Chapter

Central Air Conditioning: Systems and Applications

Mohamed Elnaggar and Mohammed Alnahhal

Abstract

It became evident nowadays that modernization influences domestic and commercial HVAC industry, and thus high technological and energy-efficient central air conditioning systems are demanded. Therefore, the selection of proper type of central air conditioning system is a crucial target in the construction industry as improper selection can maximize initial and/or running costs of the system and decreases the human comfort and indoor air quality levels. In fact, a pre-assessment of the construction type and budget available is required for selecting the proper type of central air conditioning system. Therefore, there is a continuous need for an updated material in the literature that reviews the central air conditioning systems and applications, which is the motivation of the present chapter. The present chapter reviews the central air conditioning systems and applications. Specifically, all-air systems, all-water systems, and air-water systems are discussed. In addition, all provided systems are further explored through several developed schematic diagrams enabling the identification of their various components and the understanding of their working principles. It is may be of interest to note that this chapter is suitable for undergraduate level students in the fields of HVAC and R, mechanical, and construction engineering.

Keywords: central air conditioning, all-air systems, all-water systems, air-water systems, air handling unit

1. Introduction

In central air conditioning, air, water, or both are used as working fluids to produce the required heating and/or cooling, and therefore based on working fluids, central air conditioning systems can be classified into three groups [1–5], namely:

1. All-air systems: in these systems air is used as working fluid for heating and/or cooling purposes.

2. All-water (hydronic) systems: in these systems water is used as working fluid for heating and/or cooling purposes.

3. Air-water systems: in these systems both air and water are used as working fluids for producing heating and cooling purposes.

It is may be of interest to note that each type of the central air conditioning systems has several systems of sometimes different configurations, and the use of any system depends on its advantages and disadvantages [1–5]. The following sections will provide descriptions of all types of central air conditioning systems.

2. Classifications of central air conditioning systems

2.1 All-air systems

In these systems air alone is used as working fluid to produce cooling or heating in air-conditioned zones; besides that air is responsible for controlling the zones' humidity level and provide the required ventilations to air-conditioned zones. In addition, in all-air systems, air is used for aromatizing purposes. Therefore, only air as working fluid is responsible for providing comfort, i.e., cooling, heating, controlling of humidity and ventilation odor, and thus these systems are called all-air systems [1–5].

2.1.1 Air handling unit (AHU)

Air handling unit can be considered as the heart of all-air systems since cooling and heating take place in the air handling unit. It also mixes the outside air after being purified with the return air, then the necessary psychometric processes are carried out. Air conditioner is then expelled or withdrawn to the place to be air-conditioned. These units are used for capacities exceeding 100,000 CFM (50 m^3/s) air. The main components of the air handling unit are shown in **Figure 1** [1–6].

The main components of the air handling unit shown in **Figure 1** are described below:

- **Supply fan**. Centrifugal fan type is used to provide the conditioned air to various zones.

- **Fan motor**. Electric motor is used to provide the rotating motion to the supply fan.

- **Cooling coil**. Coil placed in AHU where cold water from chiller is circulating in medium- and large-capacity AHU or expanded refrigerant in small-capacity AHU.

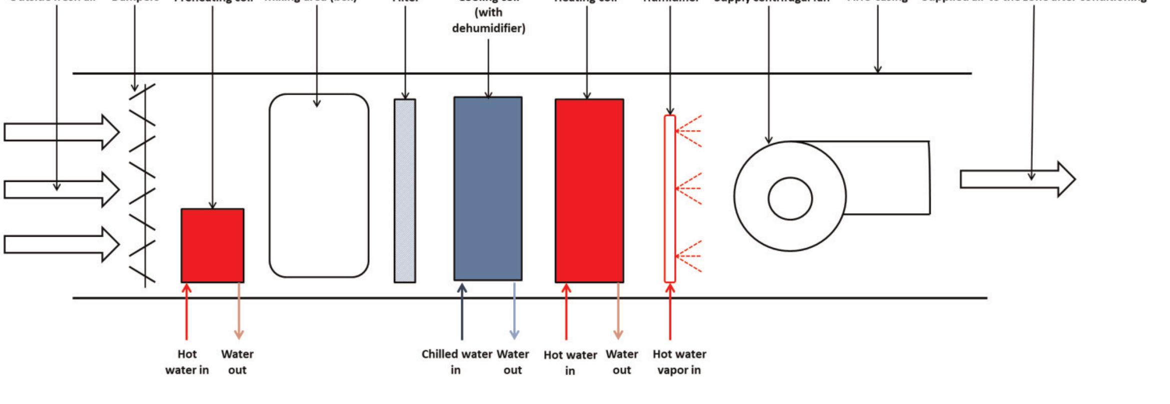

Figure 1.
A schematic diagram of an air handling unit with its main components.

- **Filters**. Filters or strainers are placed at the early air path in AHU. Filter type used may depend on application type.

- **Mixing box**. It is place where fresh air is mixed with zone return air or with fresh conditioned air. Mixing processes are performed to obtain the desired air temperature and humidity or to maintain energy-efficient performance.

- **Dampers**. Dampers are used to control the amount and direction of air before or after conditioning is performed.

- **Heating coil**. Coil placed in AHU where hot liquid or vapor water from boilers is circulating.

- **Preheating coil**. Preheating coil is placed at AHU entrance before cooling and heating coils. The task of preheating coil in hot days is to reduce the entering fresh air's relative humidity, thus preventing possibly the condensation of water vapor on cooling coil, hence preventing frost formation on the cold coil. In addition, preheater coil will prevent the freezing of water inside the coils in cold days.

- **Humidifier**. It is a system which is responsible for increasing the humidity in the conditioned zone. Humidifiers are usually used in cold days where maintaining hot climate is desired; however this will accompany low-humidity levels, and thus the use of humidifier becomes essential to maintain the comfort edge. Humidifier can provide humidity either as hot vapor or water spray. The first one is more preferable particularly in healthcare applications as hot vapor will prevent the growth of biological organisms such as bacteria or algae besides hot vapor compared to the water spray. Besides that hot vapor is more preferable as provided humidity will have higher temperature and thus will not reduce the conditioned hot air provided to the zones.

- **Centrifugal pumps**. Centrifugal pumps are used for cooling and heating air processes. They are used to maintain pumping cycle of hot water from boilers to the heating or preheating coils and back to boiler and/or pumping cycle of cold water from the chiller or cooling tower to cooling coil in AHU and back to the chiller or cooling tower.

- **Control systems**. Control systems can vary from simple control system to advanced control system that use the latest technologies such programmable logic controllers. Usually controllers are used to control the temperatures and humidity of the supply air to the zones. It also controls the damper systems in the AHU. Moreover, advanced control systems can even control the fan rotation and thus the rate of air supplied to the zone based on the required temperature in the zone and zone exit damper. In such systems, pressure sensor connected to the control system will be placed in the air duct, and as attaining the required temperature in the zone, dampers will get closer increasing the duct-sensed pressure through which the fan connected to the control system will reduce its speed and thus maintain energy-efficient performance [7, 8].

- **Casing**. Casing is a kind of AHU cover that includes all the above AHU components.

It is may be of interest to note that the configuration of air handling unit can differ slightly in design and components according mainly to the type of application and AHU capacity (e.g., healthcare buildings or other), but also initial and running costs can affect the selection of various AHU components. In addition, air handinbased on various classificationsg units can be classified based on the structure and based on the location where it is placed [2]. The following sections will demonstrate all types of air handling units based on various classifications.

2.1.1.1 Classification of air handling unit based on structure

A. Horizontal air handling unit (horizontal AHU)

The horizontal air handling units place the supply air fan, cooling coil, heating coil, and humidifier in the casing horizontally (see **Figure 2**). This design requires a large floor area as AHU components are large in size. Horizontal AHU type are usually of high capacity and are usually placed in plant room, whereas small horizontal AHU type can be placed carefully on the roof [2].

B. Vertical air handling unit (vertical AHU)

In vertical air handling units, the centrifugal fan is placed in a position above the cooling coil, heating coil, and humidifier as shown in **Figure 3**. Vertical air handling units are small in size and are low-capacity units, and thus they are installed in a small floor area of plant room [2].

2.1.1.2 Classification of air handling unit based on location of installation

A. Internal air handling unit (internal AHU)

These air handling units are normally installed indoor in a plant room. This type of air handling unit is called simply air handling unit [1].

B. Fresh air handling unit (fresh AHU)

In this type, air handling units are installed in the outdoor environment such as on the building roof. This type of air handling unit is called fresh air handling unit. Fresh air handling units are designed to withstand climatic variations. In addition,

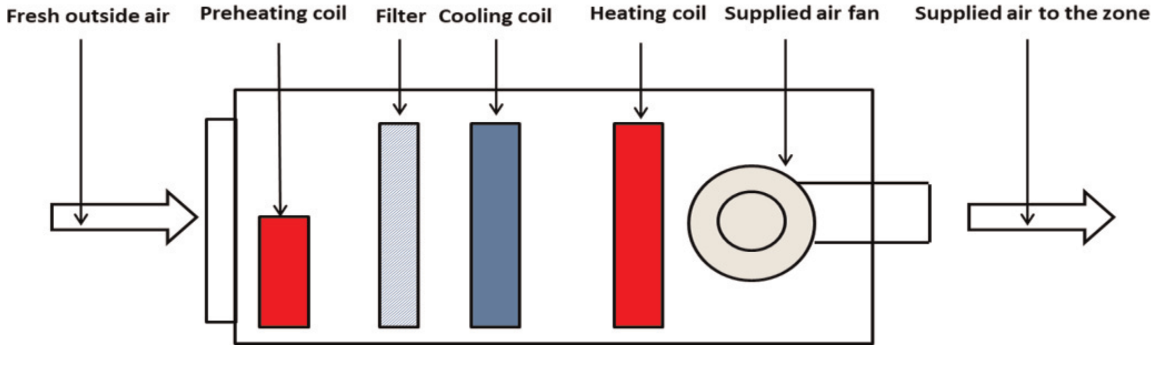

Figure 2.
A schematic diagram of horizontal air handling unit. Redrawn with modification from [2].

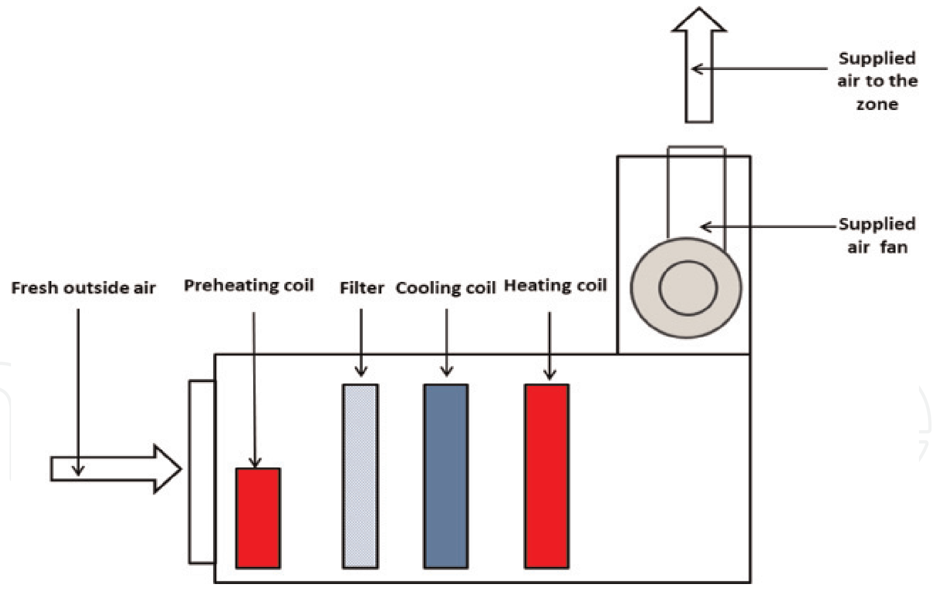

Figure 3.
A schematic diagram of vertical air handling unit. Redrawn with modification from [2].

safety measures must be taken before installing fresh air handling units on roofs due to their large weights [2].

2.1.1.3 Classification of air handling unit based on supply air fan placement

A. Blow-through units

In the blow-through units, supply air fan forces or pushes the air through the cooling coil (see **Figure 4**) to reduce the increase of supplied air temperature due to friction, and thus air can be cooled before being supplied to the various zones [2].

B. Draw-through units

In this type, the supply fan is placed after cooling coil (see **Figure 5**), heating coil, filter, and humidifier, and thus air is pulled by the supply fan. This system is commonly used as filters and coils which require small air speed and larger ducts

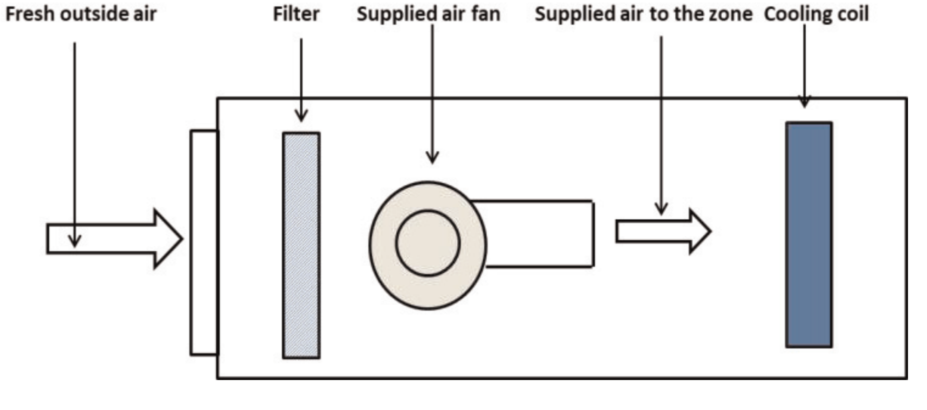

Figure 4.
A schematic diagram of blow-through type of air handling unit. Redrawn with modification from [2].

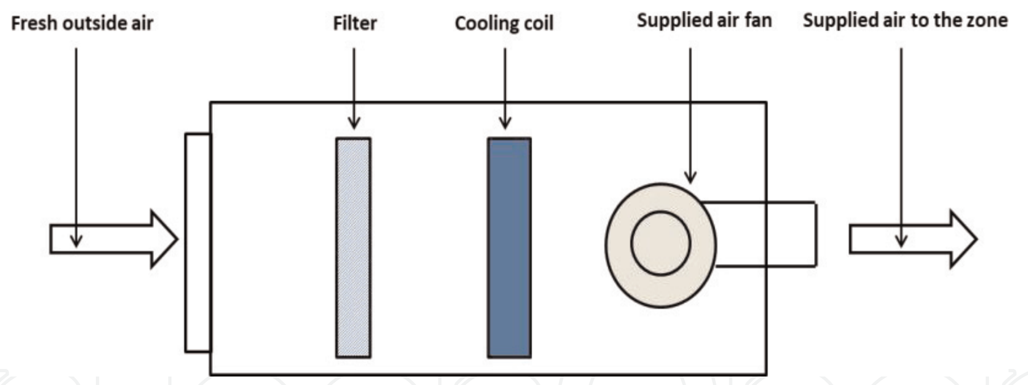

Figure 5.
A schematic diagram of draw-through type of air handling unit. Redrawn with modification from [2].

than large speeds and small ducts through the fan. The only disadvantage of this system is that the fan sound can travel with supply air to the conditioned zones [2].

2.1.2 Types of all-air systems

2.1.2.1 Conventional systems

A. Classification of conventional systems

These systems can be classified into two groups [1–5], namely:

i. Fixed supplied air volume flow rate with variable supplied air temperature

In these systems the rate of air flow remains constant, and the zone-required temperature is obtained by varying the supplied air temperature.

i. Variable supplied air volume flow rate with fixed supplied air temperature

These systems maintain fixed supplied air temperature; however the zone-required temperature is maintained by varying the volume flow rate of supplied air.

B. Advantages of conventional systems

1. Simplicity as the components are of simple configuration and can be found separated from each other

2. Low initial cost since the system has simple configuration

3. Low running cost as ventilation, return air, and side passage flows can be used, which can maintain energy-efficient performance

4. Quite operation as air handing unit including the fan is placed in plant room away from zone

5. Centralized maintenance as air handling unit is placed in the plant room

2.1.2.1.1 Single-duct conventional systems

Single-duct systems are generally used for conditioning stores, offices, and industries. A schematic diagram of a single-duct system is shown in **Figure 6**, which is fixed supplied air volume flow rate and variable supplied air temperature type, and thus the required temperature in the zone is attained by the adjustment of heating and cooling coil flow rates and thus their temperature. On the contrary, the required temperature in conditioned zone can also be attained by varying supplied volume flow rate and holding fixed supplied air temperature (**Figure 7**) which is accomplished by simply placing dampers in the single duct; thus supplied air volume rate can be varied, e.g., in summer days, higher supplied air volume rates are provided to the zone to reach required temperature.

It is worth mentioning that single-duct system is used in both single and multi-zones. Return air can be mixed with the fresh air in the mixing box in appropriate ratio. This will provide energy-efficient running of the system; however care must be taken on the quality of return air as air may have higher percentages of humidity levels [1–5, 8]. This configuration can be seen in **Figure 6** and **Figure 7**; however, in **Figure 7** variable supplied air volume flow rate and fixed supplied air temperature type has new arrangement called side passage flow (green lines) where the air once cooled is directed immediately to the mixing box to accelerate the cooling process.

2.1.2.1.2 Multi-duct conventional systems

Characteristics the characteristics of multi-duct systems are similar to single-duct systems except that two or more ducts can be used for providing conditioned air to two or more zones. The usage of several ducts in these systems provides flexibilities as long as the required condition can be varied according to the requirement in each zone. These systems are used where control of temperature and humidity in a building zone is required [1–5]. **Figure 8** shows two-duct system of variable supplied volume flow rates with fixed supplied air temperature.

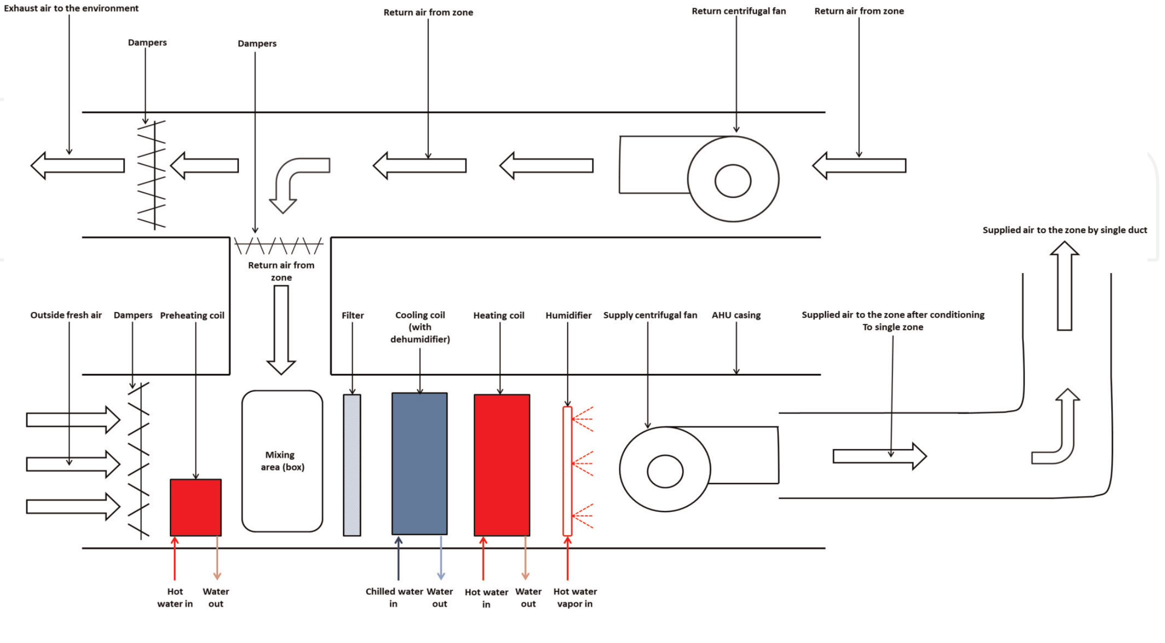

Figure 6.
A schematic diagram of single-duct system (fixed supplied air volume flow rate and variable supplied air temperature).

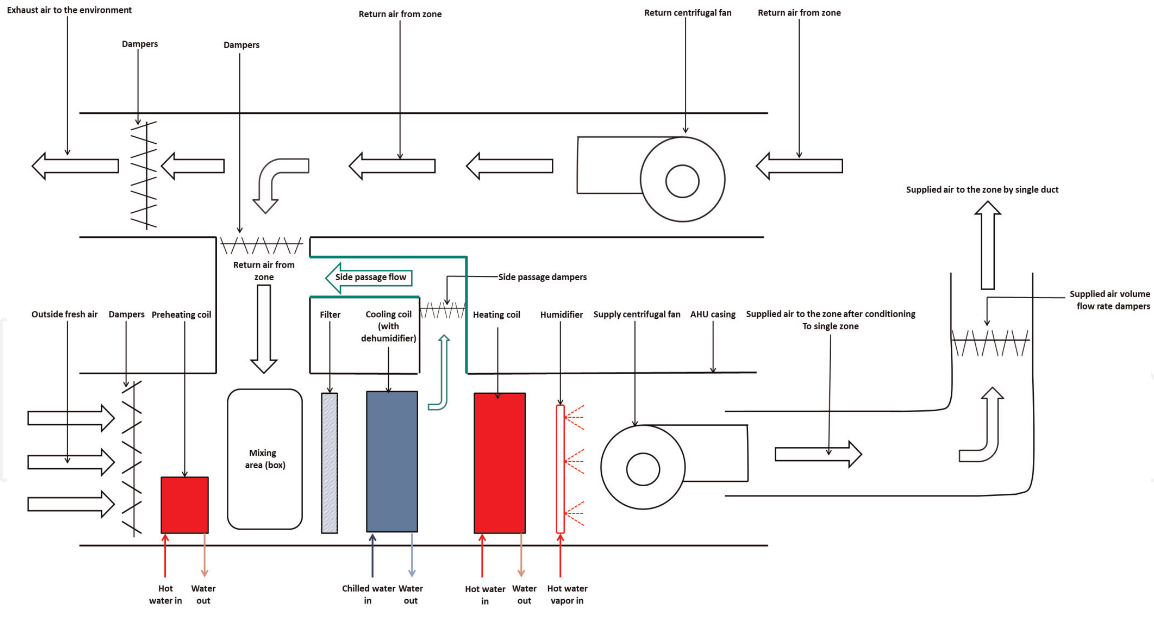

Figure 7.
A schematic diagram of single-duct system (variable supplied air volume flow rate and fixed supplied air temperature).

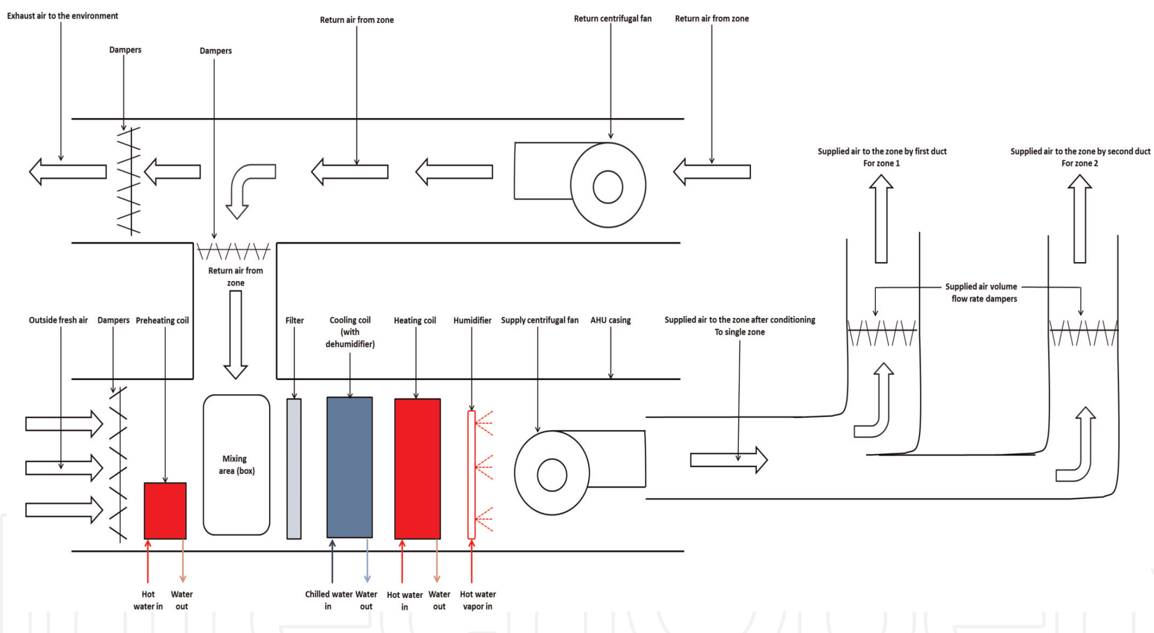

Figure 8.
A schematic diagram of multi-duct system (variable supplied air volume flow rate and fixed supplied air temperature).

2.1.2.2 Reheat systems

Reheat systems are used in applications of variable loads. In these systems air will be cooled to the zone's lowest required temperature, and then air will be circulated to all zones, and the required temperatures of various zones can be obtained by reheating the supplied air. Electric heater or hot water can be used as reheaters which are located in the terminal units (see **Figure 9**) of conditioned zones [1–5].

In addition, reheaters can be used for reducing the levels of humidity in cold temperature zones by increasing supplied air temperatures. Usually zone thermostat will be used to control the reheater according to required conditions.

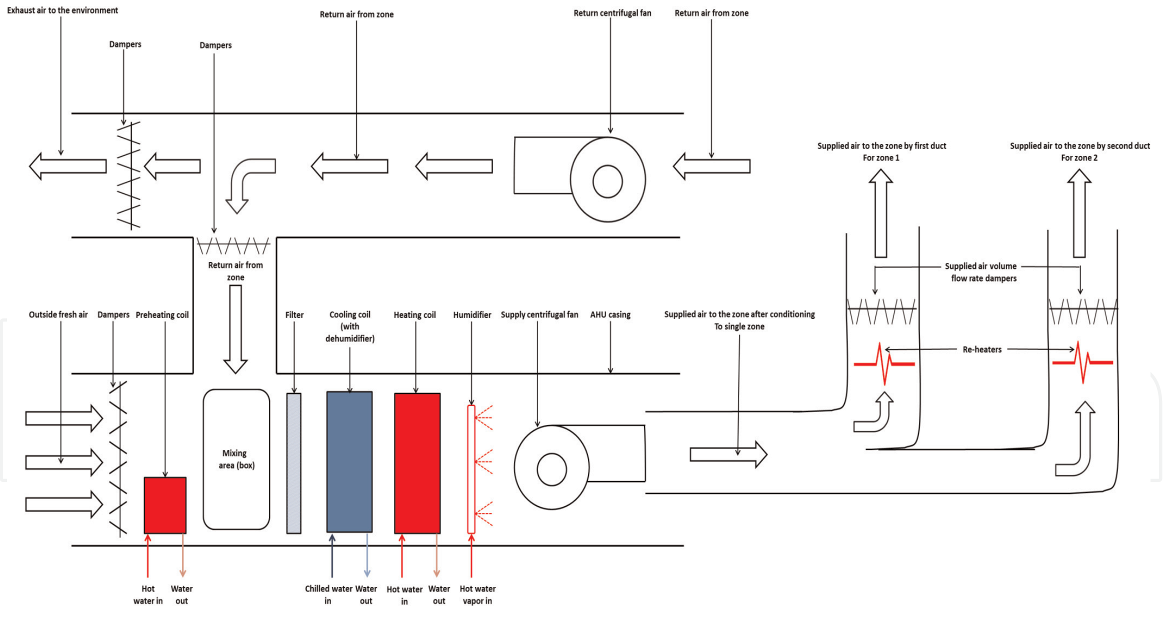

Figure 9.
A schematic diagram of a reheat system.

2.1.2.3 Constant volume induction system

In these systems, an induction unit is used either for ventilation or heating purposes. The induction unit usually contains hot water coil, and it induces the zone's air to provide further heating or air ventilation (**Figure 10**). Single or several induction units can be used based on the number of conditioned zones, and hot water is provided to them from boilers through a water circuit which return the water again for reheating. Primary air is usually provided from the air handling unit which is usually responsible for the latent and sensible thermal loads and provides the desired humidity level. In addition, primary air will be provided to induction unit. Induction units are used to meet the increase heating loads and thus can provide comfort quicker with lower running cost [1–5].

Advantages of induction units

1. Possibility of controlling room temperature as every room with induction unit can be considered as zone

2. Simple air duct design

3. Centralized supplied primary air

4. Control system simplicity

5. Economic running

6. Possibility of controlling the air ventilation and odor

7. Quite operation as fans are away from the room

2.1.2.4 Multi-zone unit systems

In multi-zone unit systems, the cooling and heating coils are placed parallel to each other where an amount of air supplied with a constant temperature is

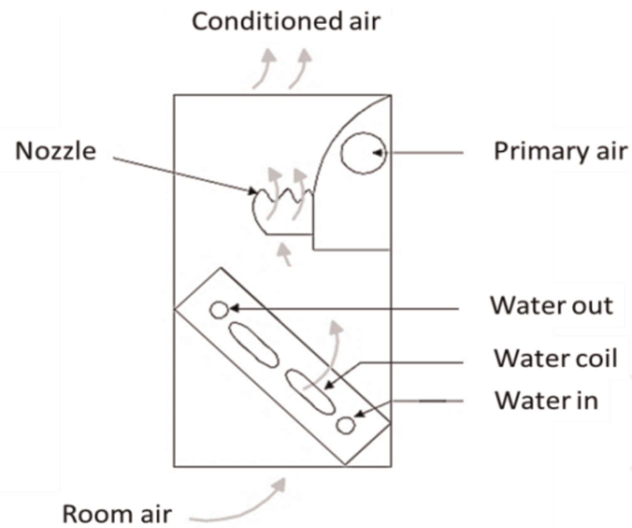

Figure 10.
A schematic diagram of an induction unit. Readapted from [5].

maintained. In these systems, hot air and cold air are mixed in required proportions, and thus the supplied air of fixed temperature and fixed volume will be provided to conditioned zone [1–5]. **Figure 11** shows a multi-zone unit system that supplies air separately to three different zones as dampers can be used.

This system is used and suitable for the following applications, namely:

i. Buildings that contain a number of small and large zones in which separate temperature control is desired as in schools and offices.

ii. Areas in building of different directions and different internal loads such as buildings, e.g., banks

iii. Buildings that have interior zones of varying sizes as in radio or television studios

Advantages of multi-zone unit systems

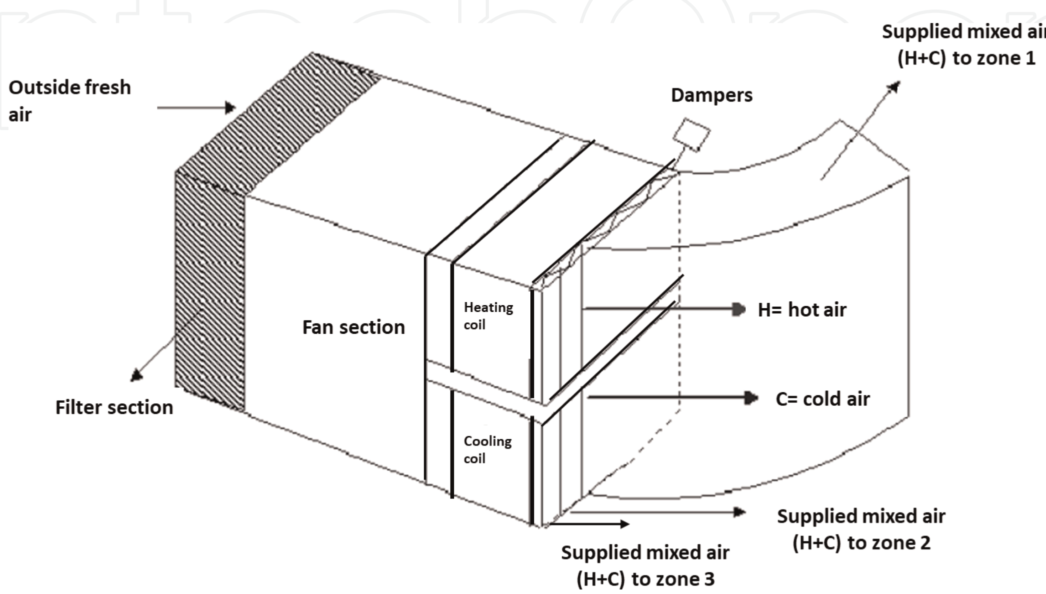

Figure 11.
A schematic diagram of multi-zone unit system. Readapted from [2].

1. These systems allow separate control of temperature in zones or places that are considered as separate area as supplied air is provided at the desire temperature.

2. It is simple to have the smallest unit size. These systems can either be assembled in plant location or in the factory and fit all requirements.

3. They are easy to switch operation from cold to hot in summer and winter seasons and vice versa as this can be simply done manually from air handling unit in plant room.

4. These systems allow easy air distribution and balance. Using only one air duct with various exits and outlets makes the balance process easier.

5. Centralized refrigeration equipment as air handling unit is used.

6. Centralized maintenance as all air handling unit is placed in the plant room.

7. Low-cost operation.

8. Quiet operation.

2.1.2.5 Dual-duct systems

Dual-duct systems allow separate control of temperatures in conditioned places and zones. Temperature control is achieved by supplying the mixing box with air from hot air duct and cold air duct; that is hot air and cold air are mixed in mixing box in proper required proportion based on the zone thermostat, and then air can be supplied to the zone to maintain required zone temperatures. These systems are commonly used in multiroom buildings such as offices, hotels, apartments, hospitals, schools, and large laboratories. **Figure 12** shows a dual-duct system that supplies different zones [1–5].

Advantages of dual-duct systems

1. Provide separate control in the temperatures in each zone as cold and hot air presence at the same time allows rapid change in temperatures.

2. Dual-duct systems can be found in the smaller size as the number of served zone by the central system is reduced, whereas the supply air is maintained through the mixing box which contains cold and hot air just at the each zone.

3. Easy switching from hot to cold modes and vice versa. This is accomplished by the zone or place thermostat which is adjusted once a year.

4. The refrigeration equipment and boilers are placed in one place, and thus electricity, water, and sewage services are located only in plant room but not in the building parts.

5. Centralized maintenance and service are accomplished.

6. Centralized outdoor air inlets. This will ensure no winds or rain are likely to enter from outdoor environment.

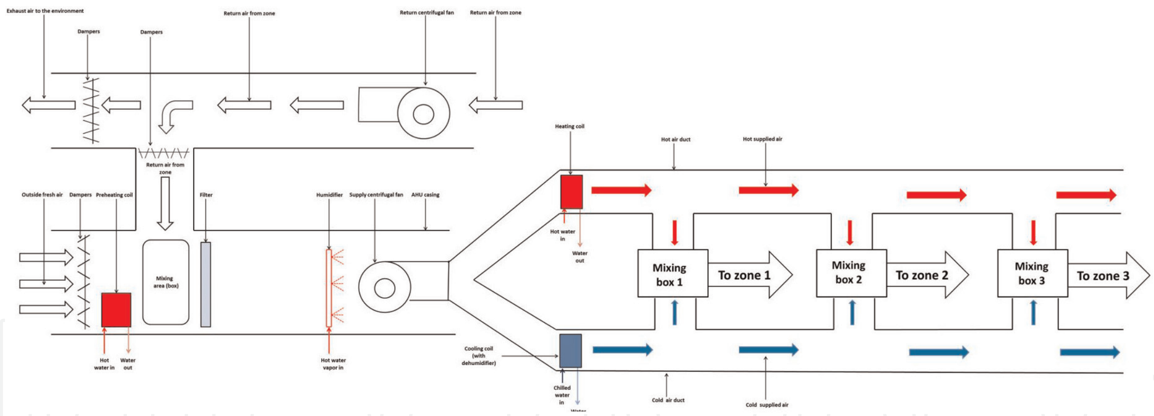

Figure 12.
A schematic diagram of dual-duct system. Redrawn with modification from [1].

7. Higher filter efficiencies can be attained.

8. Low-cost operation can be obtained with these systems.

9. These systems are operating quietly as the refrigeration machines and fan are placed away from zones.

10. These systems have flexible air duct system designs. The choice of medium and high air speeds is possible on an economic basis and according to the requirements of the building.

Disadvantages of the dual-duct systems

1. The use of separate ducts increases the initial cost compared to other systems.

2. Precise control needs a large handling unit, and as a result the total cost of the system will be enlarged.

3. The dual-duct systems are considered inefficient energy systems, and currently these systems are not recommended.

2.1.2.6 Variable air volume (VAV) systems

Variable air volume systems can vary the thermal loads according to zone thermal load variations. One advantage of these systems is that both the initial cost and the operating cost are low because the air volume requires simple control within 20% of the air outlets. These systems are used with fixed thermal loads throughout the year. Applications of these systems can be found in commercial stores, office buildings, hotels, hospitals, housing, and schools. **Figure 13** shows various common terminal units of variable air volume [1–5].

2.2 All-water systems

In all-water systems, water is used as a working fluid for providing heating and cooling. Water is pumped to the fan coil unit located in the zone which is to be conditioned. And then the fan coil unit will use the zone air or sometimes outdoor air for cooling or heating purposes. If outdoor air is used with the fan coil units, then separate air duct system will be introduced to the structure of the building [1–5].

Figure 13.
Pictures of some common variable air volume terminal units. Readapted from [2].

2.2.1 Fan coil unit

Fan coil units are used in all-water central air conditioning. Cold and/or hot water from central chillers and boilers flows through the unit coils. The air temperature is controlled by controlling the flow rate of water through the coil via control valves, e.g., solenoid valves. Fan coil units are cheap in price and widely used in hotels, office buildings, and medical centers. **Figure 14** shows a schematic diagram of a fan coil unit [1–5].

Advantages of fan coil units

1. Low cost

2. Do not need ducts

3. Does not occupy much space

4. Easy to install

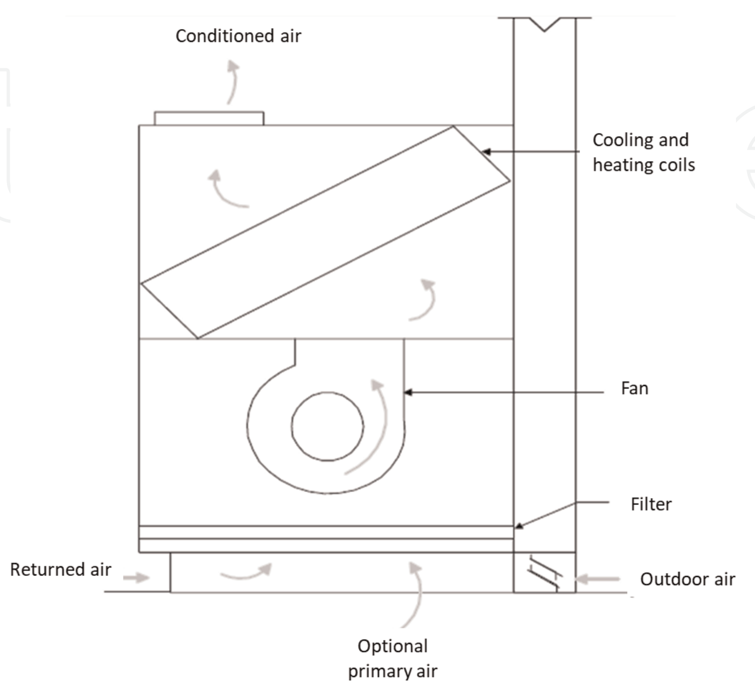

Figure 14.
A schematic diagram of a fan coil unit. Readapted from [5].

Disadvantages of fan coil units

1. Do not provide good control of room air humidity.

2. Require maintenance within the air-conditioned places.

3. Provide suitable medium for bacteria grow in water pipes.

4. The ventilation of the rooms is affected by the speed of wind and rain and insect leakage through the wall openings and cracks which are associated with optional air ventilation duct systems.

2.2.2 Types of all water systems

The all water systems are classified based on water pipe connections to the fan coil units, into two types [1–5], namely:

2.2.2.1 Single piping systems

A. Single piping system (reversed return)

In this system, there are two pipes, one pipe to feed either the cold or hot water to the fan coil unit and another pipe for returning the water back to the chiller or boiler (see **Figure 15**). In these systems the supplied water is in counterflow with the return water.

B. Single piping system (direct return)

In this system, there are two pipes, one pipe to feed either the cold or hot water to the fan coil unit and another pipe for returning the water back to the chiller or boiler (see **Figure 16**). In these systems the supplied water is flowing in a pipe which is connected directly to the chiller or boiler, where the same pipes receive the return water from each fan coil unit.

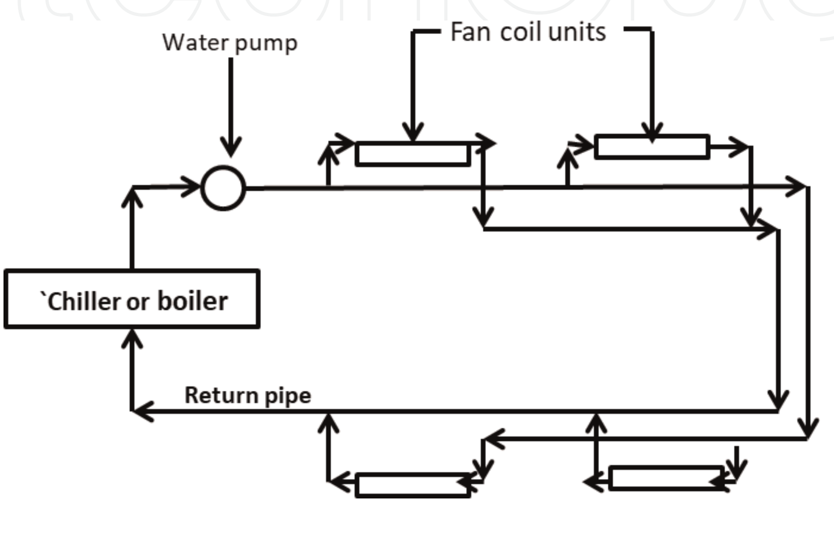

Figure 15.
A schematic diagram of a fan coil unit, two-pipe system of reversed return. Redrawn from [2].

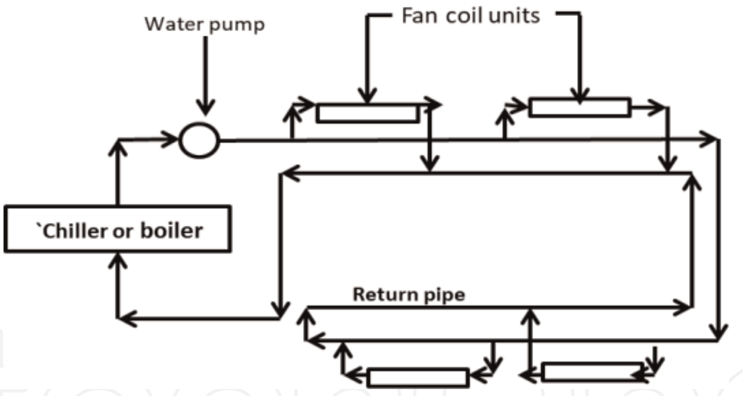

Figure 16.
A schematic diagram of a fan coil unit, two-pipe system of direct return. Redrawn with modification from [2].

2.2.2.2 Multi-piping systems

A. Three-pipe systems

In these systems, there are two pipes for providing hot and cold water to the fan coil unit and one pipe for return water (three-pipe system). **Figure 17** shows a three-pipe all-water-type system.

B. Four-pipe systems

In these systems, there are two pipes for providing hot and cold water to the fan coil unit and two pipes for return, one for cold water return and one for hot water return (four-pipe system). These systems are considered as the best system as the use of two return pipes can maintain efficient energy performance. **Figure 18** shows a four-pipe all-water-type system.

2.3 Air-water systems

In these systems both air and water produce heating and cooling effects. Usually induction or fan coil units can be used in air-water systems. The following section will describe the induction unit systems and fan coil system [1–5].

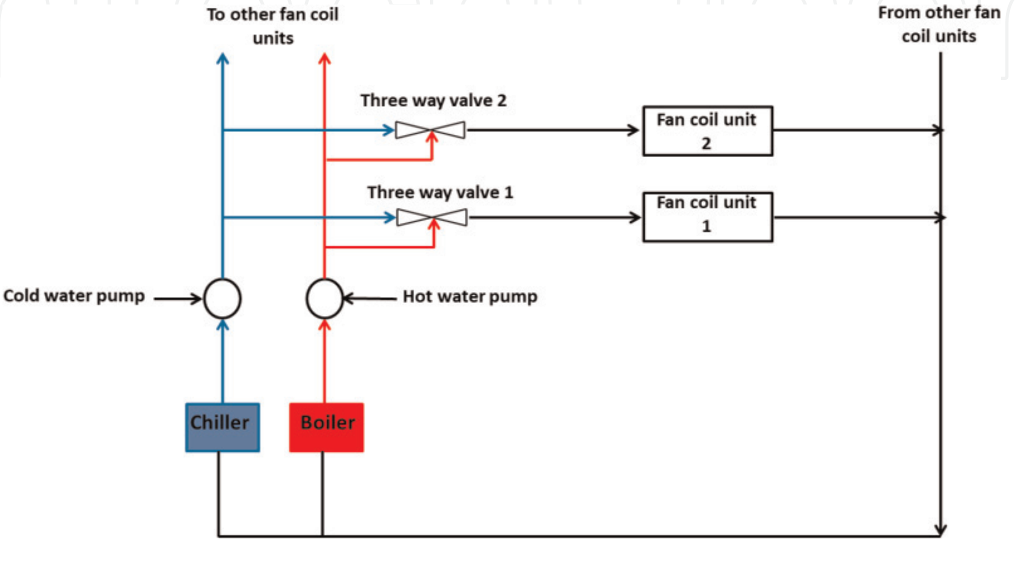

Figure 17.
A schematic diagram of a fan coil unit of three-pipe system. Redrawn with modification from [2].

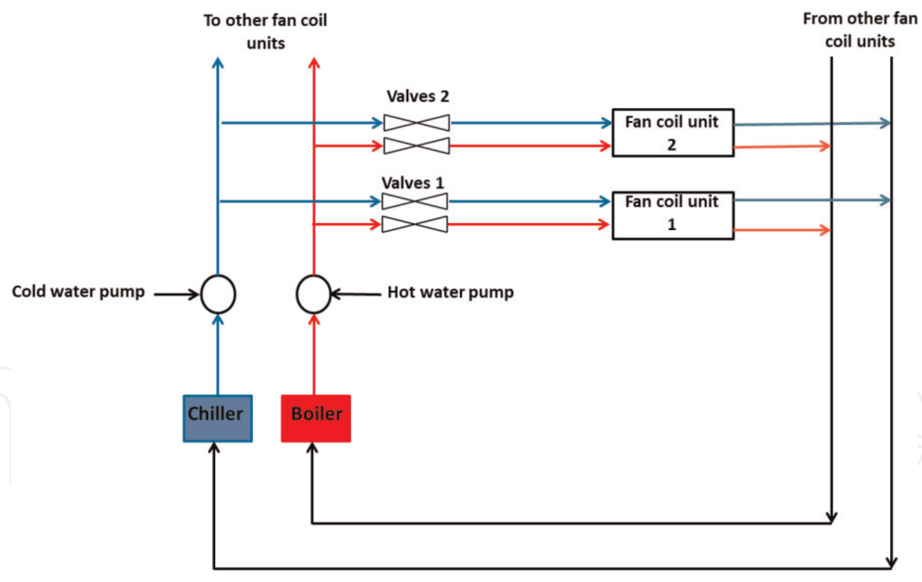

Figure 18.
A schematic diagram of a fan coil unit of four-pipe system. Redrawn with modification from [2].

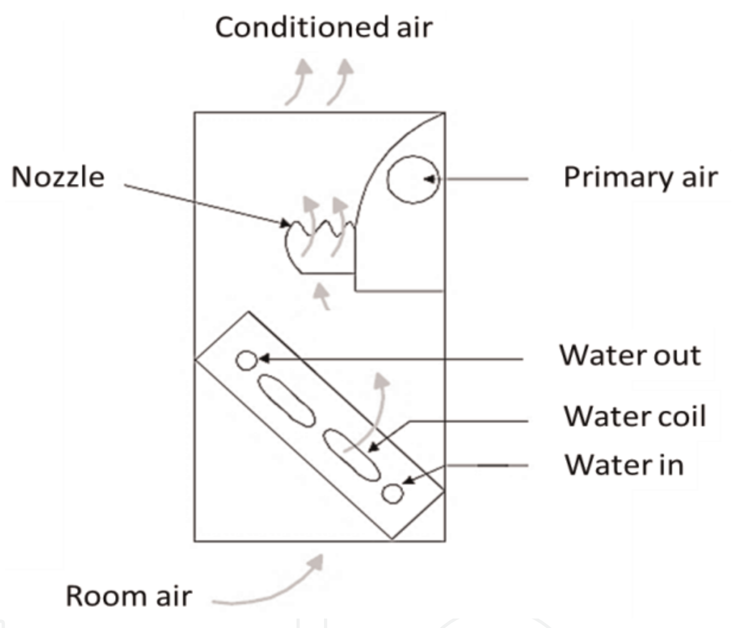

Figure 19.
A schematic diagram of an induction unit system. Readapted from [5].

2.3.1 Induction unit system

Induction unit systems in air-water central air condition are used in building of multi-surrounding rooms such as offices, hotels, hospital patient rooms, as well as apartments. These systems are used where higher thermal loads are present. In addition, these systems are suitable where some rooms require cooling, while the next other rooms require heating. Besides that, these systems are suitable for buildings such as skyscrapers where the spaces are limited. **Figure 19** shows a schematic view of induction unit system which uses primary air and external air. Return air can be used if all primary air is greater than the minimum ventilation requirements [1–5].

2.3.2 Primary air fan coil systems

The working principle of primary air fan coil systems is very similar to the induction unit system. The main difference is the use of fan. These systems are

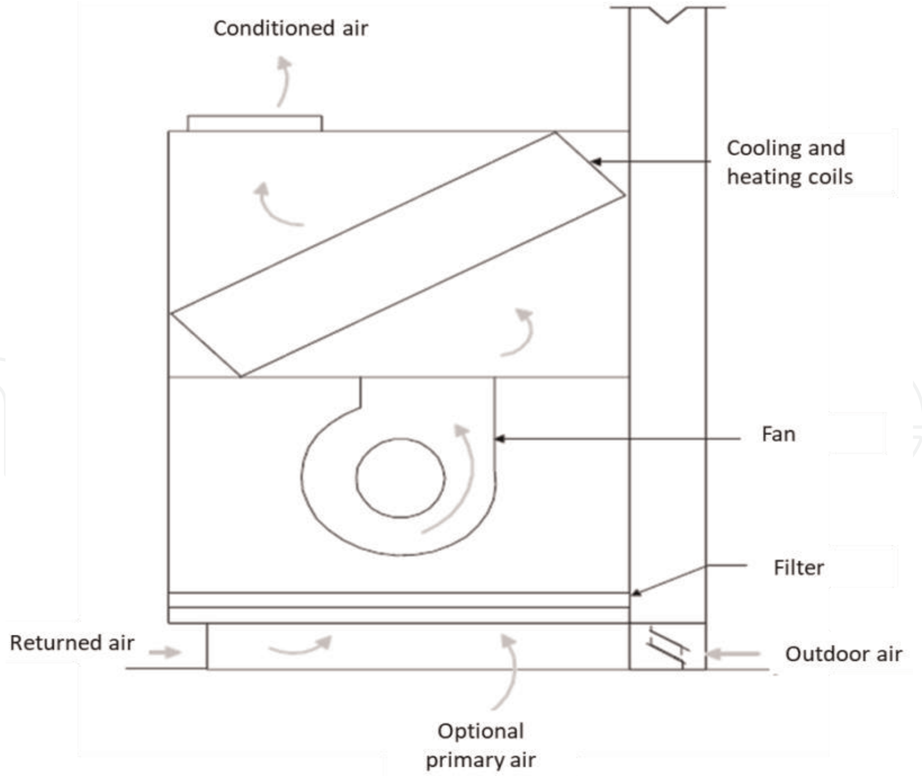

Figure 20.
A schematic diagram of a fan coil unit system. Readapted with modification from [5].

generally used in multiroom buildings such as hotels, hospitals, and apartments where the operating mode can be switched to work in cold season.

Advantages of these systems over induction units are the quite operation and the means to control required condition as fan speed can be usually controlled. But the initial cost of fan coil unit which is higher than induction units makes the induction units more preferred. **Figure 20** shows a schematic diagram of a fan coil unit with its components [1–5].

3. Conclusion

This chapter reviews the types of central air conditioning systems. Specifically, the types and applications of all-air, all-water, and air-water systems are provided. In addition, this chapter gives further insight to all systems through several developed schematic diagrams as various components and working principles of these diagrams and systems can be identified and figured out, respectively. Moreover, the differences among the given systems can be easily distinguished through this chapter.

Author details

Mohamed Elnaggar[1]* and Mohammed Alnahhal[2]

1 Laboratory of Refrigeration and Air conditioning, Department of Engineering Professions, Palestine Technical College, Deir El-Balah, Gaza Strip, Palestine

2 Department of Refrigeration, Air conditioning and Heating Engineering, Israa University, Gaza, Gaza Strip, Palestine

*Address all correspondence to: mohdhn@yahoo.com

References

[1] Pita EG. Air Conditioning Principles and Systems: An Energy Approach. 4th ed. England: Pearson; 2002

[2] Air conditioning systems and equipment (in Arabic), General Organization for Vocational and Technical Training, General Department of Curriculum Design and Development, Kingdom of Saudi Arabia; 2008

[3] Owen M. Heating, Ventilating, and Air-Conditioning Systems and Equipment. USA: ASHRAE; 2012

[4] Seyam S. Types of HVAC systems, In: HVAC System. England: IntechOpen; 2018

[5] McDowall R. Fundamentals of HVAC Systems. England: Elsevier; 2006

[6] Carrier A. Air Handling Unit Manual 39 HQ. Turkey: Trane; 2015

[7] Levenhagen J. HVAC Control System Design Diagrams. USA: McGraw Hill Companies Inc.; 1999

[8] Chua KJ, Chou SK, Yang WM, Yan J. Achieving better energy efficient air conditioning - a review of technologies and strategies. Applied Energy. 2013; **104**:87-104