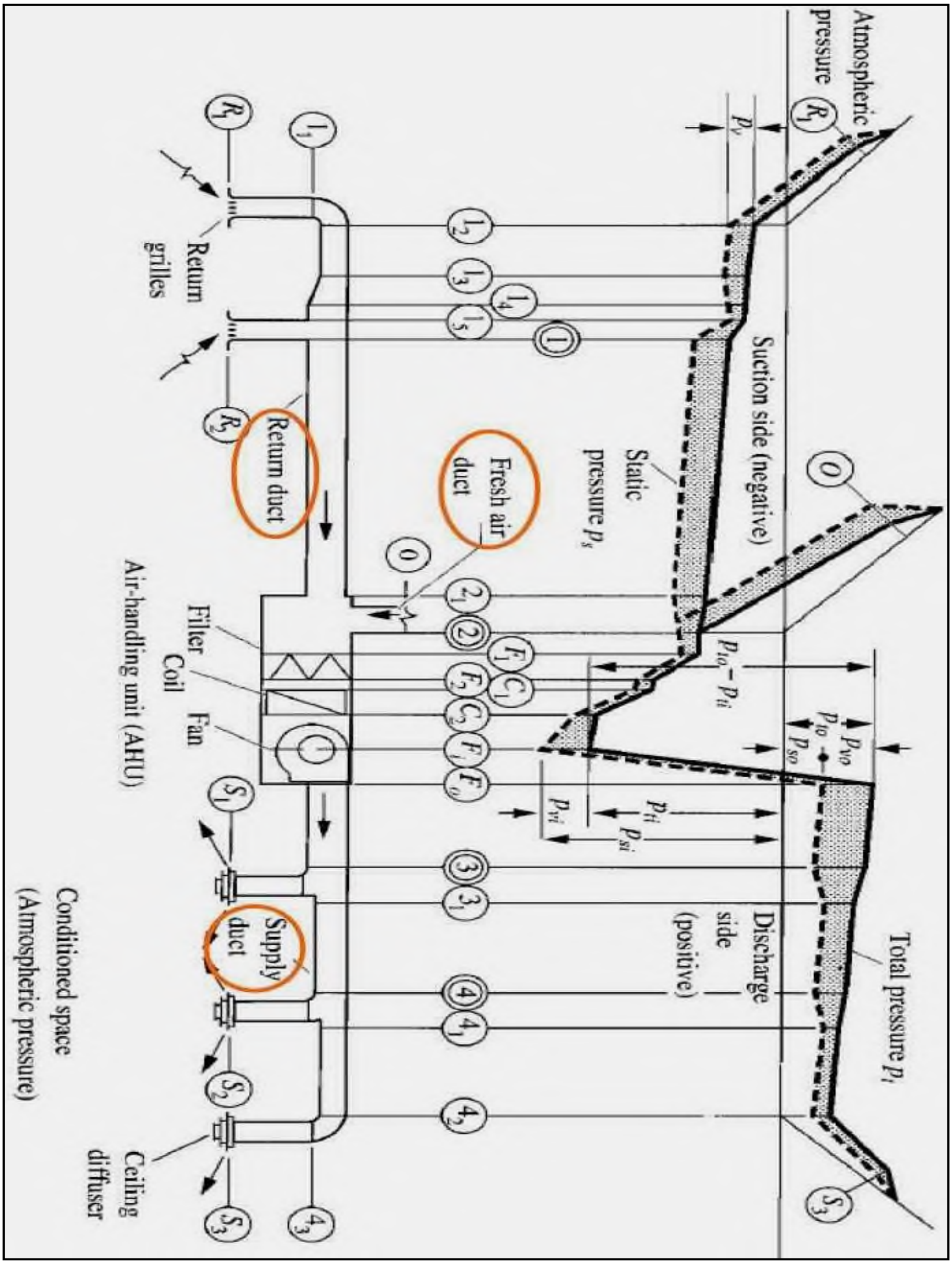
$P_{t\,fan}$ = Fan Total Pressure
$P_{t\,loss}$ = Dynamic, Component, and Frictional Pressure through the air duct system.
$P_{s\,system\,outlet}$ = Static Pressure at System Outlet
$P_{s\,system\,entry}$ = Static Pressure at System Entry
P v system entry = Velocity Pressure at System Entry
P v system outlet = Velocity Pressure at System Outlet
For most HVAC applications: (P s outlet + P s entry + P v entry) = 0

Therefore: $P_{t\,fan} = P_{t\,loss} + P_{v\,system\,outlet}$

Fan Static Pressure

The Fan Static Pressure is expressed as the Fan Total Pressure minus the velocity pressure at the fan discharge, or:
P_s fan =(P t loss + P v system outlet) - P v discharge
Where P v discharge = Velocity Pressure at the Fan Discharge.
For Exhaust Systems with resistance only on the inlet side, the fan static pressure is:
P_s fan = $P_{t\,loss}$
For exhaust system: P v system outlet = P v discharge
For Supply Systems with resistance on the outlet side, the fan static pressure is:
P s fan = P t loss - P v discharge
P v system outlet can be assumed to be 0.

Fan Total Pressure (FTP). Then the required power input to the fan is given by the diagram below illustrates the type of pressure loss within air duct system:



Fan Running Costs

Running costs can be examined as follows;
Fan power (W) =Fan pressure (Pa) × Air Volume flow rate (m3/s) / Efficiency

Annual running cost (£/annum) =Fan power (kW) × Hours run per annum × Electrical price £ per kWh

For example:

If a fan runs for 2496 hours per year and delivers 0.625 m3/s against a pressure of 200 Pa, then the annual running costs can be calculated as follows; Take electricity cost at 11.2 p/kWh = 0.112 £/kWh.

Fan power (W)= Fan pressure (Pa) x Air Volume flow rate (m3/s) / Efficiency
Fan power (W)= 200x0.625 / (say) 0.6
Fan power (W)= 208 Watts.
Fan power (kW)= 0.208 kW.
Annual running cost (£/annum) =0.208 × 2496 × 0.112
Annual running cost (£) =£58.15 per annum

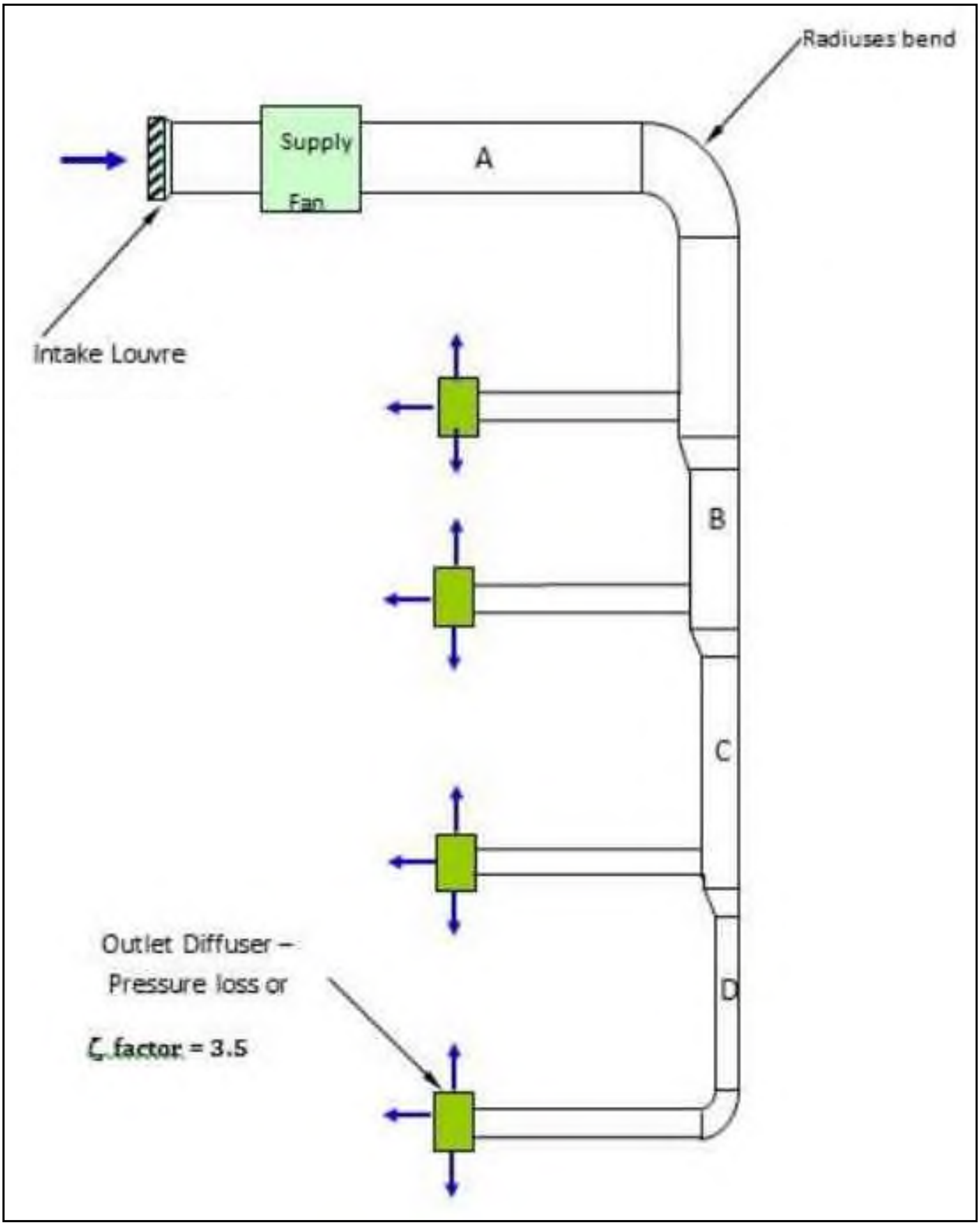
Problem (1): Find the size of rectangular air duct by using EFM method as show in figure below, also find the following:

- Gauge of galvanize iron sheet metal.
- Aspect ratio for each section
- Static and dynamic loss.
- Fan total pressure.

Note: Each diffuser give 300LPS

Solution:

Index Run :A-B-C-D


Radiuses bend
Supply
Fan
A
Intake Louvre
B
C
D
Outlet Diffuser –
Pressure loss or
ζ factor = 3.5

1	2	3	4	5	6	7	8	9	10	11=10+9	12	13	14	15
Section	Length (m)	Rate (L/s)	Pr. Drop (Pa/m)	Eq. Diam. (mm)	Velocity (m/s)	Velocity Pressure (Pa) 0.5*e*v^2	Fitting (z)	Pressure Loss: Dynamic Loss=8*7 (Pa)	Pressure Loss: Straight Duct=4*2 (Pa)	Total Pressure Loss (Pa)	Cumulative Pr. Loss (Pa)	Duct Area W*H mm^2	Sheet Gauge	A.R.
A	10	1200	1.16	430	7	29.4	0.24+0.04+0.2= 0.48	14.1	11.6	25.7	25.7	450*350	24	1.28
B	3	900	1.16	410	6.8	27.7	0.09+.2=0.29	8	3.5	11.5	37.2	400*350	24	1.14
C	6	600	1.16	340	5.9	20.88	0.07+.2=0.27	5.6	7	12.56	49.7	350*275	24	1.2
D	8	300	1.16	230	5	15	0.36+3.5=3.85	57.85	9.3	67.13	116.83Pa	350*125	24	2.8

T.F.P.=116.83

Q=1200L/s

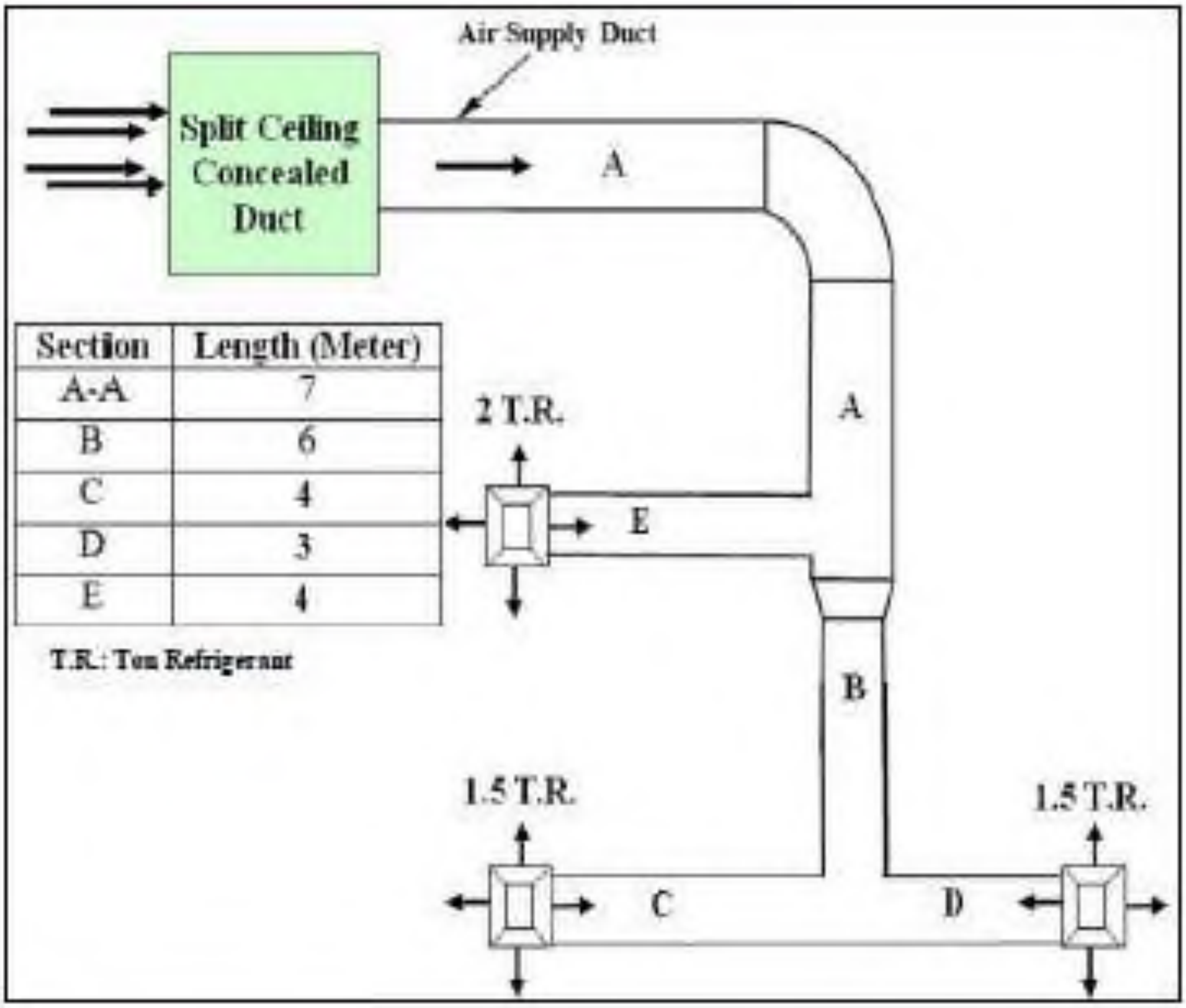
Tutorial Sheet
Assume Any Missing Data

Problem One:

Find the size of rectangular air duct as show in figure below, also find the following:

- Gauge of galvanize iron sheet metal.
- Aspect ratio for each section.
- Static and dynamic loss.
- Fan total pressure.

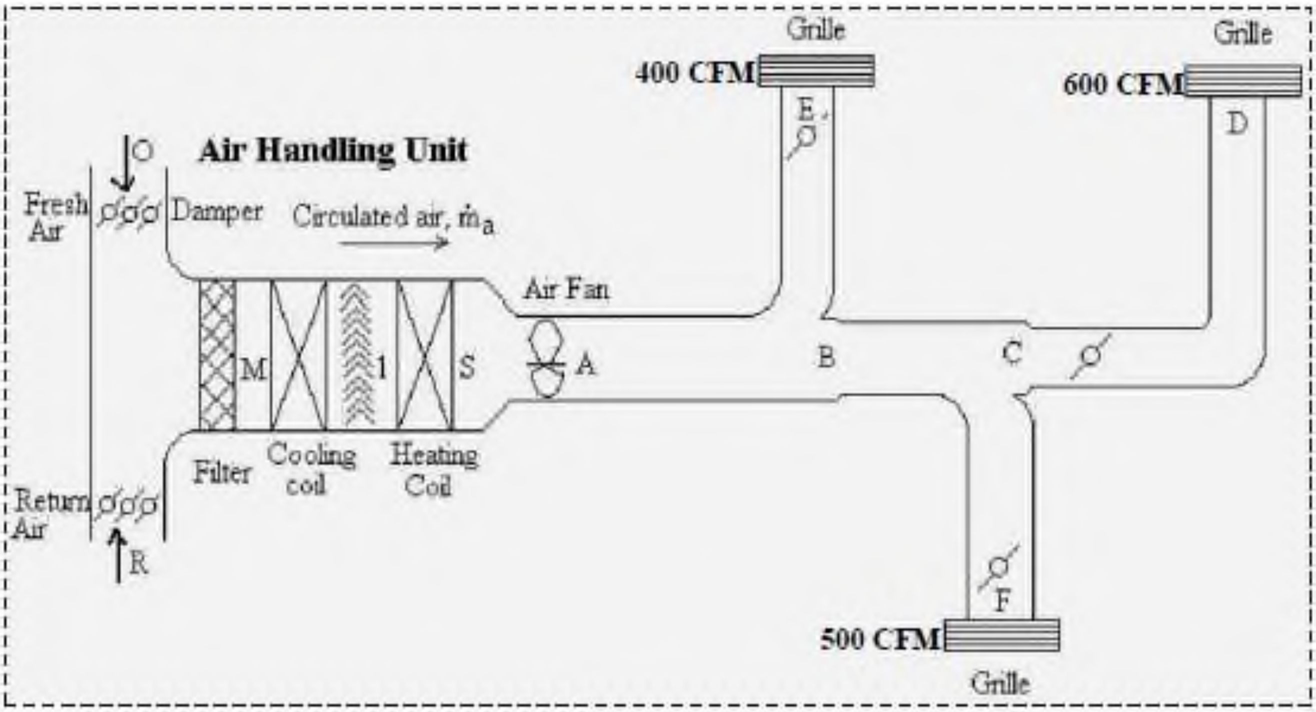
Take Height of air duct =30cm, design ΔT=8°C and main velocity 7.2m/s



Section	Length (Meter)
A-A	7
B	6
C	4
D	3
E	4

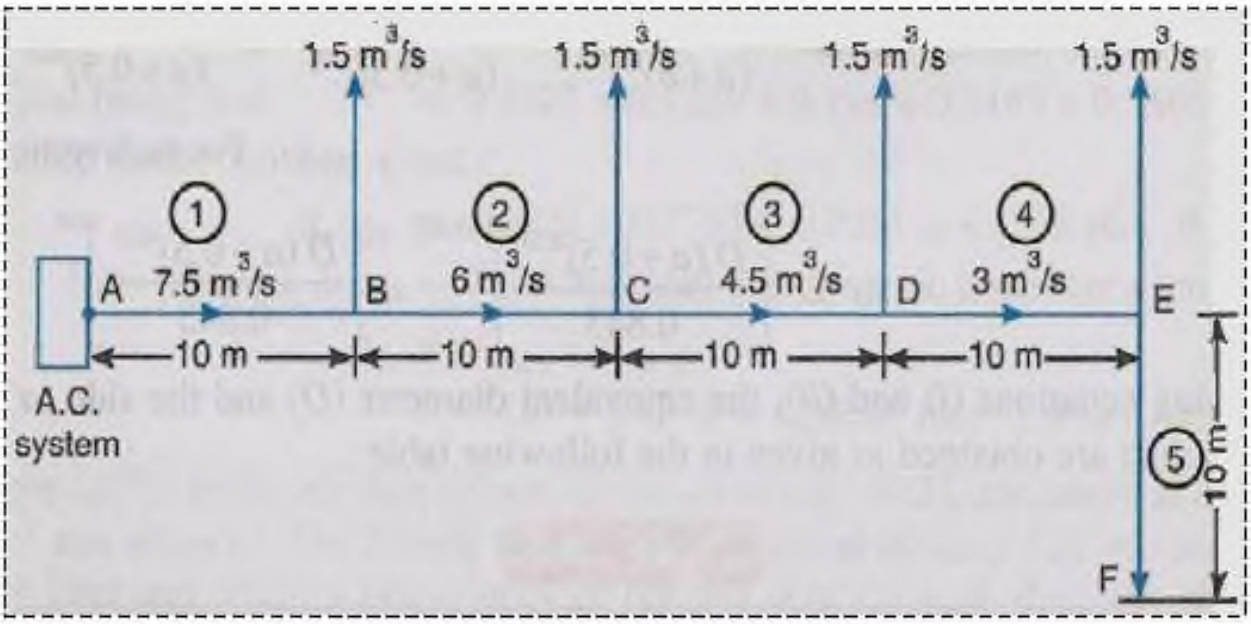
Problem Two: Find the size of Circular air duct as show in figure below, also find the following:

- Gauge of galvanize iron sheet metal.
- Static and dynamic loss.
- Fan total pressure.



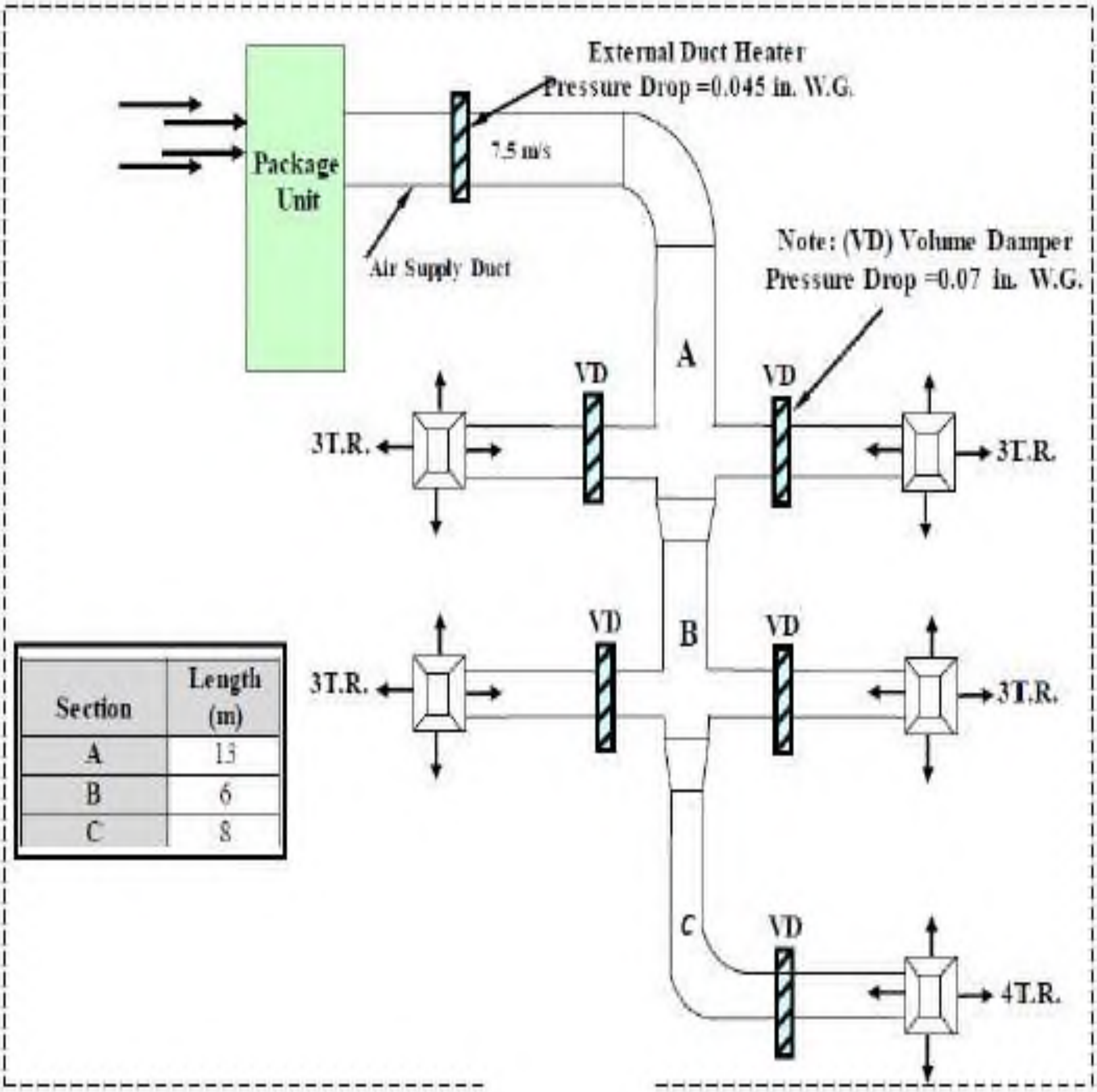
Problem Three:

Find the size of Circular air duct as show in figure below:



Problem Four: Find the size of Circular air duct as show in figure below, also find the following:

- Gauge of galvanize iron sheet metal.
- Static and dynamic loss.
- Fan total pressure.



Section	Length (m)
A	13
B	6
C	8

Blank Paper

Northern Technical University
Technical College of Engineering
Department of Power Mechanics Techniques

Fourth Year
Air Conditioning System Design

Chapter Three
“Lecture One”
Air Distribution

Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

Chapter Three
Air Distribution

1. **Class** : Fourth Year

2. **Subject** : Air Delivery and Distribution in rooms

3. **Number of weeks:** Two week

4. Central idea: How to distribution air into zone, Types of diffuser and grill, How to select correct size for air outlet

5. **The Test & Problems**:

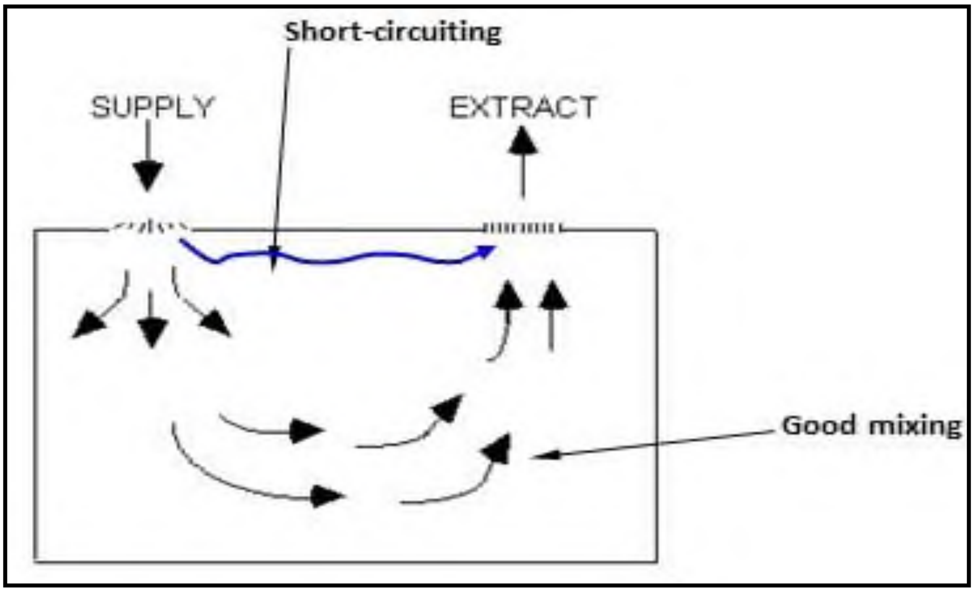
Air Distribution and Air Diffuser Selection

Introduction:

Air is supplied into rooms via air diffusers or air grill. These are used to direct the air in one, two and three or four directions if square or rectangular units are installed.

- Return or Extract air is removed via a grille. These are not required to direct the air and are simpler in construction.
- For continuity and aesthetic reasons diffusers may be used for both supply and extract.

  It is difficult to supply or extract air at low level in rooms because draughts may result from low-level supplies and vertical ductwork in rooms is not generally feasible. It is therefore usual to supply or extract air from the ceiling as shown below, but this means that air velocities at diffusers must be sufficient to ensure adequate mixing within the space otherwise short-circuiting of grilles may occur.

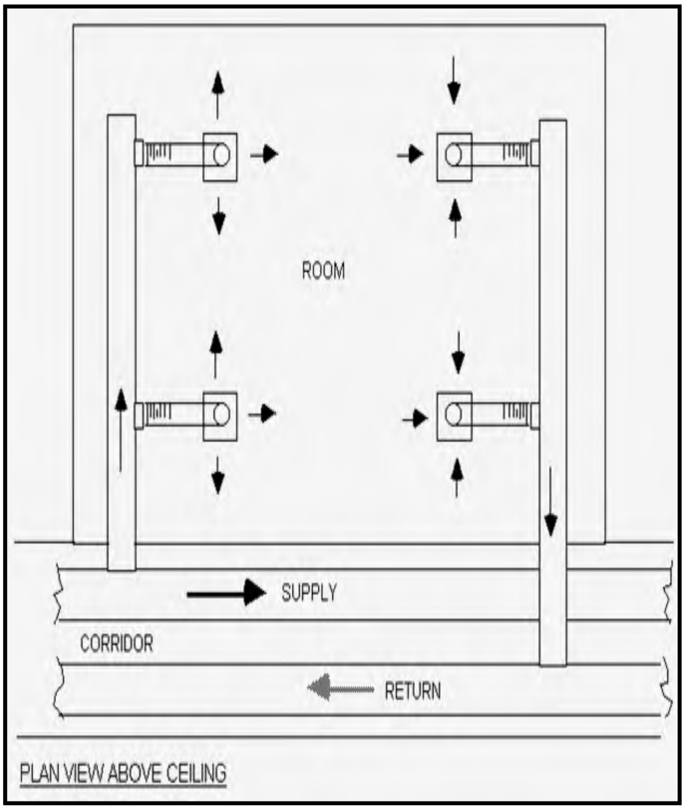


Air Distribution within space

Circular diffusers may be used in some areas especially if they blend into the ceiling layout or room shape. Another option is to use **linear slot diffusers** which can give a continuous long system of air distribution. This may be an advantage in some types of room. In rooms with a very high ceiling it may be necessary to use a **nozzle** which acts like a jet to force the air down to the occupied space. One difficulty associated with high velocity jets is noise production. This is one of the aspects of air distribution which must be addressed by the engineer.

Air System Layout:

When designing ventilation systems it must be remembered that since most of the ductwork is installed within ceiling spaces, it is a good idea to liaise closely with the Architect at the early stages of design so that **space requirements** are met. It is common practice to use flexible ductwork to grilles and diffusers. These have several advantages; sharp bends are eliminated, flexible ductwork has better sound adsorption qualities compared to sheet metal, it is easier to install especially in a congested area and it allows more freedom in positioning the grille or diffuser. A **plenum box** can be used to connect the ductwork system to the grille or diffuser. This has a larger cross sectional area than the connecting duct and reduces the air velocity before it enters the diffuser thus giving better air distribution over total diffuser area. A less expensive method is to use diffusers with factory-fitted square or round necks, which can be fitted directly to the flexible duct connection. Each grille or diffuser should have a **damper** to regulate flow of air. This **damper** can be an opposed blade type incorporated within the diffuser or a butterfly volume control damper (VCD) positioned in the branch duct. All dampers require **access.**



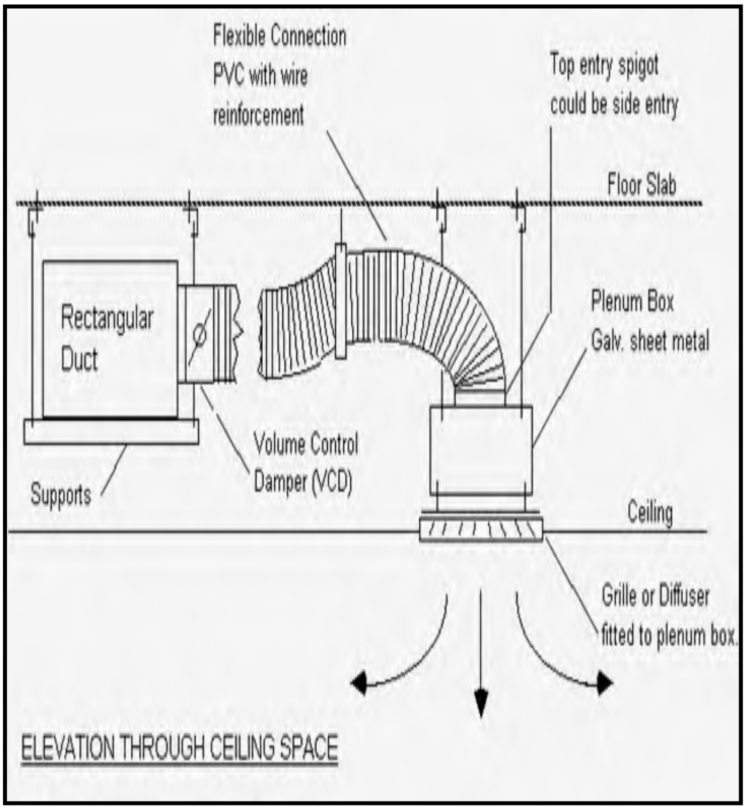
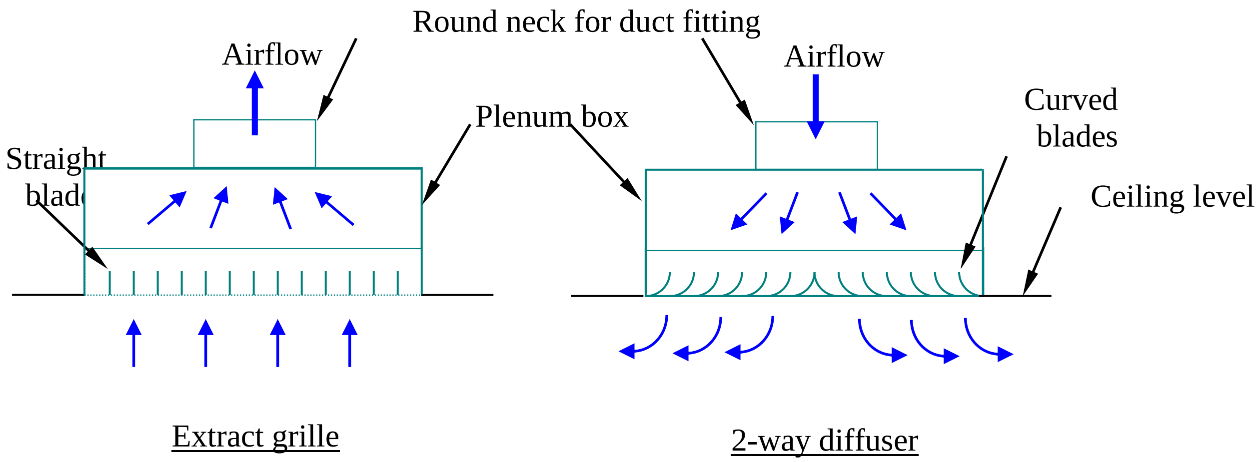


Figure above shows a typical system using linear or slot diffusers. These have the advantage that air can be distributed over a wider area and the **'coanda'** effect can be utilised.

Grilles and Diffusers

A grille is a device for supplying or extracting air vertically without any deflection. A diffuser normally has profiled blades to direct the air at an angle as it leaves the unit into the space, as shown below.



Grilles and Diffusers can be manufactured in:

- Aluminium
- Mild steel
- Stainless steel
- Plastic

Finishes can be white, any colour, brushed or anodised aluminium, stainless steel or chrome.

Grilles and diffusers may be mounted in ceilings, floors, walls, doors and in ducts. Some are suitable for horizontal or vertical mounting while floors grilles tend to be especially strong to withstand foot traffic.

Types of Grille and Diffuser

There are several types of grille and diffuser to choose from, as follows;

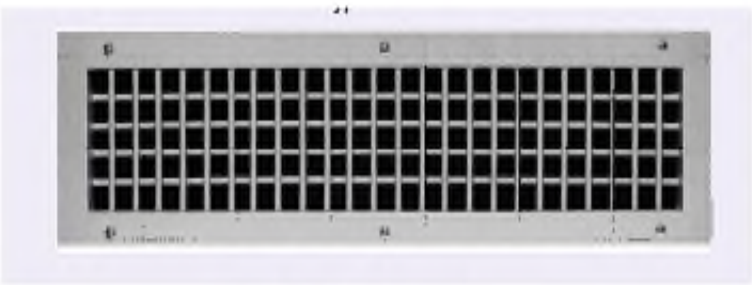
- Egg grate grille
- Bar grille
- Transfer grille
- Louvre bladed diffuser
- Straight bladed diffuser

❖ Linear slot diffuser

Less commonly used diffusers are as follows;

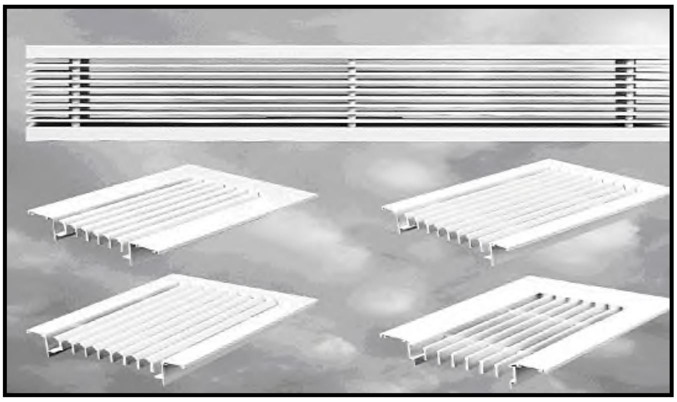
- Swirl diffuser
- Floor outlet diffuser
- Jet diffuser
- Punkah diffuser
- Barrel diffuser
- Perforated diffuser
- Valves
- Plain face diffuser

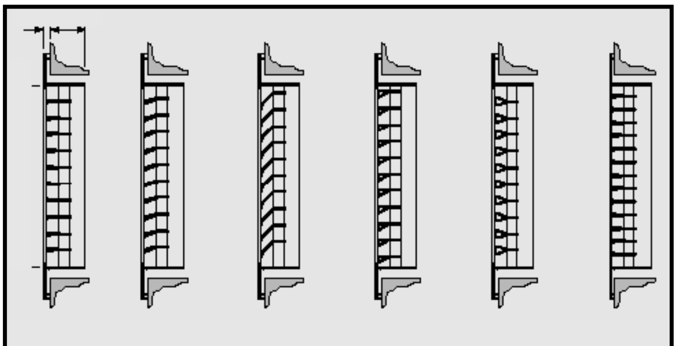
Egg Crate Grille:



Egg crate grille

Bar Grille

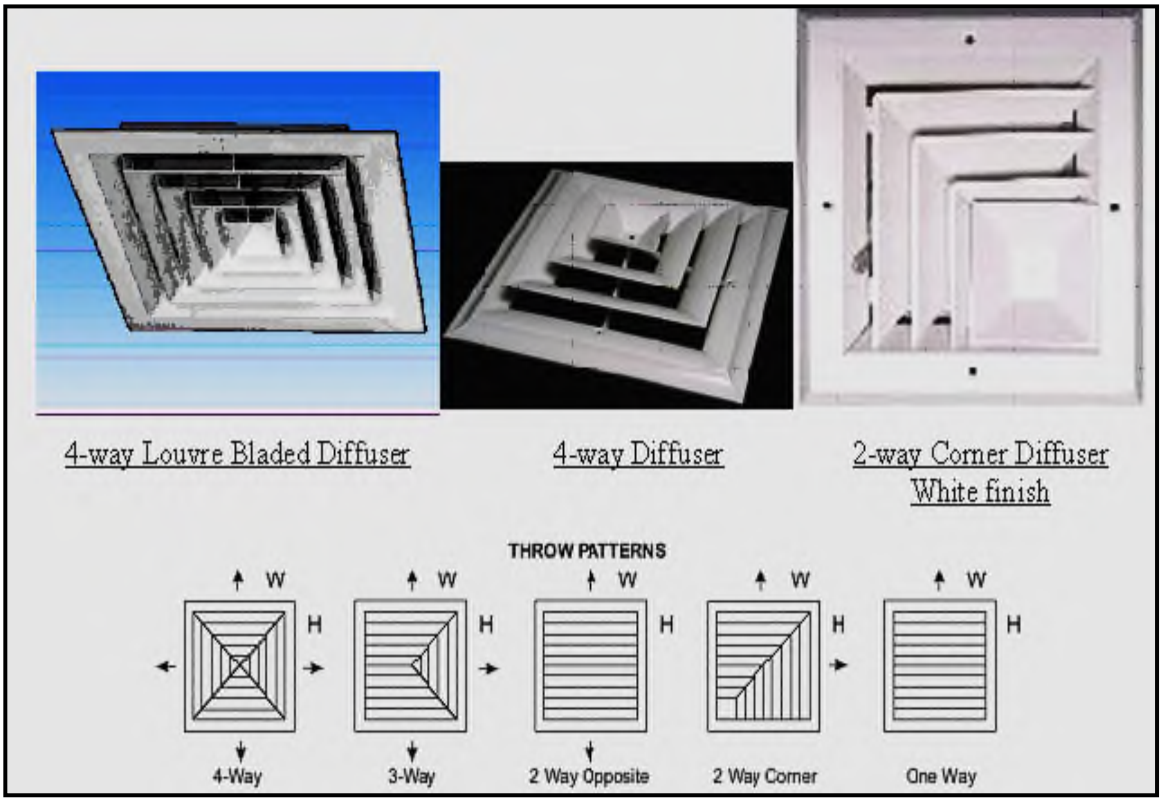




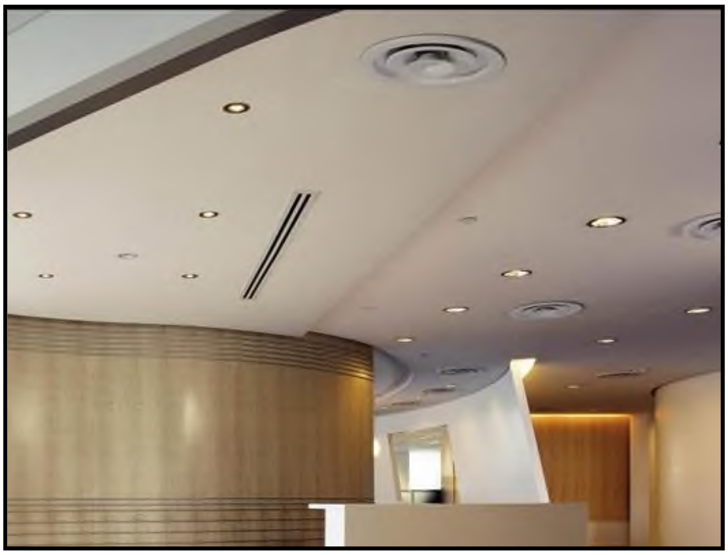
Blade shapes for Linear Bar grilles

Louvre Bladed Diffuser:

These are used to supply air at ceiling level.
The curved blades deflect air in one, two, three or four directions depending on where the diffuser is situated.

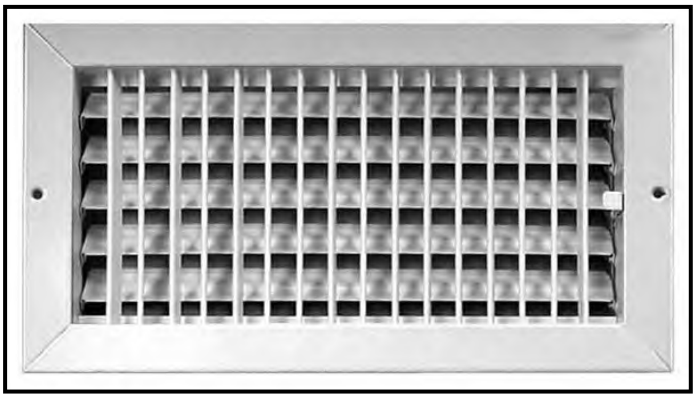


Diffusers may also be circular as shown below.



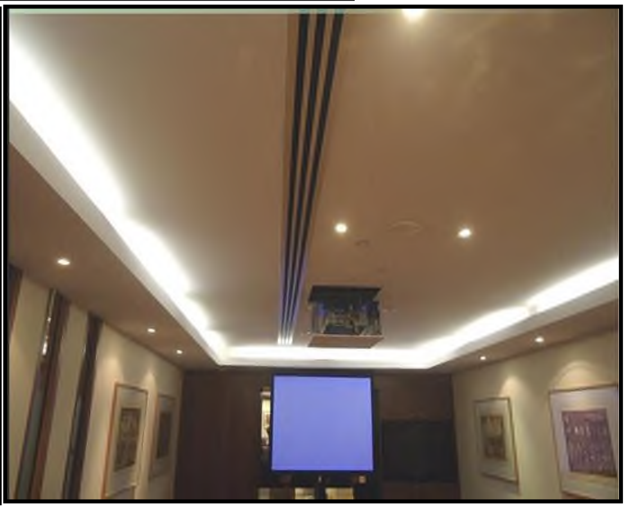

Straight Bladed Diffuser

These are cheaper than Louvre Bladed Diffusers .Some types have adjustable bladed as shown below.



Linear Slot Diffuser:

These are used for an alternative air distribution pattern and for aesthetic reasons. Air can be delivered around the perimeter of a room as opposed to point sources interposed in a ceiling space. Linear slots can be used for return air as well as supply.

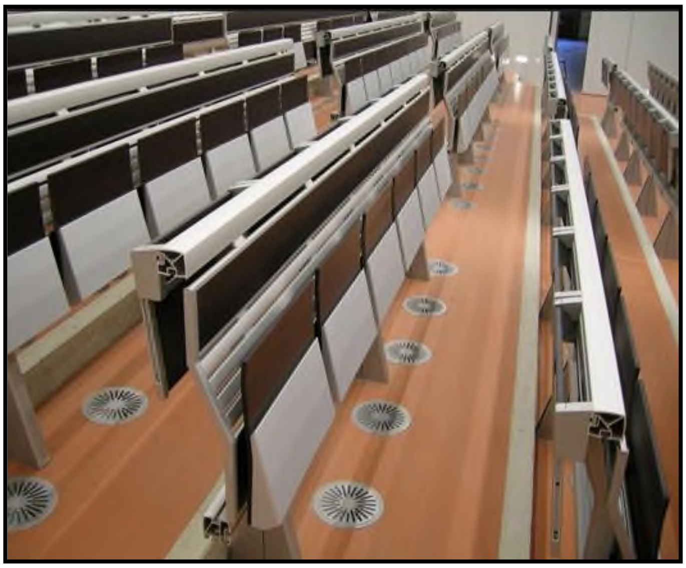


Swirl Diffuser:

High turbulence occurs immediately within the proximity of the diffuser.


Floor Outlet Diffuser (Under Floor Diffuser):

There is an advantage in supplying cool air conditioned air at low level. This can be achieved by floor outlets. Floor diffusers are also useful in areas with raised floors so that ductwork can be accommodated under the floor. Another area for floor outlets is under large areas of glass so that condensation and cold down draughts are eliminated.




Jet Diffuser:

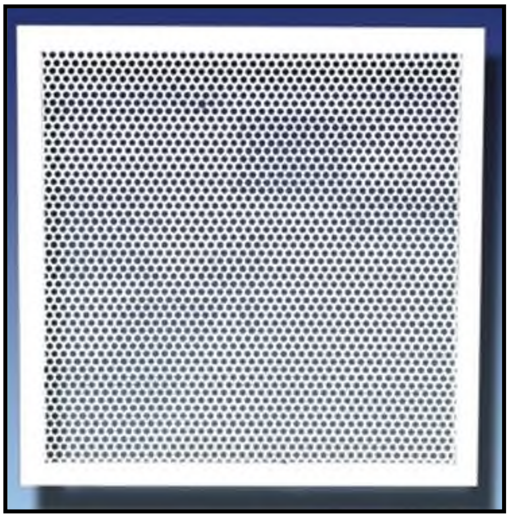
Used in areas where the ceiling is high and large air velocities are needed to reach the occupied space.



The high volume and long throw of these diffusers makes them suitable for large halls Some jet diffusers can be reversible and rotatable which allows the air jet to be adjusted for both pattern and deflection.

Perforated Diffuser:

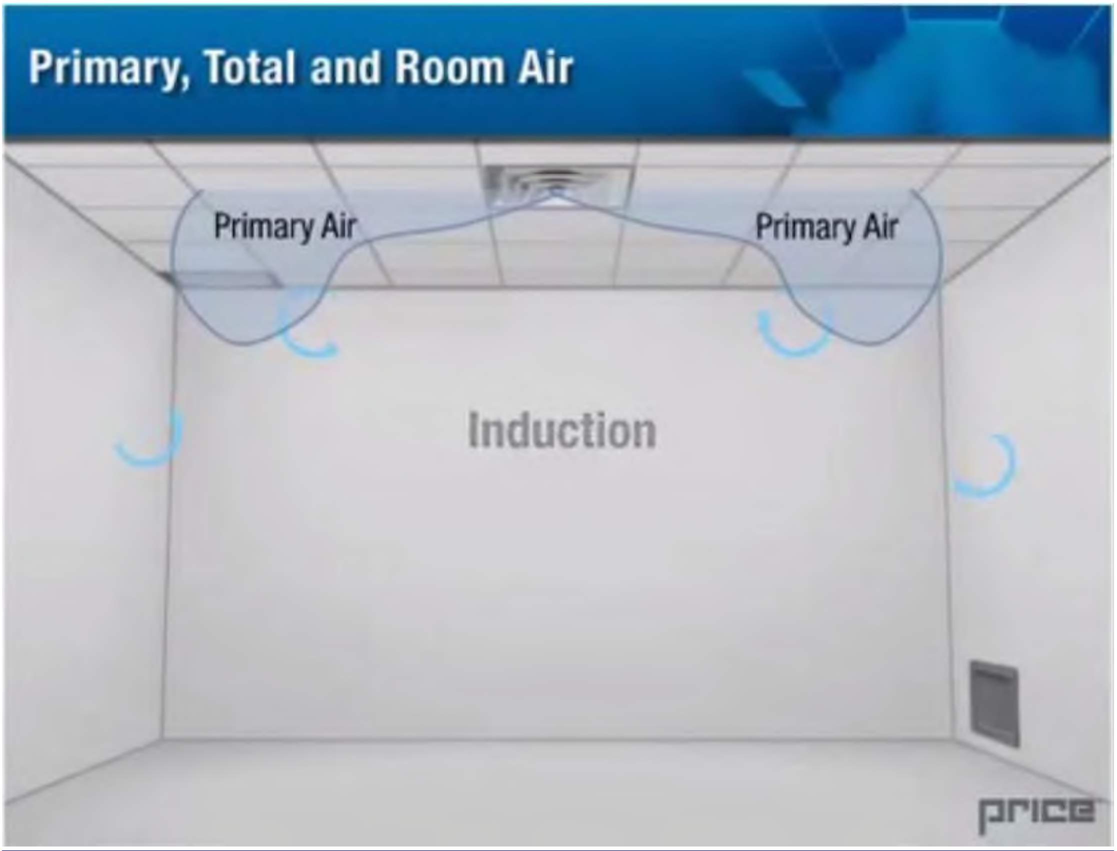
Perforated diffusers are suitable for installation in 600mm ceiling tiles. The face plate may be pivoted down to gain access. The diffusers are constructed from aluminium or stainless steel the flat face plates are perforated, this means that they are easily cleaned and are used in some kitchens.

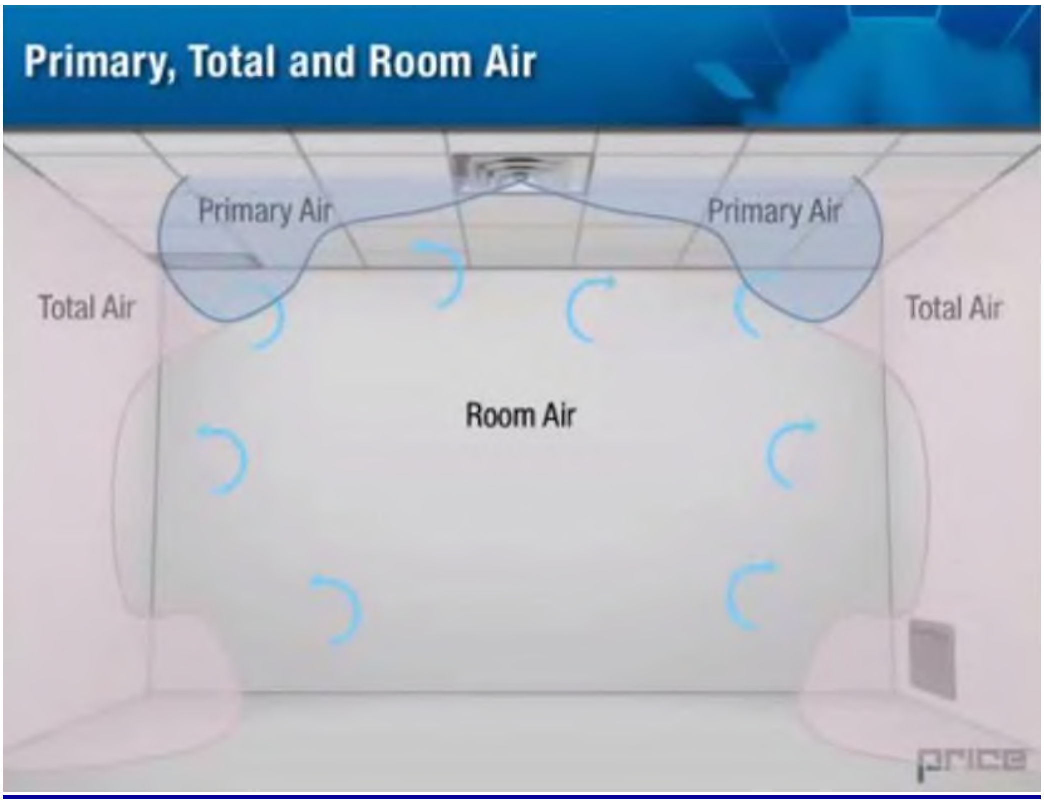


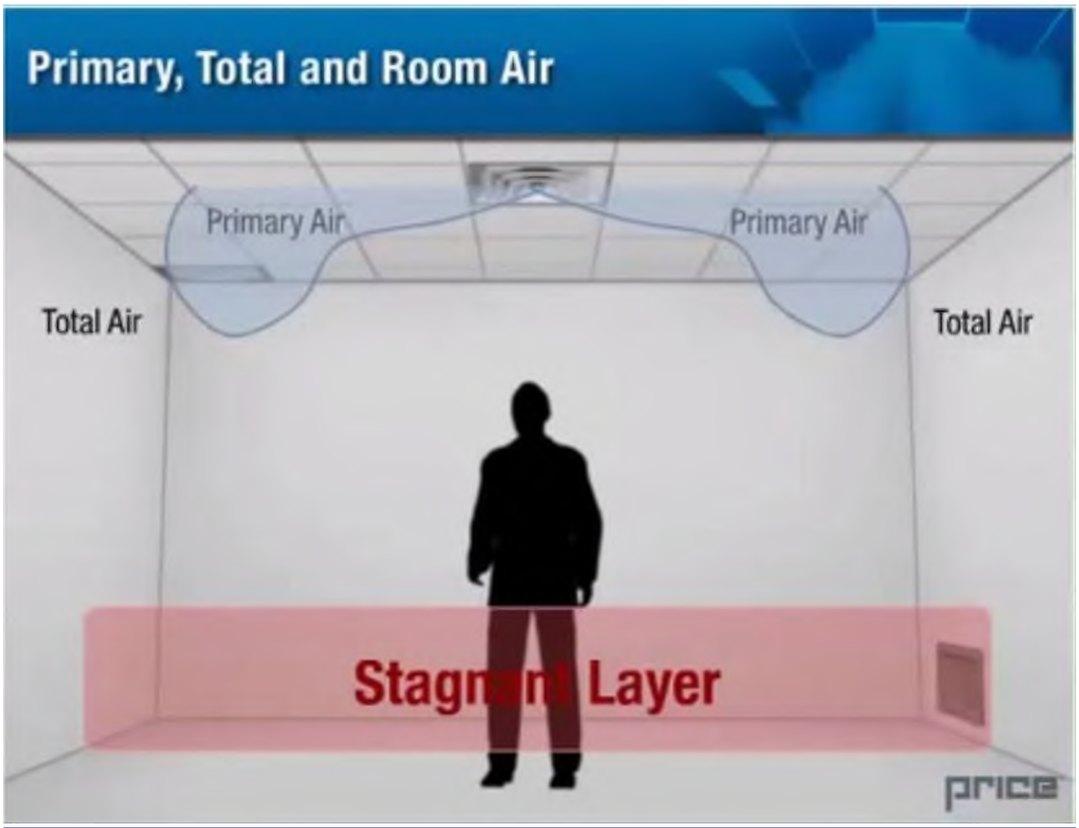
Valves:

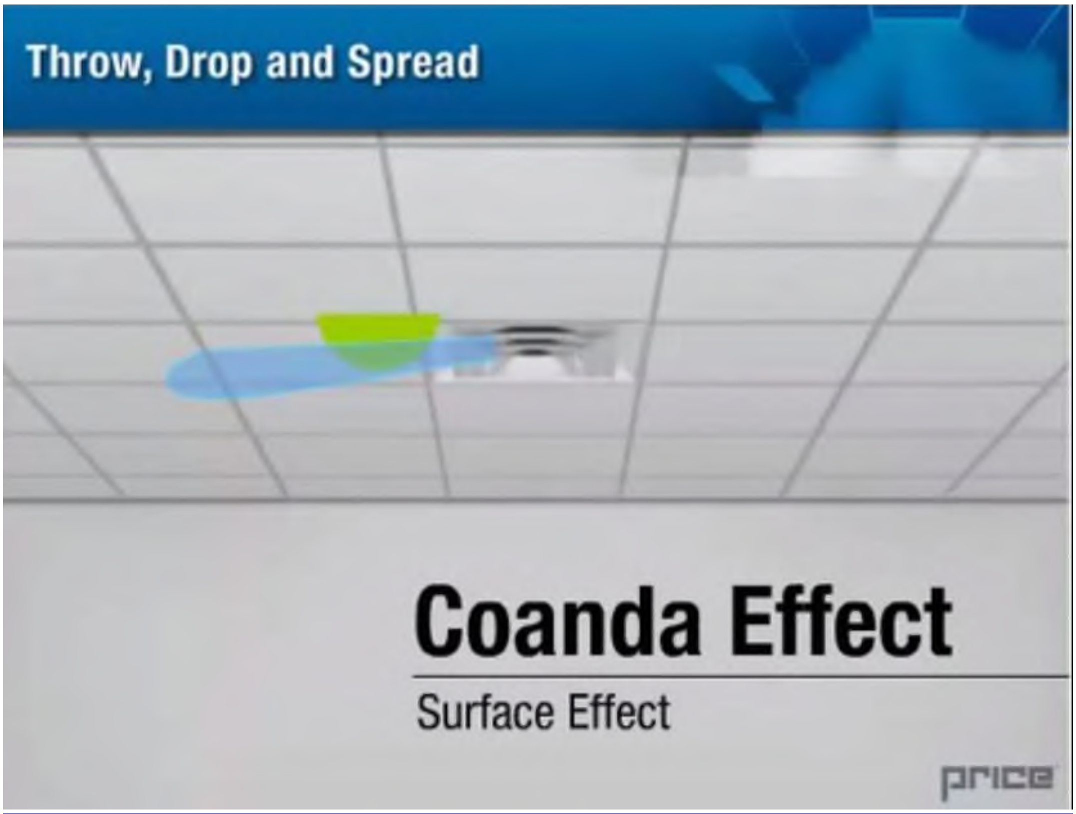
Valves are used where the air flow needs to be regulated or throttled and are suitable for supply and exhaust applications.

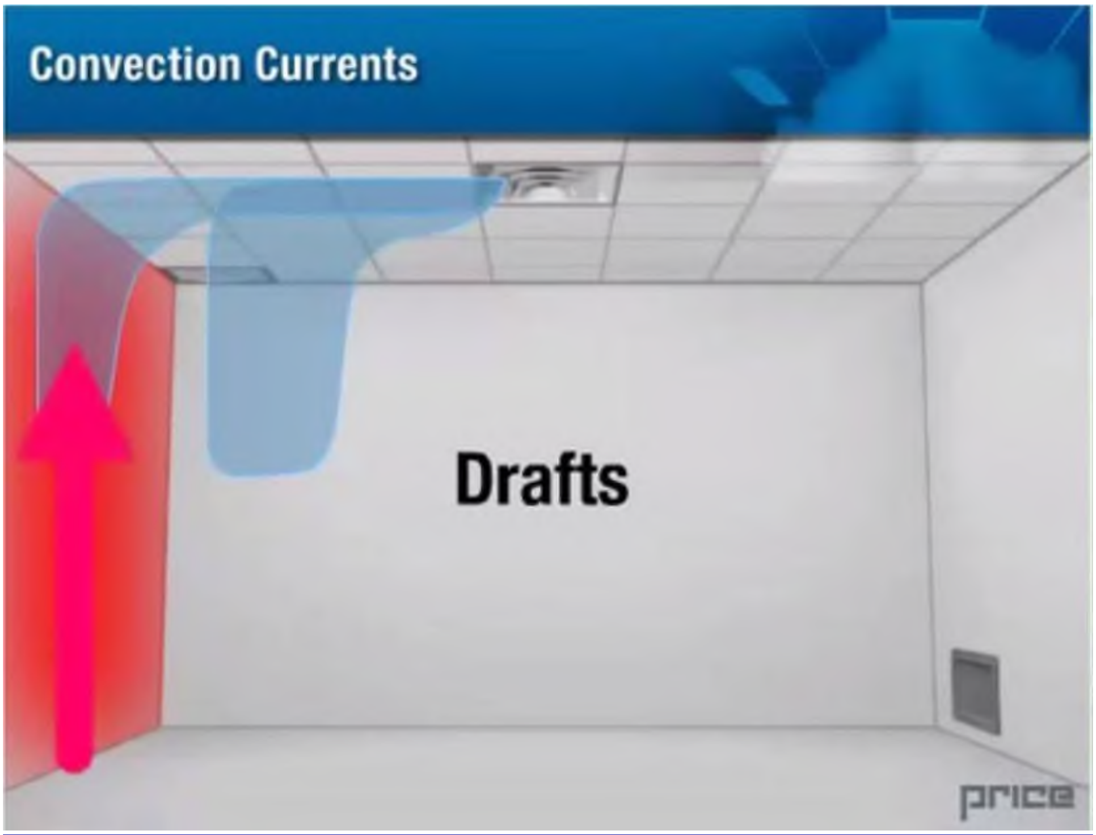

The Occupied Zone
1 foot
Occupied Zone
6 feet
1 foot


Primary, Total and Room Air
Primary Air
Primary Air
Induction
price


Primary, Total and Room Air
Primary Air
Primary Air
Total Air
Total Air
Room Air
price


Primary, Total and Room Air
Primary Air
Primary Air
Total Air
Total Air
Stagnant Layer
price


Throw, Drop and Spread
Coanda Effect
Surface Effect
price


Convection Currents
Drafts
price

Northern Technical University
Technical College of Engineering
Department of Power Mechanics Techniques

Fourth Year
Air Conditioning System Design

Chapter Three
"Lecture Two"
Air Distribution

Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

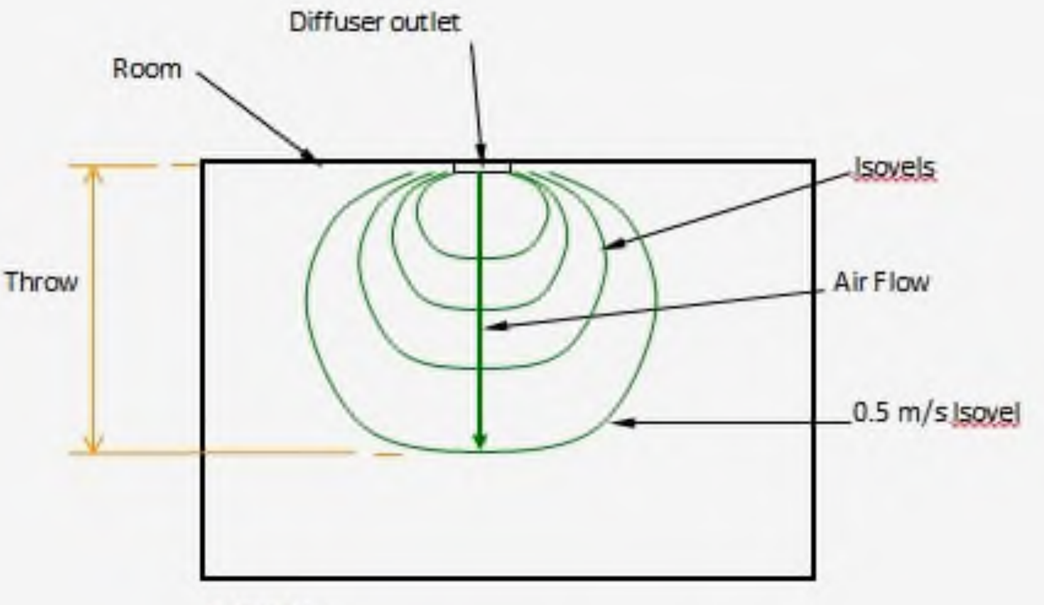
Diffuser Terminology:

There are several terms used in diffuser and grille systems as follows;

- **Isovel**: A contour of equal velocity.
- **Throw**: The distance from the terminal to the position where the velocity has decayed to 0.5 m/s.

The lower velocities of 0.5 m/s and 0.25 m/s are important because this is near the comfort zone.

- **Spread**: This is the width of the 0·5 m/s isovel.
- **Drop** : This is the vertical distance from the centre-line of the terminal to the bottom edge of the 0·25 m/s isovel.



Air Flow from a Diffuser into a Room

- **Occupied zone** : is defined as all the space in the conditioned zone that is from the floor to a height of 1.8 m and about 30 cms from the walls. In the occupied zone, the maximum variation in temperature should be less than 1°C and the air velocity should be in the range of 0.15 m/s to 0.36 m/s.

- **Draft in the occupied zone (should avoid it):** is defined as the localized feeling of cooling or warmth. Draft is measured above or below the controlled room condition of 24.4 °C and an air velocity of 0.15 m/s at the center of the room. The effective draft temperature (EDT) for comfort is given by:

$$EDT = (DBT - 24.4) - 0.1276(V - 0.15)$$

Where DBT is the local dry bulb temperature (in °C) and V is the local velocity (m/s).

For comfort, the EDT should be within –1.7°C to +1.1°C and the air velocity should be less than 0.36 m/s.

- **Air Distribution Performance Index (ADPI):**

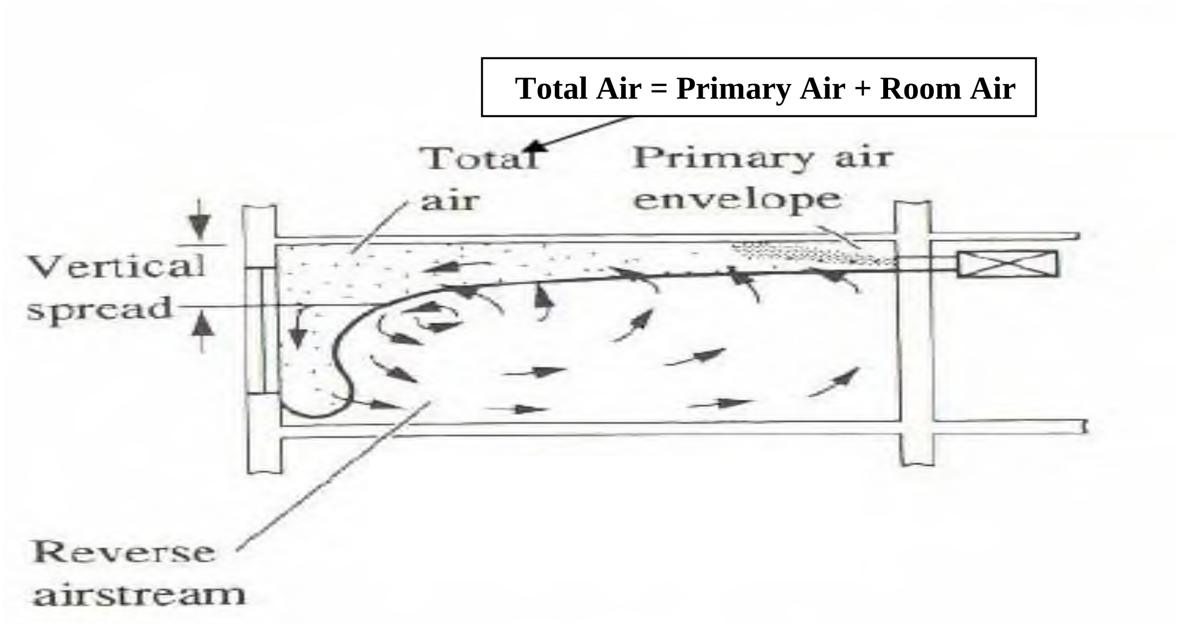
  The ADPI is defined as the percentage of measurements taken at many locations in the occupied zone of space that meets EDT criteria of –1.7oC to +1.1oC, that is:

$$ADPI = \left(\frac{N_\theta}{N}\right) x100$$

Where N is the total number of locations at which observations have been made, and Nθ is the number of locations at which the effective draft temperature is within –1.7°C to +1.1°C.

The objective of air distribution system design is to select and place the supply air diffusers in such a way that the ADPI approaches 100 percent. The ADPI provides a rational way of selecting air diffusers. Studies show that the value of ADPI depends very much on space cooling load per unit area. A large value of space cooling load per unit area tends to reduce the value of ADPI.

- **Total Air:** The figure below explain total air



Example (1): The following table shows the measurements made at 9 points in the occupied zone of an air conditioned building.
Evaluate the design of the air distribution system.

Measuring point	DBT (°C)	Air velocity (m/s)
1.	21.1	0.30
2.	21.7	0.25
3.	22.5	0.20
4.	23.5	0.21
5.	24.1	0.10
6.	24.7	0.08
7.	23.7	0.11
8.	22.8	0.19
9.	22.0	0.24

Answer:
From the DBT and air velocity (V) data, the Effective Draft Temperature (EDT) for each point is calculated using the equation:

$$EDT = (DBT - 24.4) - 0.1276(V - 0.15)$$

Measuring point	DBT (°C)	Air velocity (m/s)	EDT (°C)
1.	21.1	0.30	-3.32
2.	21.7	0.25	-2.71
3.	22.5	0.20	-1.91
4.	23.5	0.21	-0.91
5.	24.1	0.10	-0.29
6.	24.7	0.08	+0.31
7.	23.7	0.11	-0.69
8.	22.8	0.19	-1.61
9.	22.0	0.24	-2.41

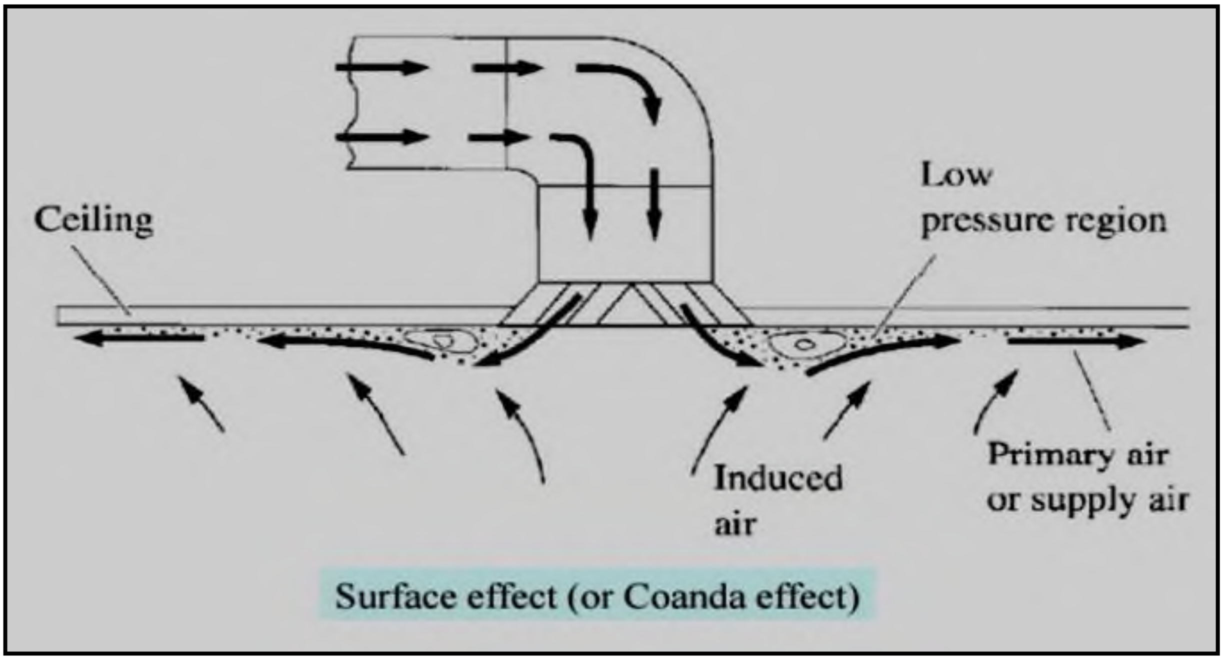
The calculated EDT values are shown in the table. It is seen from the table that the EDT value varies widely from −3.31ºC to +0.3ºC, indicating improper distribution.
(For comfort, the EDT should be within –1.7ºC to +1.1ºC and the air velocity should be less than 0.36 m/s.)

For this space the Air Distribution Performance Index (ADPI) is calculated using the equation:

$$ADPI = \left(\frac{N_\theta}{N}\right) x100 = \left(\frac{5}{9}\right) x100 = 55.6 \qquad \text{(Ans.)}$$

Where Nθ is the number of locations at which the effective draft temperature is within –1.7ºC to +1.1ºC.
An ADPI value of 55.6 indicates the need for improving the design of the air distribution system, as it indirectly indicates that only about 56% of the occupied zone meets the comfort criteria, whereas the remaining space gives rise to drafts.

- **Coanda effect:**
  As the air is discharged from the high side outlet, due to surface effect the air jet tends to stick to the ceiling as shown in the figure below:



Surface effect (or Coanda effect)

Design Criteria for Diffuser Design:

There are three criteria that determine diffuser size and number.
These are:

- Throw
- Pressure loss
- Noise level

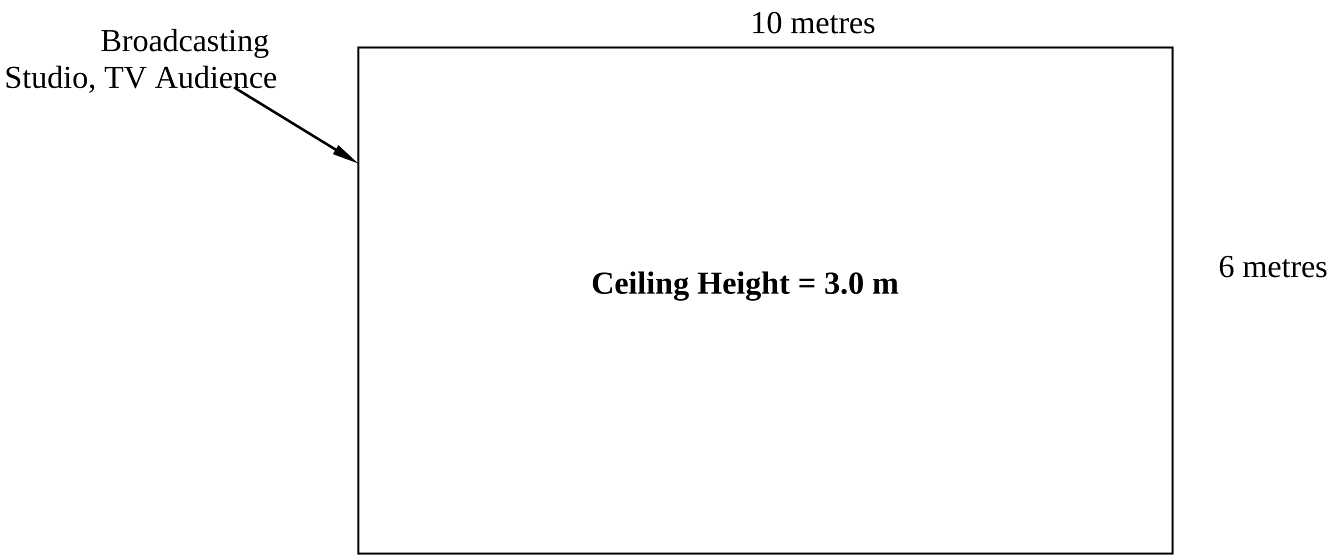
The throw is discussed on the previous page and the pressure loss is the pressure resistance to air flow and is required in duct and fan sizing calculations. The maximum Noise level is determined for various room types.

Example (2):

Design the diffuser system for the supply and return air ventilation for the room shown below.

DATA:

Air change rate is 10 ACH
The Noise Rating is 25dB.
The throw required is Ceiling height 3.0 minus 0.8m = 2.2 metres.
Keep the pressure drop below 20Pa.
Use M Series 4-way diffusers.



First step: Calculate ventilation rate for room in litres / second

Ventilation rate (m^3/h) =Air Change Rate (/h) x Room Volume (m^3)

Ventilation rate (m^3/h)=10 ACH x 10 x 6 x 3

Ventilation rate (m^3/h)= 10 ACH x 180 m^3.

Ventilation rate (m^3/h)=1800 m^3/h

Ventilation rate (m^3/s) =Ventilation rate (m^3/h) / 3600

Ventilation rate (m^3/s)=1800 m^3/h / 3600

Ventilation rate (m^3/s)=0.5 m^3/s

Ventilation rate (l/s)=Ventilation rate ($m^3/3$) x 1000

Ventilation rate (l/s)=0.5 m^3/s x 1000

Ventilation rate =500 l/s

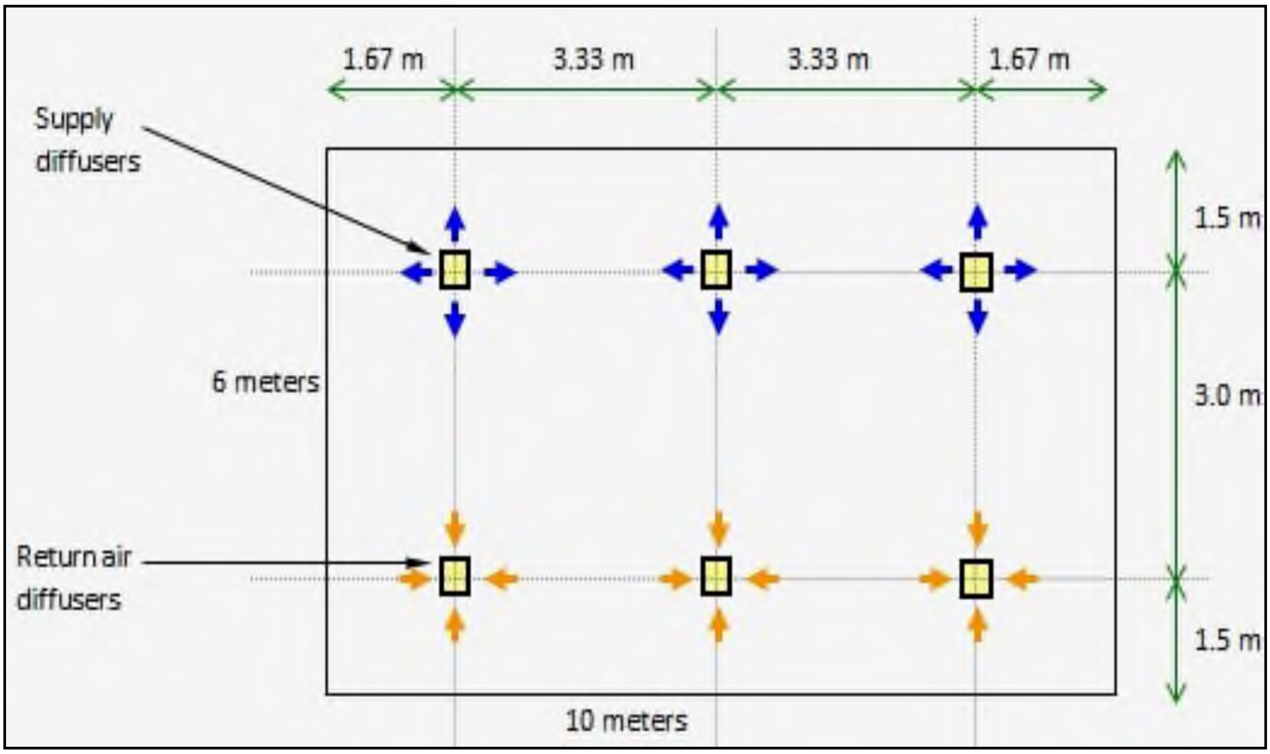
Second Step: Look at Waterloo catalogue and choose suitable sizes of diffusers to provide air into the room and meet the design criteria.

The design criteria are; Throw 2.2m, NR 25 and 20Pa. If two diffusers are used each flow rate is; 500 / 2 =250 l/s

From the sizing chart below for a flow rate of 270 l/s, an M450/M500 gives 2.5m throw, 33NR, 33 Pa.
This is too noisy with too much pressure drop. If three diffusers are used each flow rate is; 500 / 3 =167 l/s
From the sizing chart below for a flow rate of 180 l/s, an M450/M500 gives 2.0m throw, 23NR, 15 Pa.
This is good, the throw is just slightly less than 2.3m.
If four diffusers are used each flow rate is; 500 / 4 =125 l/s
From the sizing chart below for a flow rate of 135 l/s, an M450/M500 gives 1.5m throw, - NR, 9 Pa. The throw is not enough but the other criteria are met.
On the basis of the above data three M450/M500 diffusers are chosen.

Third Step: Show diffuser layout on a drawing.

The final diffuser layout should consider ceiling layout and lighting layout.
If ceiling tiles are used the diffusers position will be determined by the tile grid pattern. Careful co-ordination is required to install all the equipment into modern ceilings including warning devices and other services.



4 way air flow rate l/s		34	45	56	68	79	135	180	225	270	315	405	506	608	709
M300	Throw	1.0	1.2	1.5	1.6	2.0	-	-	-	-	-	-	-	-	-
	NR	-	-	-	-	21	-	-	-	-	-	-	-	-	-
	Pa	9	15	23	33	43	-	-	-	-	-	-	-	-	-
M450 M500	Throw	-	-	-	-	-	1.5	2.0	2.2	2.5	3.0	-	-	-	-
	NR	-	-	-	-	-	-	23	28	33	36	-	-	-	-
	Pa	-	-	-	-	-	9	15	23	33	43	-	-	-	-
M600 M625	Throw	-	-	-	-	-	-	-	-	-	2.0	2.5	3.5	4.0	4.5
	NR	-	-	-	-	-	-	-	-	-	25	32	37	40	44
	Pa	-	-	-	-	-	-	-	-	-	9	15	23	33	43
M300 extract	NR	-	-	-	21	24	-	-	-	-	-	-	-	-	-
	Pa	10	17	25	36	47	-	-	-	-	-	-	-	-	-
M450 M500 extract	NR	-	-	-	-	-	21	26	31	36	39	-	-	-	-
	Pa	-	-	-	-	-	10	17	25	36	47	-	-	-	-
M600 M625 extract	NR	-	-	-	-	-	-	-	-	-	28	35	40	43	47
	Pa	-	-	-	-	-	-	-	-	-	10	17	25	36	47

Directional blanking corrections (achieved with BM blanking kits)	As table	Air flow x 1.3	Air flow x 2	Air flow x 4

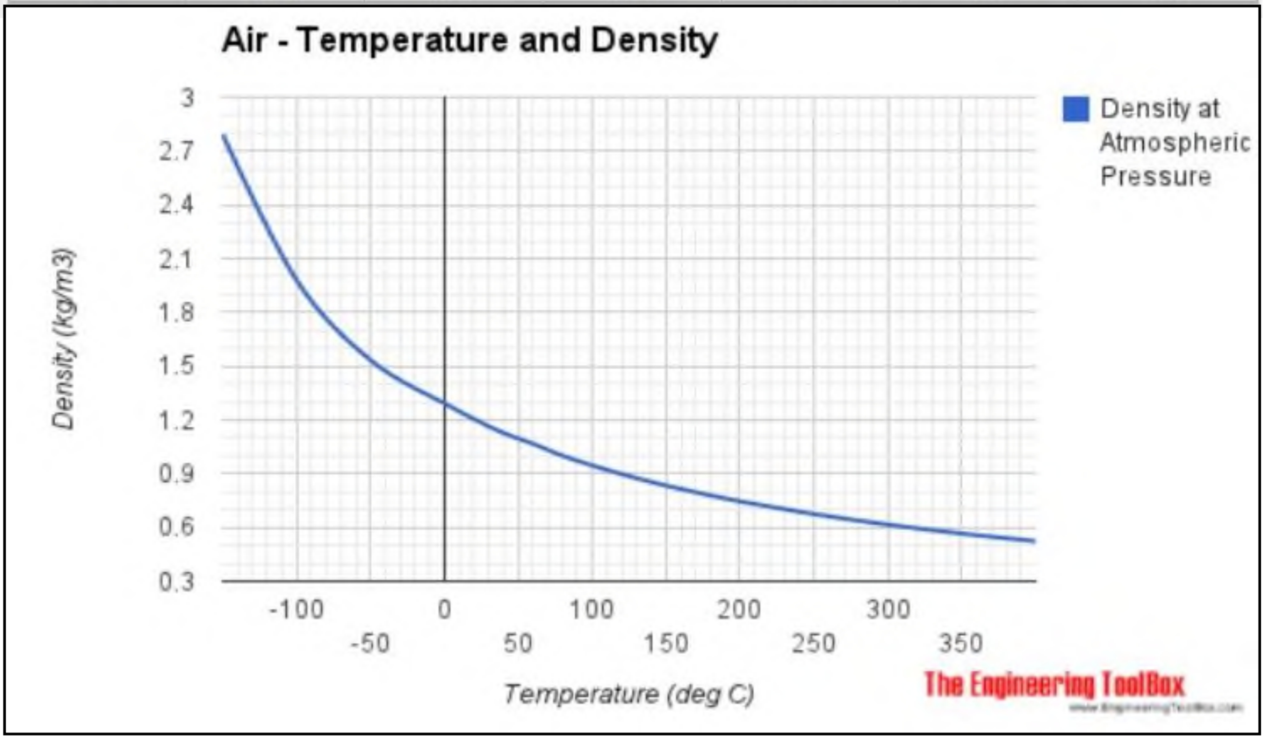
Room Types		Octave Band Analysis[a] NC/RC[b]	Approximate Overall Sound Pressure Level[a] dBA[c]	dBC[c]
Rooms with Intrusion from Outdoor Noise Sources[d]	Traffic noise	N/A	45	70
	Aircraft flyovers	N/A	45	70
Residences, Apartments, Condominiums	Living areas	30	35	60
	Bathrooms, kitchens, utility rooms	35	40	60
Hotels/Motels	Individual rooms or suites	30	35	60
	Meeting/banquet rooms	30	35	60
	Corridors and lobbies	40	45	65
	Service/support areas	40	45	65
Office Buildings	Executive and private offices	30	35	60
	Conference rooms	30	35	60
	Teleconference rooms	25	30	55
	Open-plan offices	40	45	65
	Corridors and lobbies	40	45	65
Courtrooms	Unamplified speech	30	35	60
	Amplified speech	35	40	60
Performing Arts Spaces	Drama theaters, concert and recital halls	20	25	50
	Music teaching studios	25	30	55
	Music practice rooms	30	35	60
Hospitals and Clinics	Patient rooms	30	35	60
	Wards	35	40	60
	Operating and procedure rooms	35	40	60
	Corridors and lobbies	40	45	65
Laboratories	Testing/research with minimal speech communication	50	55	75
	Extensive phone use and speech communication	45	50	70
	Group teaching	35	40	60
Churches, Mosques, Synagogues	General assembly with critical music programs[e]	25	30	55
Schools[f]	Classrooms[c]	30	35	60
	Large lecture rooms with speech amplification	30	35	60
	Large lecture rooms without speech amplification	25	30	55
Libraries		30	35	60
Indoor Stadiums, Gymnasiums	Gymnasiums and natatoriums[g]	45	50	70
	Large-seating-capacity spaces with speech amplification[g]	50	55	75

الجدول 3.9 الضجيج المسموح به حسب التطبيق

No. of Outlets	1	2	3	4	8	10	20	40
dB Boost	0	3	5	6	9	10	13	16

الجدول 4.9 مقدار الزيادة في الضجيج حسب عدد الفتحات

Temperature - t - (^oC) (deg F)	Density - ρ - (kg/m^3) (slugs/cu.ft)	Specific Heat - c_p - (kJ/(kg K)) (Btu/lb F)	Thermal Conductivity - k - (W/(m K))	Kinematic Viscosity - ν - x 10^{-6} (m^2/s)	Expansion Coefficient - b - x 10^{-3} (1/K)	Prandtl's Number - P_r -
-150	2.793	1.026	0.0116	3.08	8.21	0.76
-100	1.980	1.009	0.0160	5.95	5.82	0.74
-50	1.534	1.005	0.0204	9.55	4.51	0.725
0	1.293	1.005	0.0243	13.30	3.67	0.715
20	1.205	1.005	0.0257	15.11	3.43	0.713
40	1.127	1.005	0.0271	16.97	3.20	0.711
60	1.067	1.009	0.0285	18.90	3.00	0.709
80	1.000	1.009	0.0299	20.94	2.83	0.708
100	0.946	1.009	0.0314	23.06	2.68	0.703
120	0.898	1.013	0.0328	25.23	2.55	0.70
140	0.854	1.013	0.0343	27.55	2.43	0.695
160	0.815	1.017	0.0358	29.85	2.32	0.69
180	0.779	1.022	0.0372	32.29	2.21	0.69
200	0.746	1.026	0.0386	34.63	2.11	0.685
250	0.675	1.034	0.0421	41.17	1.91	0.68
300	0.616	1.047	0.0454	47.85	1.75	0.68
350	0.566	1.055	0.0485	55.05	1.61	0.68
400	0.524	1.068	0.0515	62.53	1.49	0.68



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Northern Technical University
Technical College of Engineering
Department of Power Mechanics Techniques

Fourth Year
Air Conditioning System Design

Chapter Four
"Lecture One"
Fan Types and Characteristics

Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

Chapter Four
Fan Types and Characteristics

1. Class: Fourth Year

2. Subject: Fan Types, Fan Characteristics and Fan laws and application

3. **Number of weeks:** Two weeks

4. Central idea: How to select good fan, types of fan that use in A/C system and running cost analysis

4. The Test & Problems:

Types of Fans:

There are several types of fan to choose from in ventilation. These are:

1. Propeller
2. Axial flow
3. Centrifugal
4. Mixed flow

1. Propeller Fan

Used in situations where there is minimal resistance to air flow.
Typical outputs are; up to **4 m^3/s** and up to **250 Pa pressure**.
Fan efficiency is low at about **40%.**Suitable for wall, window and roof fans where the intake and discharge are free from obstacles. Can move large volumes of air. Low installation cost.

PROPELLER FANS

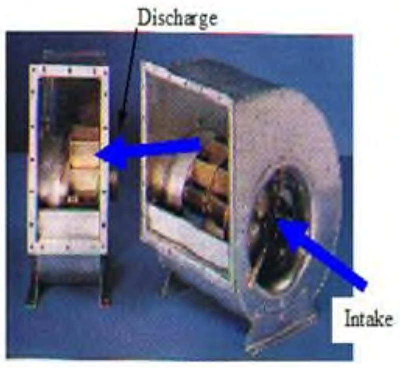
2. Axial Flow Fan

High volume flow rate is possible with this type of fan with high efficiency, about **60% to 65%.**Typical outputs are; up to **20 m^3/s** and up to **700 Pa pressure**. The fan is cased in a simple enclosure with the motor housed internally or externally

Axial Flow Fan with External Motor

3. Centrifugal Fan

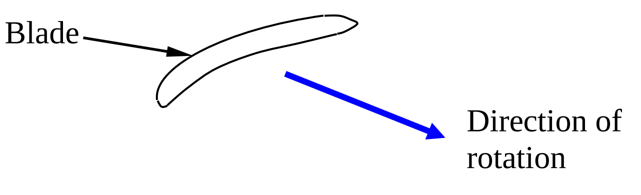
High pressure air flow is possible with this type of fan. Used in air handling units and other situations to overcome high resistance to air flow. The impeller is made of thin blades which are either forward or backward curved. The air changes direction by 90 degrees in a centrifugal fan so more space is required. Usually the motor is placed external to the casing and a v-belt and pulley drive.



Small Centrifugal Fans

Centrifugal Blades

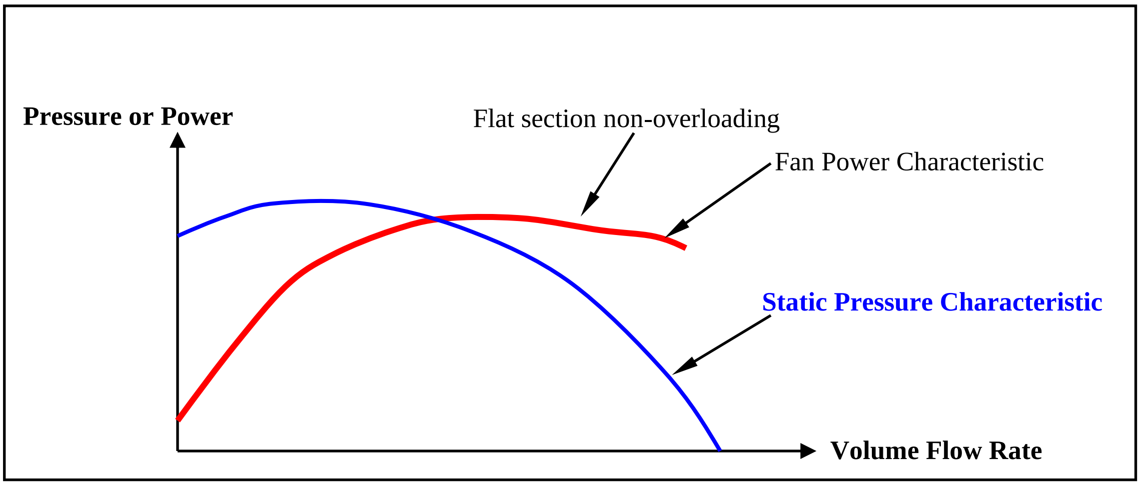
Centrifugal curved fan blades generally have **higher efficiencies** than if a plain flat blade is used. The efficiency of a fan with forward curved blades is about **50% to 60%.**The forward curve has a scoop effect on the air thus a higher volume may be handled.



Forward Curved Blade

Backward curved blades offer even better efficiency, **70% to 75%.**This improves airflow through the blade and reduces shock and eddy losses. High pressures can be developed with backward curved blades. Even further improvements may be made by using an aerofoil section blade in which case the efficiency may be **80% to 85%.**

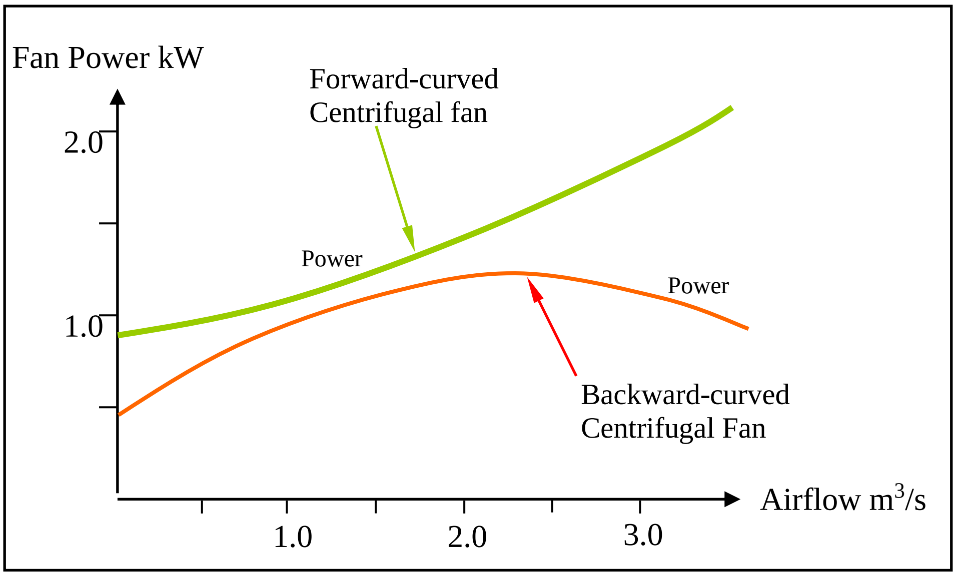
Another feature of backward curved blades is their **non-overloading** characteristic.



Fan Characteristics Curve

Disadvantage is the high blade tip speed, necessary to obtain a comparable rate of discharge to forward curved blades, makes the fan noisy.

The backward–curved fan is less liable to over-loading than the forward-curved centrifugal fan and it is also able to deliver a relatively constant amount of air as the system resistance varies. The power of a backward curved fan reaches a peak and then begins to fall, this is called the self-limiting characteristic. This is shown below:



Centrifugal Fan Characteristics

4. Mixed Flow Fan

Mixed Flow fans can be used for return air, supply, or general ventilation applications where low sound is critical. As compared to similarly sized axial fans, a mixed flow fan can be 5-20 dB quieter.

MIXED FLOW FAN

Fan Static Pressure

The Fan Static Pressure is expressed as the Fan Total Pressure minus the velocity pressure at the fan discharge:

P_s fan =(P_t loss + P_v system outlet) - P_v discharge

Where P_v discharge = Velocity Pressure at the Fan Discharge.

For Exhaust Systems with resistance only on the inlet side, the fan static pressure is:

P_s fan = $P_{t\,loss}$

For exhaust system: P_v system outlet = P_v discharge

For Supply Systems with resistance on the outlet side, the fan static pressure is:

P_s fan = P_t loss - P_v discharge

P_v system outlet can be assumed to be 0.

Fan Total Pressure (FTP). Then the required power input to the fan is given by

Northern Technical University
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Department of Power Mechanics Techniques

Fourth Year

Air Conditioning System Design

Chapter Four
"Lecture Two"
Fan Types and Characteristics

Prepare By Assist Prof.
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2025 - 2026

Fan Total Pressure:

To overcome the fluid friction and the resulting head, a fan is required in air conditioning systems. When a fan is introduced into the duct through which air is flowing, then the static and total pressures at the section where the fan is located rise. This rise is called as Fan Total Pressure (FTP). Then the required power input to the fan is given by:

$$W_{fan} = \frac{\dot{Q}_{air}\,.FTP}{\eta_{fan}}$$

The FTP should be such that it overcomes the pressure drop of air as it flows through the duct and the air finally enters the conditioned space with sufficient momentum so that a good air distribution can be obtained in the conditioned space. Evaluation of FTP is important in the selection of a suitable fan for a given application. Fan total Pressure is the pressure differential between the inlet and the outlet of the fan. It can be expressed in these terms:

$$\mathbf{P_{t\,fan} = P_{t\,loss} + P_{v\,system\,outlet} + (P_{s\,system\,outlet} + P_{s\,system\,entry} + P_{v\,system\,entry})}$$

$P_{t\,fan}$ = Fan Total Pressure
$P_{t\,loss}$ = Dynamic, Component, and Frictional Pressure through the air duct system.
$P_{s\,system\,outlet}$ = Static Pressure at System Outlet
$P_{s\,system\,entry}$ = Static Pressure at System Entry
P_v system entry = Velocity Pressure at System Entry
P_v system outlet = Velocity Pressure at System Outlet
For most HVAC applications: (P_s outlet + P_s entry + P_v entry) = 0

Therefore: $\mathbf{P_{t\,fan} = P_{t\,loss} + P_{v\,system\,outlet}}$

Fan's Laws:

The Fan Laws are as follows:

- No.1 Speed / Volume

Where; $\frac{N_1}{N_2} = \frac{Q_1}{Q_2}$

N: Fan speed (rev. per minute or r.p.m.)

Q: Volume flow rate of air (m3/s)

This means that fan speed and volume flow rate of air are directly proportional.

- No.2 Speed / Pressure

Where; $\left(\frac{N_1}{N_2}\right)^2 = \frac{p_1}{p_2}$

N: Fan speed (rev. per minute or r.p.m.)

p: Fan pressure (N/m2)

This means that as the fan speed is doubled, for example, the pressure developed is raised by a factor of 4.

- No.3 Speed / Power

Where; $\left(\frac{N_1}{N_2}\right)^3 = \frac{P_1}{P_2}$

N: Fan speed (rev. per minute or r.p.m.)

P: Fan power (Watts).

Problem:

A centrifugal fan delivers (252CMM) of air at a static pressure of (100 pa), rotational speed of 1250 rpm and dynamic pressure (200 pa), if the volume flow rate is reduced to (6763CFM). **Find at new case the following:**

(1) Rotational speed

(2) Static pressure

(3) Total pressure

(4) Power.

Note: Take the efficiency of fan 75%.

Solution:

Given Data	
Q_1 (volume flow rate). m³/s	4.2 m³/s
P_{s1} (Static pressure). Pa	100 Pa
N_1 (Rotational speed). rpm	1250 rpm
P_{d1} (Dynamic pressure).Pa	200 Pa
Q_2 (volume flow rate). m³/s	3.19 m³/s
Total Efficiency of Fan 75%	

Convert Table
1LPS =2.12 CFM (Cubic Feet Per Minute)
1LPS=0.06 CMM (Cubic Meter Per Minute)
1LPS= 0.001 m³/s

Case (1)
Case (2)

$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2}$$

Q_1=252 CMM or 4.20 m³/s Volume Flow Rate @ $case_1$
Q_2=6763 CFM or 3.19 m³/s Volume Flow Rate @ $case_2$
N_2=949.4 rpm

$$\left(\frac{N_1}{N_2}\right)^2 = \frac{p_1}{p_2}$$

Ps_2=57.7 Pa

$$W_{fan} = \frac{Q_{air}.FTP}{\eta_{fan}}$$

$FTP_1=P_{d1}+P_{s1}$
=100+200=300 Pa , **$Power_1$=1680 W**

$$\left(\frac{N_1}{N_2}\right)^3 = \frac{Power_1}{Power_2}$$

$Power_2$=736 W , **FTP_2=173 Pa**

New Data @ Case (2)	
N_2 (Rotational speed)	949.4 rpm
P_{s2} (Static pressure)	57.7 Pa
P_{T2} (Total pressure)	173 Pa
$Power_2$ (Fan Power)	736W

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Department of Power Mechanics Techniques

Fourth Year

Air Conditioning System Design

Chapter Five

"Lecture One"

Air Filtration

Prepare By Assist Prof.
Mr. Badran Mohammed Salim
2025 - 2026

Chapter Five
Air Filtration

1. **Class** : Fourth Year
2. **Subject** : The cleaning of air, air impurities, Dry Filtering, Electrostatic Filtering.
3. **Number of weeks:** One week
4. **Central idea** : Study the types of filter that use in the A/C system and how to select best filter to satisfy the condition of application .
5. **The Test**:

Introduction:

Air Filter used for removing airborne particle from the air that could cause discomfort to your building's occupants or possibly damage sensitive equipment. Filter and other air cleaning devices are available in four general types:

1. Typical commercial filters that remove visible dirt, dust, lint and soot.
2. Electrostatic filter that remove microscopic particles such as smoke and haze
3. Activated charcoal that destroy odor
4. Ultraviolet lamps that kill bacteria

Rating Filters:

Three operations characteristic that distinguish the various types of air filter:

1. **Efficiency:** The ability of the filter to remove particulate matter from an air stream.
2. **Air Flow resistance**: is the pressure drop across the filter at given air flow rate.
3. **Dust –Holding capacity**: The amount of particulate type of dust hat filter can hold when it is operated at a specific air flow rate

Particle size:

The most important characteristic of the air stream that most affect the air filter. Particles less than 2.5 micrometer in diameter are generally reoffered to as fine with those greater than 2.5micrometer being considered as coarse

Major factors influencing filter design and selection:

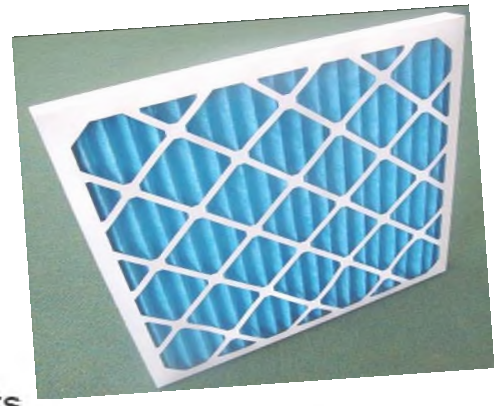
1. Degree of air cleanliness required
2. Specific particle siz range
3. Aerosol concentration

Filter Selection (Evaluation of air filter):

1. Degree of air cleanliness required
2. Dispoal of dust after it is removed from air filter
3. Amount and type of dust in the air to be filtered
4. Opreating resistance to air flow (pressure drop)
5. Space available for filtration equipement
6. Cost of maitaining or replacing filters
7. Intial cost of the system

Types of Filter:

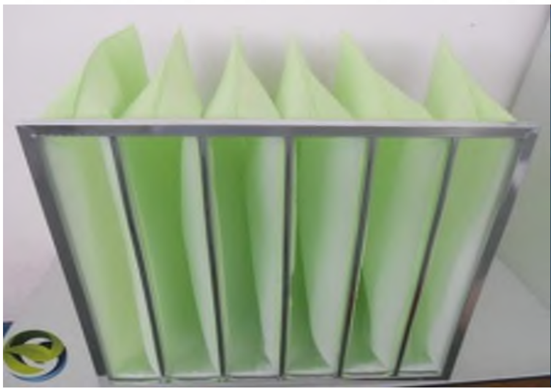
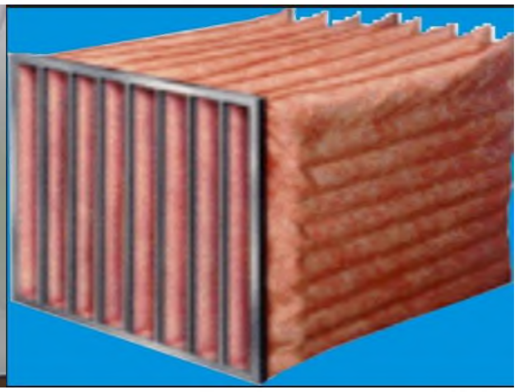
A. Low Efficiency Filter



- Dust spot efficiency lower than 30%
- Panel type
- Dimension 500mm x 500mm
  - Filter media
  - Corrugated metal wire mesh
  - Dry and reusable-nylon
  - Dry and disposable – Glass fibre mats

B. Medium Efficiency Filter

- Filter efficiency between 30% to 95%
- Extended surfaces such as pleated mats or bags are used to
  - Increase surface area of the filter media
  - Increase air velocity flowing through the filter media

C. High Efficiency Particulate Air Filter

Principle of operation

- It remove dust particle by filtration of the passing air;

Construction:

- The filter media is glass fibre of submicrometer diameter that is formed into pleated paper mats (dry and disposable).
- The performance of filter media is measured by alpha value which is a function of penetration in % and pressure drop (mm).
- Typical size of filter is 600mm x 600mm x 300mm
- Surface filter media area may be 5C

Application: meet the requirement of di-octyl phthalate (DOP) 99.97% efficiency for dust particle ≧0.3μm

- Clean room
- Clean space for microelectronic industry
- Pharmaceutical industry
- Precision manufacturing industry
- Operating theatre in hospital

Application:

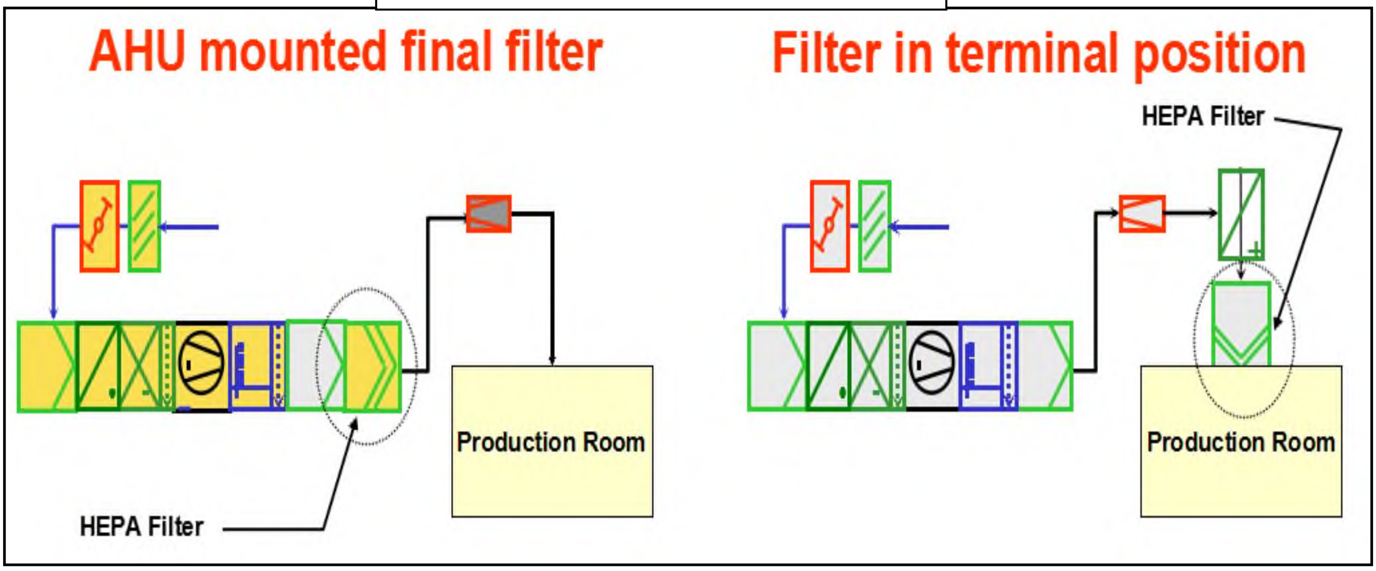
Standard for labs , clean room,nuclear , hospital, semiconductor , electronics, pharmaceutical manufacturing .

- ***HEPA Filter Media*** - Typically a microfine fiberglass media, synthetic fibers, expanded film such as Polytetrafluorethylene (PTFE) that can be pleated back and forth to form a compact element. Close pleating is necessary to fit all the required media into the desired space, because the paper has a high resistance to airflow and the media velocity is usually in the range of 6 feet per minute.
- ***HEPA Filter Separators*** - These devices support the HEPA media pleats, and provide channels through which the air can flow to reach the media in a laminar flow pattern.

- ***HEPA Filter Pack*** - This is the term used to describe the combined HEPA media and separator unit.
- ***HEPA Filter Sealant*** - This is an adhesive, commonly urethane or silicone, used to create a leak-proof seal between the HEPA filter pack and it's supporting frame. Sealant may also be used to patch any small leaks that are found in the HEPA filter during in-situ leak testing.

- ***EPA Filter Seal*** - This is the seal on a HEPA filter frame that prevents air bypass around the filter. In most instances it is either a closed cell neoprene gasket attached to the face of the filter frame, or a groove in the frame to allow a knife-edge to penetrate a 'non-Newtonian gel' (a gel that will not be influenced to fall out due to the forces of gravity).

HEPA Filter Position



D. ULPA filters:

- Stands for Ultra Low Penetration Air filters.
- ULPA filters can remove particles as small as about 0.1microns.
- Ultra low penetration air filters are extended media dry filters in a rigid frame that have a minimum particle collection efficiency of 99.999 percent for particles greater than or equal to 0.12 micron in size

ULPA filters can remove particles as small as 0.1 microns.

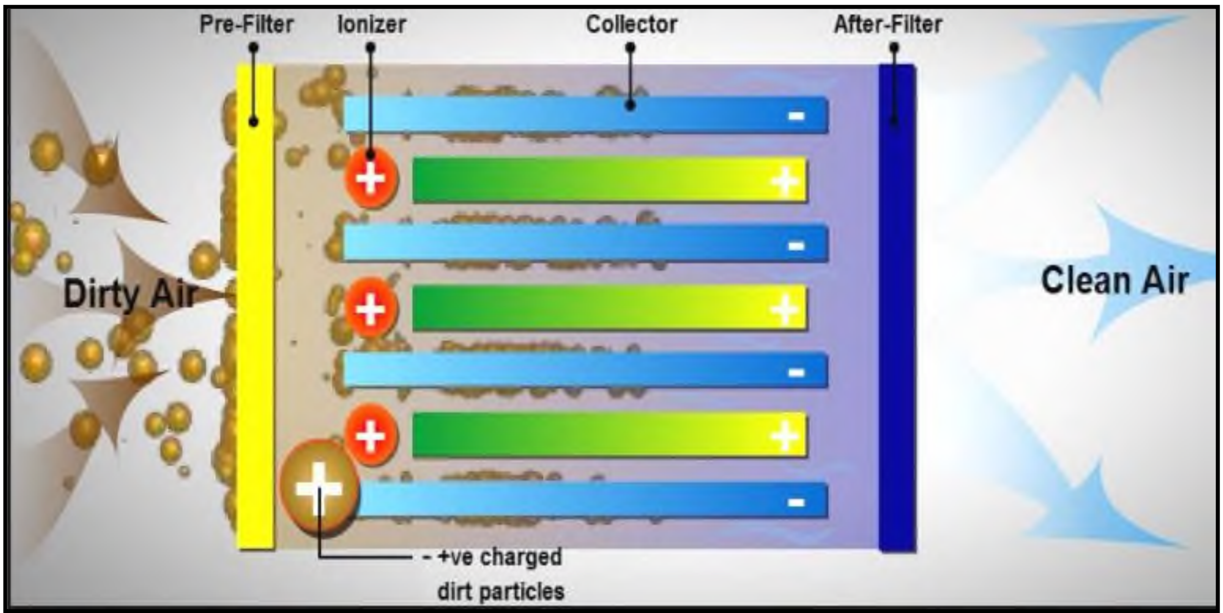
Ultra low penetration air filters are extended media dry filters in a rigid frame that have a minimum particle collection efficiency of 99.999% for particles greater than or equal to 0.12 micron in size.

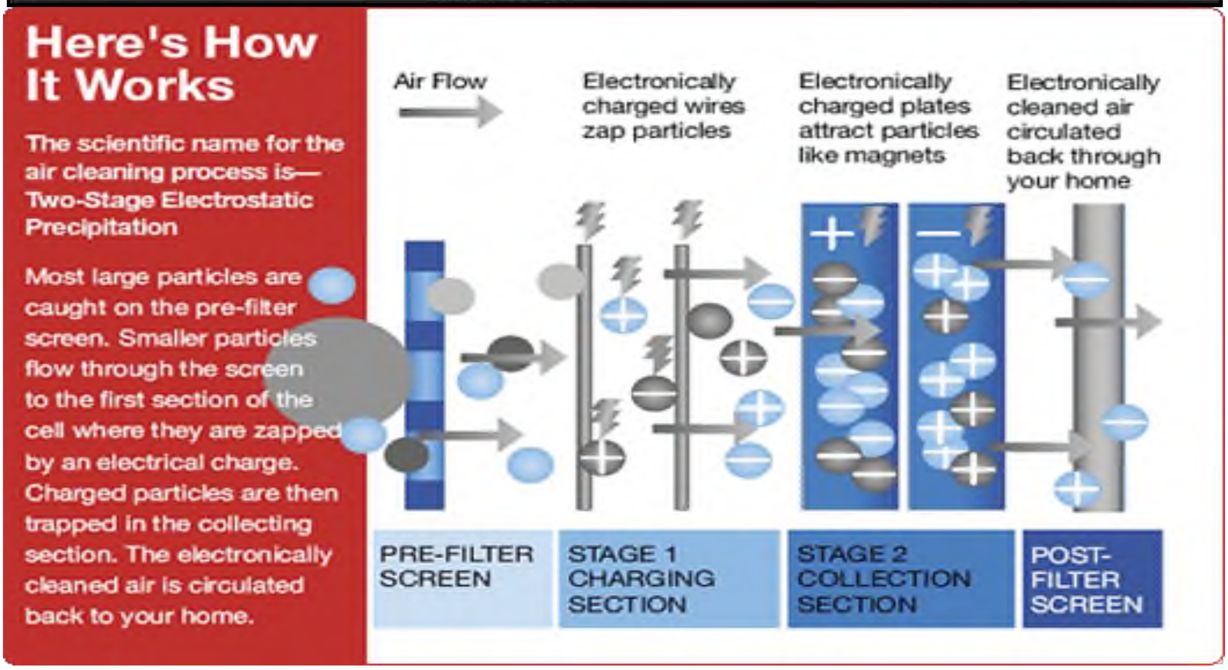
Type	Eurovent class	New Class	Efficiency	Measured by
Coarse dust filter	EU1	G1	<65	Synthetic dust weight arrestance
	EU2	G2	>65, <80	
	EU3	G3	>80, <90	
	EU4	G4	>90	
Fine dust filter	EU5	F5	40, <60	Atmospheric dust spot efficiency
	EU6	F6	>60, <80	
	EU7	F7	>80, <90	
	EU8	F8	90<95	
	EU9	F9	>95	
High efficiency particulate air filter (HEPA)	EU10	H10	85	Sodium chloride or liquid aerosol
	EU11	H11	95	
	EU12	H12	99.5	
	EU13	H13	99.95	
	EU14	H14	99.995	
Ultra Low Penetration Air Filter (ULPA)	EU15	U15	99.9995	Liquid aerosol
	EU16	U16	99.99995	
	EU17	U17	99.999995	

E. Electronic air cleaner(cont'd)

A high DC potential of 1.2kV is applied to the ionizing field.

- Positive ions generated from the ionizer wire charge the dust particles.
- After passing the ionizing section, dust particles come to a collecting section.
- This section consists of several plates alternatively grounded and insulated.
- A strong electric field is produced by a DC potential of 6KV is applied to these plates. Dust particles become positively charged which are attracted and attached to the ground plates.





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