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BIM4Energy Project

Title: Efficient HVAC Systems and Energy Vectors

1 – Aims

An Efficient HVAC Systems and Energy Vectors tutorial aims to equip participants with a comprehensive understanding of energy-efficient heating, ventilation, and air conditioning (HVAC) systems and the various energy vectors that can power them. The primary objectives of such a tutorial typically include:

The objectives of this Efficient HVAC Systems and Energy Vectors tutorial are as follows:

- Knowledge of various energy sources like electricity, natural gas, propane, solar, geothermal, and biomass, and their suitability for HVAC applications.
- Learning about HVAC System Fundamentals: understanding of the components, principles, and operation of different HVAC systems.
- Understanding of key performance indicators (KPIs) to measure the efficiency of HVAC systems, such as seasonal energy efficiency ratio (SEER), heating seasonal performance factor (HSPF), and energy efficiency ratio (EER).
- Knowing how to choose the most appropriate HVAC system for different building types and climates based on energy efficiency and cost-effectiveness.
- Understanding of how to integrate renewable energy sources (e.g., solar, geothermal) into HVAC systems to maximize energy efficiency and sustainability.
- Knowledge of routine maintenance tasks and troubleshooting techniques to ensure optimal system performance and longevity.
- Understanding of strategies to reduce energy consumption, such as demand-side management, load shedding, and time-of-use pricing.

2 - Learning methodology

The teacher will give an explanation about Efficient HVAC Systems and Energy Vectors of about 30 minutes.

Students will read this tutorial and follow the steps shown in the tutorial, namely:

- The necessity of HVAC systems;
- Energy vectors used in HVAC systems: advantages, disadvantages, and applications;
- Basics of HVAC systems: components, functions, and interaction;
- Calculation and interpretation of energy efficiency metrics: energy efficiency ratio (EER), coefficient of performance (COP), and seasonal energy efficiency ratio (SEER);
- Current types of HVAC systems;
- Innovative technologies for HVAC systems;

- Maintaining and optimizing HVAC systems. Preventive maintenance schedules, troubleshooting techniques, and strategies for improving system performance.

In order to evaluate the success of the application, a questionnaire will be held for the students.

3 - Tutorial duration

The implementation described in this tutorial will be carried out through the BIM4ENERGY Project website by self-learning.

3 lesson hours are suitable for this training.

4 – Necessary teaching recourses

Computer room with PCs with internet access.

Required software: Microsoft Office.

5 – Contents & tutorial

5.1 – The necessity of HVAC systems

5.1.1. The role of HVAC systems

HVAC systems are essential for maintaining a comfortable and healthy indoor environment with acceptable Indoor Air Quality (IAQ) – air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

They provide several key benefits:

- **Temperature Control**: They regulate temperatures to suit the preferences of occupants, ensuring you're neither too cold nor too hot.
- **Improved Air Quality**: HVAC systems filter out pollutants, allergens, and dust, reducing the risk of respiratory problems and allergies.
- **Humidity Control**: They help maintain optimal humidity levels, preventing mold and mildew growth and ensuring a comfortable atmosphere.
- **Energy Efficiency**: Modern HVAC systems are designed to be energy-efficient, helping you save on utility bills.

- **Comfort and Productivity**: A comfortable indoor environment can significantly improve your mood, productivity, and overall well-being.

In essence, **HVAC systems create a healthier and more pleasant living** or working space, contributing to a better quality of life.

5.1.2. Air contaminants

Indoor air quality is a crucial component of a healthy indoor environment, as we spend a significant amount of our time indoors. It is said that we will spend indoor around 90% of our life.

How did we get here? Well, firstly, our modern jobs are mostly indoor, and computer related. Secondly, we **air-tightened our buildings** for energy saving but we neglected IAQ for many years. We replaced all the natural building components in our modern buildings with huge amounts of **synthetic materials**, that we later discovered that many of them **"leak" in our air a lot of chemical pollutants**. Some of them are classified as human carcinogens by IARC - International Agency for Research on Cancer.

Poor indoor air quality can have adverse effects on our health, productivity, and overall well-being. **Air contaminants** are one of the most significant contributors to poor indoor air quality (see Figure 1), and this tutorial aims to provide you with a comprehensive understanding of the types of air contaminants, their sources, and their effects on human health [1].

Figure 1. Common air contaminants within the indoor environment

Throughout this learning activity, you will learn about the different types of indoor air pollutants, including volatile organic compounds (VOCs), particulate matter, and biological contaminants. You will also learn about the sources of these contaminants and how they can enter our indoor environment, strategies to reduce exposure and improve indoor air quality [2].

At the end of this tutorial, you will have a deeper understanding of the potential health effects of exposure to indoor air pollutants and practical strategies to improve indoor environmental quality and create a healthier indoor environment for yourself and those around you.

Air contaminants are substances that can be found in the air and have the potential to cause harm to human health or the environment. In the context of IAQ, air contaminants refer to pollutants that are present indoors such as in homes, schools, and workplaces. These pollutants can have harmful effects on human health, especially since people tend spend a significant amount of time indoors [3].

There are several types of air contaminants, and they can be classified based on their source and chemical composition:

1. **Volatile organic compounds (VOCs)**: These are chemicals that can be emitted from building materials, cleaning products, and other consumer products. Some common VOCs include formaldehyde, benzene, and toluene.
2. **Formaldehyde**: This is a common VOC found in many building materials, furniture, and household & beauty products.
3. **Particulate matter**: This refers to tiny particles that can be found in the air, such as dust, pollen, and mold spores.
4. **Particulate matter from cooking**: Fumes and particles can be generated from cooking activities that can degrade indoor air quality.
5. **Carbon monoxide**: This is a gas that is produced by combustion sources, such as gas stoves and heaters, and can be deadly in high concentrations.
6. **Nitrogen dioxide**: This is a gas that can be produced by gas stoves and other combustion sources and can cause respiratory problems.
7. **Radon**: This is a naturally occurring radioactive gas that can seep into buildings from the ground and can cause lung cancer.
8. **Biological contaminants**: These include mold, bacteria, dust mites and viruses, which can cause a range of health problems, particularly for people with allergies or asthma.
9. **Asbestos**: This is a mineral fibre that was commonly used in building materials before its health hazards were recognized. Asbestos exposure can cause lung cancer and mesothelioma.
10. **Lead**: This is a heavy metal that can be found in some building materials and can cause developmental problems in children and other health issues in adults.
11. **Ozone**: This is a gas that can be produced by some air purifiers and can cause respiratory problems.
12. **Pesticides**: These are chemicals used to kill pests, but they can also be harmful to human health.
13. **Second-hand smoke**: This is the smoke that is exhaled by smokers or emitted from burning tobacco products.
14. **Flame retardants**: These chemicals are added to furniture and electronics to reduce the risk of fire but can also be harmful to human health.

It is important to note that this is not an exhaustive list of all possible indoor air pollutants, but these are some of the most common ones.

5.1.3. Strategies to improve the Indoor Air Quality

There are several strategies that can be employed to enhance indoor air quality. These approaches, listed in order of increasing effectiveness, can significantly improve the air quality within your space.

1. **Regular cleaning**: Regular cleaning of the indoor environment can help to remove dust, mold, and other allergens that can contribute to poor indoor air quality. This includes vacuuming carpets and upholstery, dusting surfaces, and washing bedding and curtains.
2. **Minimizing the use of products that emit pollutants**: Many household products, such as cleaning agents, paints, and solvents, can emit pollutants into the air. To minimize exposure, it is important to choose products that are low in VOCs or are labelled as "green" or "eco- friendly". It is also important to use these products in well-ventilated areas and to dispose of them properly. Choosing safe and eco-friendly products can help to minimize exposure to pollutants.
3. **Adding plants**: Certain types of plants can help to improve indoor air quality by absorbing pollutants and releasing oxygen. Examples of these include the spider plant, peace lily, and English ivy.
4. **Using air purifiers**: Air purifiers can help to remove pollutants from the air, such as dust, allergens, and volatile organic compounds (VOCs). There are various types of air purifiers available, such as HEPA filters, activated carbon filters, and ionizers.
5. **Avoiding smoking indoors**: Tobacco smoke is a major indoor air pollutant and can lead to respiratory problems, allergies, and other health issues. It is important to avoid smoking indoors and to encourage others to do the same.
6. **Increasing ventilation**: One of the most effective ways to improve indoor air quality is by increasing the amount of outdoor air that enters the building. This can be done by opening windows and doors, using exhaust fans, and ensuring that the ventilation system is functioning properly.

The most important of them all, having the most impact is increasing ventilation. Reducing the emitting materials, regular cleaning and plants have a small impact on IAQ. Air purifiers are good only if they are sized properly but keep in mind that air purifiers recirculate indoor air and have effect only on specific pollutants such as dust, allergens, VOCs, so it will not be useful for most of the contaminants presented.

5.2– Energy vectors used in HVAC systems

5.2.1. Types of energy vectors

Energy vectors are the mediums through which energy is transferred in an HVAC system [4]. These vectors can be classified into two primary categories:

1. Thermal Energy Vectors:

- **Air**: The most common medium for both heating and cooling. Air is heated or cooled and then circulated throughout the space.
- **Water**: Used in hydronic systems, water is heated or cooled and then circulated through pipes to heat or cool spaces.
- **Steam**: Another hydronic medium, steam is used primarily for heating applications.
- **Refrigerant**: Used in refrigeration cycles to extract heat from a space and transfer it to a higher temperature level.

2. Electrical Energy Vectors:

- **Electricity**: Powers the fans, pumps, compressors, and other components of HVAC systems.

Additional Considerations:

- **Combined Heat and Power** (CHP): Some HVAC systems can utilize CHP, where the same fuel source is used to generate both electricity and heat, improving overall energy efficiency.
- **Renewable Energy Sources**: Solar, wind, and geothermal energy can also be used to power or supplement HVAC systems, reducing reliance on traditional energy sources.

5.2.2. Advantages and Disadvantages of different energy vectors in HVAC systems

Air is a versatile and widely available energy vector for HVAC systems. Its ability to both heat and cool spaces makes it a flexible choice for various applications. Additionally, air is relatively inexpensive and easy to install, making it a cost-effective option for many HVAC projects. Its good thermal conductivity ensures efficient heat transfer, resulting in effective heating and cooling performance.

Air-based HVAC systems, while versatile, have several drawbacks. Inefficiency due to factors like air leakage and infiltration can reduce energy efficiency. Noise generated by high-speed fans may be disruptive. Air quality can be compromised if allergens and pollutants are not adequately filtered. Additionally, limited temperature range can make air-based systems less suitable for applications requiring extreme temperatures.

While air offers several advantages as an energy vector in HVAC systems, it's important to consider its potential drawbacks and weigh them against the specific needs and requirements of the application.

Water-based HVAC systems offer several benefits. Their efficiency allows for transferring large amounts of heat with minimal energy loss. They are generally quieter than air-based systems, reducing noise pollution. Water can be used for both heating and cooling, as well as for domestic hot water or radiant heating. Additionally, water-based systems provide precise temperature control, ensuring optimal comfort levels.

While water-based HVAC systems offer many advantages, they also have some disadvantages. Initial costs for piping and equipment can be higher compared to air-based systems. Maintenance can be more complex due to the extensive piping network and pumps. In cold climates, freezing concerns must be addressed through antifreeze or freeze protection measures. Finally, water-based systems may be less flexible for retrofitting existing buildings, requiring significant modifications to the structure.

Steam-based HVAC systems offer several advantages. Their high heat capacity allows for rapid heat delivery, making them ideal for large commercial or industrial buildings. Steam can also be used for other industrial processes, increasing its versatility. Additionally, steam systems are well-suited for heating large spaces efficiently.

Steam-based HVAC systems, while effective for heating, have several drawbacks. Safety concerns arise due to the high temperatures and pressures involved, requiring careful handling. Initial costs for boilers and piping can be substantial. Maintenance is complex, requiring specialized knowledge and equipment. Lastly, steam systems are not suitable for cooling applications, limiting their versatility.

Refrigerant-based HVAC systems offer several benefits. Their efficient cooling makes them ideal for cooling applications. Refrigerants can also achieve very low temperatures, making them suitable for various industrial processes. Additionally, refrigerant-based systems are generally quieter than air-based systems, reducing noise pollution.

Refrigerant-based HVAC systems, while effective for cooling, have several disadvantages. Environmental concerns arise due to the impact of many refrigerants on the environment, leading to regulations. Maintenance requires specialized knowledge and equipment for handling refrigerants safely. Initial costs can be high due to the specialized equipment and installation requirements. Finally, refrigerant-based systems are primarily used for cooling, with limited heating capabilities.

Electricity-based HVAC systems offer several advantages. Their flexibility allows for powering a variety of components, making them adaptable to different system configurations. When combined with other energy-saving technologies, electricity can be highly efficient. Additionally, electricity-based systems provide precise control over HVAC operations, ensuring optimal performance and comfort.

Electricity-based HVAC systems, while offering many advantages, also have some drawbacks. Costs can be significant, especially in regions with high electricity rates. Reliability may be affected by power outages or fluctuations. Additionally, electricity generation from fossil fuels can contribute to environmental concerns such as greenhouse gas emissions.

The best energy vector for a specific HVAC system depends on various factors, including the building's size, location, climate, and desired level of comfort.

5.2.3. Applications of different energy vectors in HVAC systems

As previously discussed, many energy vectors are adaptable to a wide range of applications [5]. These versatile mediums can be effectively utilized in residential, commercial, and industrial settings, demonstrating their broad applicability. The following examples illustrate their versatility in various contexts.

Air: Commonly used in all three sectors. Residential applications include central air conditioning, forced-air heating, and heat pumps. Commercial applications often involve VRF systems, rooftop units, and fan coil units. Industrial applications may utilize large-scale ventilation systems and dust collection systems.

Water: Frequently used in residential and commercial settings. Residential applications include radiant heating and hydronic systems. Commercial applications often involve boiler plants and chilled water systems. Industrial applications may utilize process heating and cooling systems.

Steam: Primarily used in industrial and commercial settings. Industrial applications include steam turbines for power generation and process heating. Commercial applications may involve steam heating systems for large buildings.

Refrigerant: Primarily used in commercial and industrial settings. Commercial applications include supermarket refrigeration systems and ice machines. Industrial applications may involve process cooling systems and cold storage facilities.

Electricity: Used in all three sectors. Residential applications include electric baseboard heaters, heat pumps, and electric air conditioning. Commercial applications often involve electrical chillers and fan coil units. Industrial applications may utilize electrical heating elements and process cooling systems.

These examples demonstrate the versatility of different energy vectors in HVAC systems, allowing for tailored solutions to meet the specific needs of various applications. By understanding the different energy vectors used in HVAC systems, it is possible to optimize energy efficiency and select the most appropriate system for a given application.

5.3– Basics of HVAC systems: components, functions, and interaction

HVAC systems are designed to maintain comfortable indoor environments by controlling temperature, humidity, and air quality. These systems typically consist of several key components that work together to achieve these goals

5.3.1. Components of HVAC systems

Essential components of a HVAC system include:

- **a) heat source;**
- **b) cooling source;**
- **c) air handler;**
- **d) humidifier and/or dehumidifier;**
- **e) fans;**
- **f) ducts;**
- **g) dampers;**
- **h) registers;**
- **i) thermostat.**

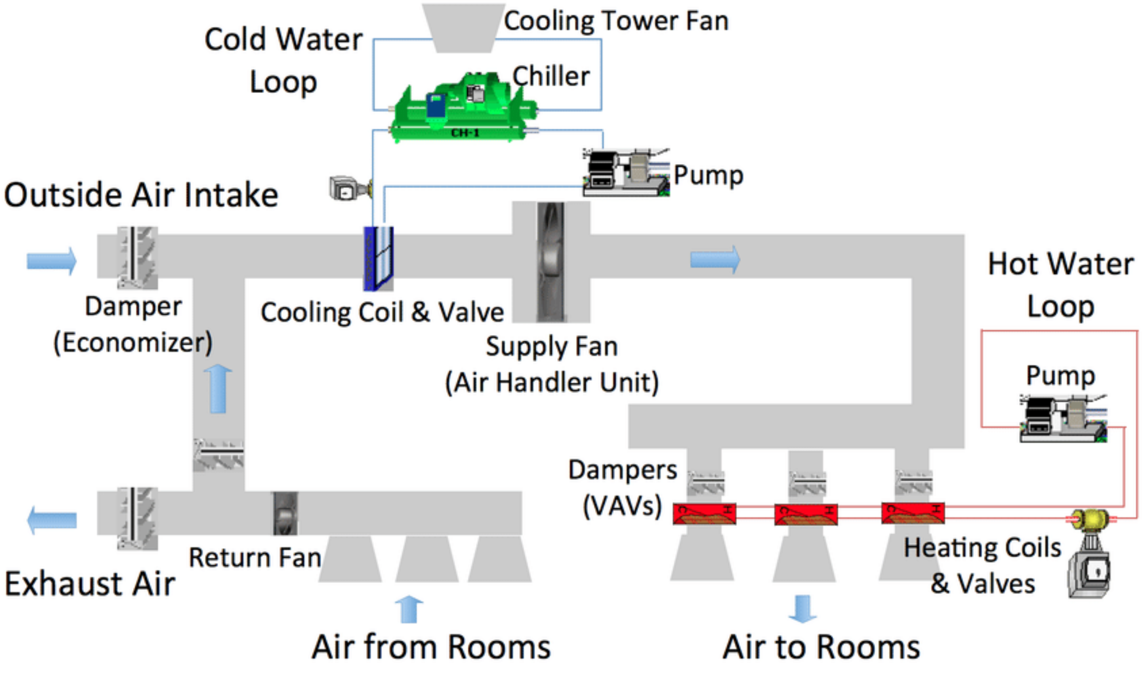


Figure 2. Components of a HVAC system

These interconnected elements work together to regulate temperature, humidity, and air quality within indoor spaces [6].

a) A common **heat source** in residential and commercial buildings, are the **furnaces** that utilize fossil fuels like natural gas, propane, or oil to generate heat. This heat is then transferred to the air that circulates throughout the HVAC system, providing warmth to the indoor spaces. **Boilers**, commonly employed in larger commercial and industrial buildings, heat water or steam, which is then circulated through a network of pipes to provide warmth to various areas of the structure. Another popular heat source, **heat pumps**, offer the versatility of both heating and cooling spaces. These energy-efficient devices transfer heat from a warmer source, such as the outside air or ground, to a colder source, like the indoor air.

b) HVAC systems employ various **cooling sources** to lower indoor temperatures. **Air conditioners**, commonly found in residential and commercial buildings, extract heat from the indoor environment and expel it outdoors. **Chillers**, often used in larger commercial and industrial settings, cool water or refrigerant, which is then circulated throughout the HVAC system to reduce indoor temperatures.

Figure 3. Cooling sources: Air conditioner (left); Chiller (right)

c) The **Air Handler Unit (AHU)** is a crucial component of HVAC systems that circulates air throughout the building. It typically includes a powerful fan, a filter to remove contaminants, and coils for heating or cooling the air, ensuring a comfortable and healthy indoor environment [7].

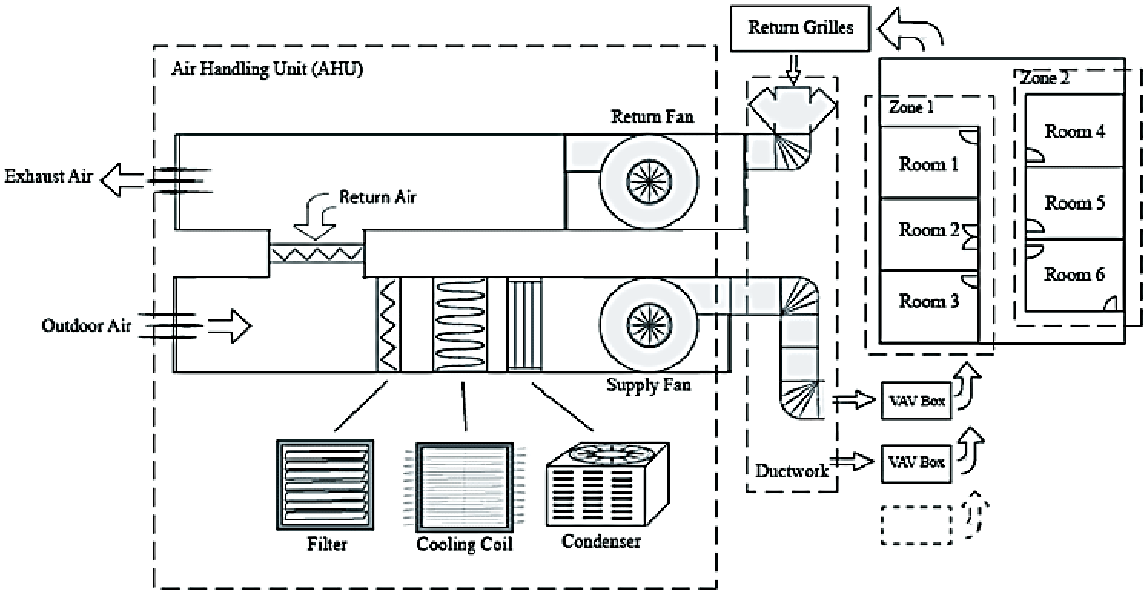


Figure 4. Air Handler Unit (AHU) [7]

To illustrate the air handler operation, consider a homeowner who sets the thermostat to 26°C. When the indoor temperature rises above this setpoint, the thermostat detects the deviation and sends a signal to the HVAC system. In response, the air handler, a central component of the system, commences operation.

The fan within the air handler begins to rotate, drawing air from the indoor space. As air passes through the air handler, it is filtered to remove contaminants such as dust, pollen, and allergens, enhancing indoor air quality. Subsequently, the cooling coil within the air handler is activated, effectively cooling the incoming air to the desired temperature.

The cooled air is then propelled through ducts and vents throughout the home, gradually reducing the indoor temperature. The thermostat continuously monitors the indoor environment, ensuring that the temperature remains at the desired setpoint. Once the desired temperature is achieved, the air handler and cooling coil will automatically shut down, conserving energy.

In this example, the air handler plays a crucial role in cooling the home by drawing in air, filtering it, cooling it, and distributing it throughout the space.

d) **Humidifiers and Dehumidifiers** are also essential components of HVAC systems that help regulate indoor humidity levels. These devices play a crucial role in maintaining a comfortable and healthy environment by preventing issues such as dry skin, respiratory problems, and mold growth.

Humidifiers add moisture to the air. They are often used in dry climates or during winter months when indoor air can become excessively dry due to heating systems. By increasing humidity, humidifiers can help alleviate dry skin, nasal congestion, and static electricity.

Dehumidifiers remove moisture from the air. They are commonly used in humid climates or during summer months when high humidity can lead to mold growth, mildew, and musty odours. By reducing humidity, dehumidifiers can help prevent these problems and create a more comfortable environment.

Both humidifiers and dehumidifiers typically work by using a fan to draw air into the unit. The air then passes over a filter or other component that either adds or removes moisture. The treated air is then released back into the room.

By effectively using humidifiers and dehumidifiers, you can maintain optimal humidity levels in your indoor space, creating a healthier and more comfortable environment.

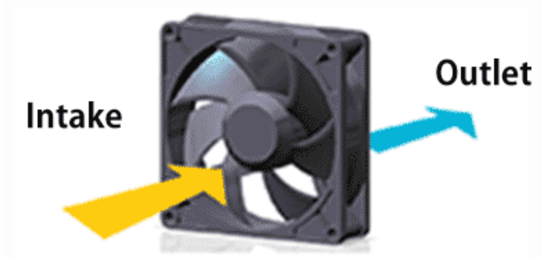
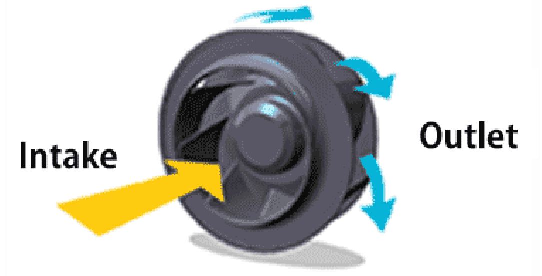
e) **Fans** are devices that create airflow by rotating blades. They are used in a variety of applications in the HVAC systems and are essential for circulation, ventilation, heat transfer and moisture control.

Fans distribute conditioned air throughout a building, ensuring even heating or cooling in all areas. In heating systems, fans help to move warm air from the furnace to the rooms. In cooling systems, they draw in warm air to be cooled and then distribute the cool air.

Fans help to exchange indoor air with outdoor air, improving air quality and preventing the buildup of pollutants. Fans can also help to reduce humidity by moving air and preventing moisture from accumulating.

There are different types of fans, including axial fans, centrifugal fans, and blower fans (see Table 1). The type of fan used depends on the specific application and the required airflow characteristics. Essentially, fans are the heart of HVAC systems, ensuring that conditioned air is efficiently delivered to where it's needed.

Table 1 – Types of fans

Fan type	Exterior	Structure
Axial		
Centrifugal		
Blower		

f) **Ducts** are a critical component of HVAC systems, responsible for distributing conditioned air (heated or cooled) throughout a building. As depicted in Figure 5, the ducts form a network that connect the air handler to various rooms and spaces.

Figure 5. Network of ducts [8]

Ducts operate on a simple principle: The HVAC unit, typically located in a basement, attic, utility room, or outside heats or cools air using a heating or cooling source. This conditioned air is then pushed into a network of supply ducts. These ducts are usually made of metal or flexible materials. The supply ducts branch out and carry the conditioned air to different rooms in the building. This air is expelled through vents or registers. As the conditioned air heats or cools the indoor spaces, it becomes less effective. This used air is drawn back into the HVAC unit through return ducts. The return air passes through a filter to remove dust, pollen, and other contaminants. It is then recirculated through the system, repeating the process.

Ducts come in two main types: rigid and flexible. The rigid ducts (circular or rectangular shape) are constructed from sheet metal, are durable and offer efficient airflow. The flexible ducts (circular shape), made from a flexible material are easier to install but may have slightly lower efficiency.

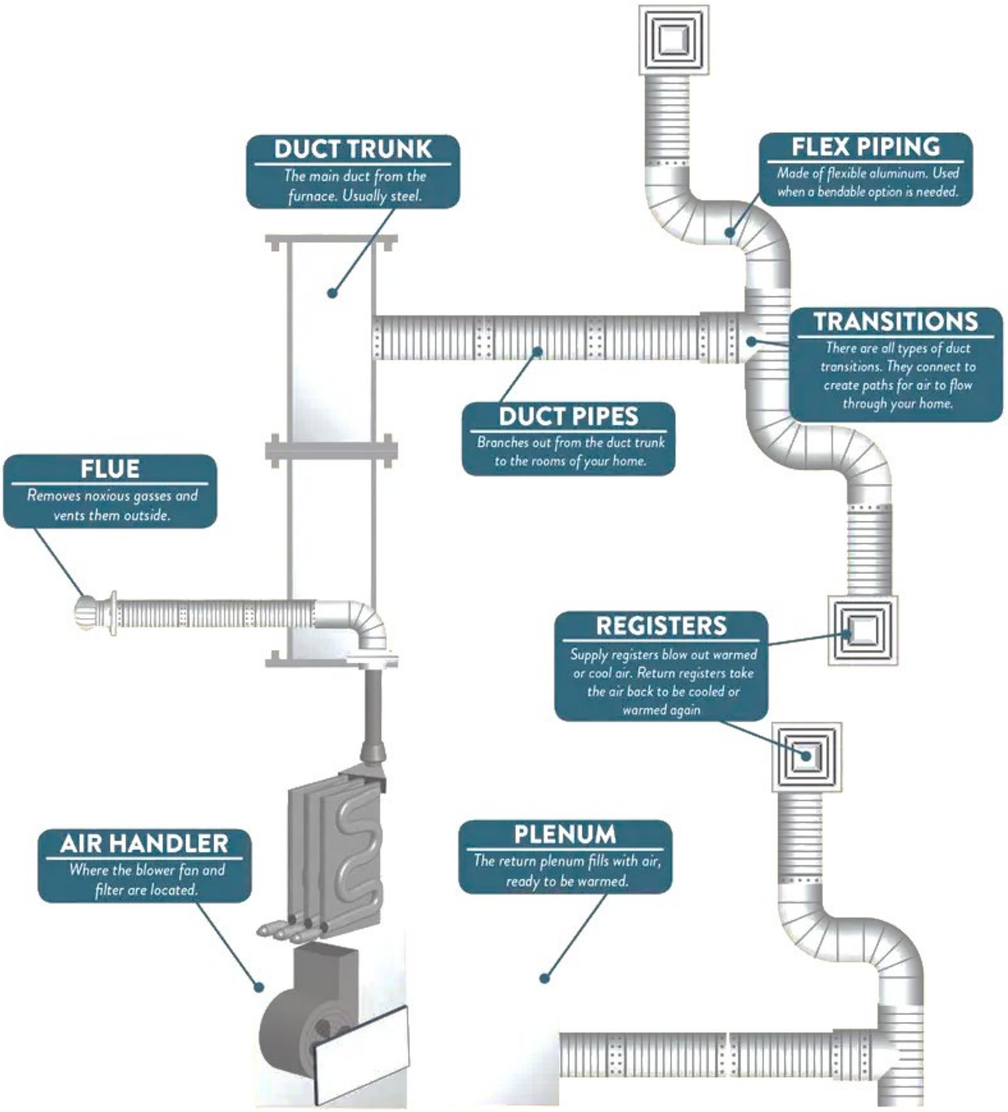


Figure 6. Elements of the ducts network [9]

Efficient HVAC system operation relies on well-designed and installed ductwork. Leaky or poorly insulated ducts can reduce energy efficiency and increase costs. Insulating ducts helps prevent heat loss or gain, improving energy efficiency. Properly sealed ducts prevent air leaks and infiltration of outdoor pollutants, enhancing indoor air quality. Ducts ensure conditioned air reaches all areas of the building, providing consistent comfort.

Regular duct maintenance is essential for optimal performance and energy efficiency. Inspections can reveal leaks, blockages, or other issues that may impact airflow. Cleaning removes dust, dirt, and contaminants that can reduce efficiency. Sealing leaks helps prevent energy loss and lowers utility bills.

By understanding the role of ducts in HVAC systems and ensuring their proper maintenance, building owners and occupants can enjoy optimal comfort and energy efficiency.

g) **Dampers** are mechanical devices employed in HVAC systems to effectively manage airflow. These components play a crucial role in maintaining optimal indoor environmental conditions. By regulating the volume of air that passes through various ducts and vents, dampers enable precise control over the distribution of conditioned air throughout a building. This ensures that different areas receive the appropriate amount of heating or cooling, leading to enhanced comfort and energy efficiency.

Figure 7. Different dampers depending on the duct’s type

Dampers come in various types to suit different needs: manual dampers – are adjusted manually by hand or with a tool; motorized dampers – are controlled by electric motors and can be automated for remote operation; and pneumatic dampers – are actuated by compressed air, allowing for precise and responsive control.

Dampers perform a variety of functions to ensure optimal indoor comfort and efficiency. Their primary roles include:

- ✓ Balancing airflow: Dampers distribute conditioned air evenly throughout a building, preventing hot or cold spots.
- ✓ Temperature control: By regulating the volume of air passing through heating or cooling coils, dampers maintain desired temperature levels.
- ✓ Backdraft prevention: Dampers prevent air from flowing back into the system, ensuring efficient operation and preventing contaminants from entering.
- ✓ Energy efficiency: Dampers help optimize energy consumption by minimizing air leakage and balancing airflow, reducing the overall energy demand.

- ✓ Indoor air quality: By controlling ventilation rates, dampers help maintain a healthy indoor environment by removing pollutants and introducing fresh air.

Here's an example of how dampers work: Imagine a large commercial building with multiple floors and zones. Each zone has its own thermostat to control the temperature in that area. To ensure that the correct amount of air is delivered to each zone, dampers are installed in the ductwork.

- If a zone requires more heat or cooling, the thermostat will signal the HVAC system to increase airflow to that area. The damper controlling the airflow to that zone will open, allowing more air to pass through.
- If a zone requires less heat or cooling, the thermostat will signal the HVAC system to decrease airflow to that area. The damper controlling the airflow to that zone will close, restricting the amount of air that can pass through.

By adjusting the position of these dampers, HVAC systems can effectively control the temperature and airflow in different areas of a building, ensuring optimal comfort and energy efficiency.

h) **Registers** are openings in walls or ceilings that provide a pathway for conditioned air from the ductwork to enter the rooms.

They are typically equipped with grilles or louvers that can be adjusted to control the amount of airflow. By adjusting the position of the grille or louvers, you can control the amount of air that flows into a room. This allows to customize the temperature and airflow in different areas of your home or building. Registers help to ensure even distribution of conditioned air throughout the building, preventing hot or cold spots.

Registers come in a variety of types depending on their position within the building (see Figure 8). Wall registers are typically located in the walls of a room and can be either rectangular or circular in shape. Ceiling registers are in the ceiling and are often used in rooms with high ceilings. Floor registers are less common but can be found in some older building.

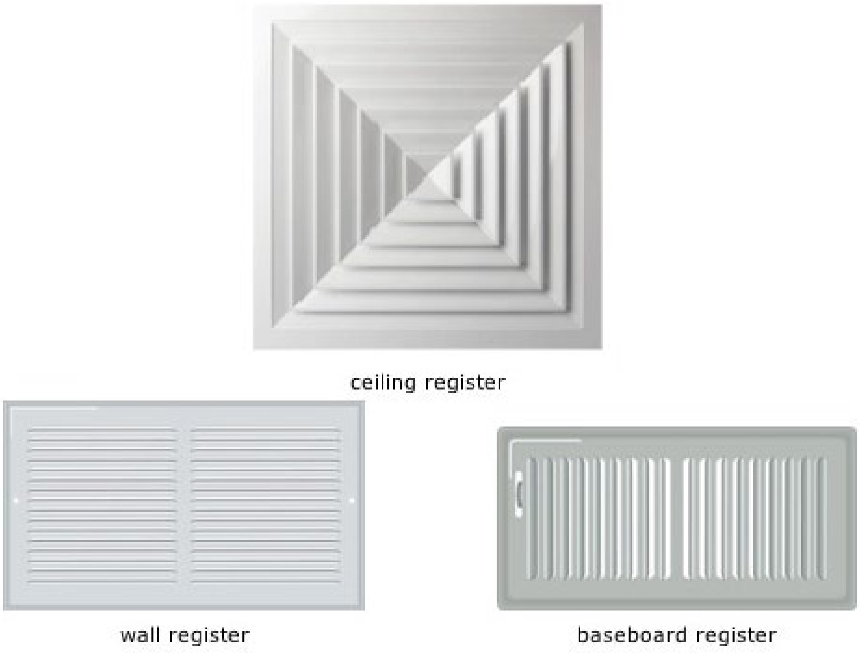


Figure 8. Types of registers [10]

i) **Thermostat** is the central control unit that regulates the operation of the HVAC system. It acts as a temperature-sensitive switch, turning the system on or off to maintain a desired temperature. The thermostat is equipped with a temperature sensor, usually a thermistor. This sensor continuously monitors the ambient temperature in the room. The thermostat compares the measured temperature to the desired temperature set by the user. Based on this comparison, the thermostat sends signals to the HVAC system. For example, when the thermostat detects a drop in temperature, it activates the heat source. The heat source warms the air, which is then circulated through the air handler and ducts to the indoor space. The air handler may also include a filter to remove contaminants from the air before it is distributed.

Similarly, when the thermostat detects a rise in temperature, it activates the cooling source. The cooling source removes heat from the air, which is then circulated through the air handler and ducts to the indoor space. Humidifiers and dehumidifiers are used to regulate humidity levels, ensuring optimal comfort and preventing potential health issues.

5.3.2. Functions of HVAC systems

HVAC systems perform the following primary functions:

1. **Heating:** They warm indoor spaces to a comfortable temperature, using various methods like furnaces, heat pumps, boilers, or electric heaters.
2. **Cooling:** They cool indoor spaces to a comfortable temperature, typically using air conditioning units that remove heat and humidity.

3. **Ventilation:** They exchange indoor air with outdoor air to maintain adequate air quality and prevent the buildup of pollutants and stale air.
4. **Humidity control:** They regulate the humidity level in indoor spaces, preventing excessive dryness or moisture that can lead to discomfort or health problems.
5. **Air filtration:** They filter out airborne contaminants like dust, pollen, and allergens to improve indoor air quality.

HVAC systems are responsible for creating a comfortable, healthy, and efficient indoor environment by controlling temperature, humidity, and air quality.

The following video is available for a better understanding of the working principles of HVAC systems.

5.3.3. Interaction between components in HVAC systems

HVAC systems are complex networks of interconnected components that work together to regulate indoor temperature, humidity, and air quality [5,6]. The interactions between these components are crucial for the efficient and effective operation of the system.

1. **Thermostat and Controller**: The thermostat measures the indoor temperature and sends a signal to the controller. Based on the temperature reading, the controller activates the appropriate heating or cooling equipment.
2. **Heating and Cooling Equipment**: Heating equipment (e.g., furnaces, boilers) converts fuel into heat, while cooling equipment (e.g., air conditioners, chillers) removes heat from the indoor air. Fans in both heating and cooling equipment circulate the conditioned air throughout the building.
3. **Ductwork**: Ducts transport conditioned air from the heating or cooling equipment to the various rooms in the building. Dampers within the ductwork control the amount of air that flows to different areas.
4. **Registers** are openings in the walls or ceilings that allow conditioned air to enter the rooms. Registers can be adjusted to regulate the amount of air delivered to individual rooms.
5. **Filters** remove contaminants from the air, such as dust, pollen, and allergens. Filters also protect the heating and cooling equipment from damage caused by contaminants.
6. **Sensors** monitor various conditions within the HVAC system, such as temperature, humidity, and airflow. The data collected by sensors is used by the controller to adjust the system's operation as needed.

HVAC systems often include ventilation components that exchange indoor air with outdoor air, improving air quality and removing moisture. Dehumidifiers or humidifiers may be used to regulate indoor humidity levels.

HVAC systems can be integrated with building automation systems to optimize energy consumption.

These components and functions work together in a coordinated manner to create a comfortable and healthy indoor environment. The specific configuration of an HVAC system will vary depending on the building's size, location, and desired level of comfort.

5.4– Calculation and interpretation of energy efficiency metrics

When evaluating the energy efficiency of HVAC systems, three primary metrics are commonly used: Energy Efficiency Ratio (EER), Coefficient of Performance (COP), and Seasonal Energy Efficiency Ratio (SEER). These metrics measure the efficiency of a system in converting energy input into useful output.

5.4.1. Energy Efficiency Ratio (EER)

- **Definition:** EER is a measure of how efficiently an air conditioner or heat pump converts electrical energy into cooling or heating output.
- **Calculation:** EER = Cooling capacity (BTU/h) / Power input (watts)
- **Interpretation:** A higher EER indicates a more efficient system. For example, an EER of 14 means that the system produces 14 BTU of cooling for every watt of electricity consumed.

5.4.2. Coefficient of Performance (COP)

- **Definition:** COP is a similar metric used for heat pumps, measuring the efficiency of converting electrical energy into heating output.
- **Calculation:** COP = Heating capacity (BTU/h) / Power input (watts)
- **Interpretation:** A higher COP indicates a more efficient heat pump.

5.4.3. Seasonal Energy Efficiency Ratio (SEER)

- **Definition:** SEER is a measure of a system's average energy efficiency over a cooling season. It considers factors like outdoor temperature and humidity.
- **Calculation:** SEER is calculated based on a series of EER values across different outdoor temperatures.
- **Interpretation:** A higher SEER indicates a more efficient system over the entire cooling season.

Key Points:

- **Units:** EER, COP, and SEER are typically expressed in units of BTU/h per watt.
- **Efficiency comparison:** These metrics allow for direct comparison of the energy efficiency of different HVAC systems.
- **Regulatory standards:** Many regions have minimum SEER requirements for new HVAC equipment to promote energy efficiency.

By understanding these metrics, consumers can make informed decisions when selecting HVAC systems that are both efficient and cost-effective.

5.5– Current types of HVAC systems

Based on their size, construction, and operating characteristics, HVAC systems can be classified as:

a) Individual Room or Individual Systems

b) Space-Conditioning Systems or Space Systems

c) Unitary Packaged Systems or Packaged Systems

d) Central Hydronic or Central Systems

5.5.1. Individual Room or Individual Systems

An **individual system** normally employs either a single, self-contained, packaged room air conditioner (installed in a window or a wall) or separate indoor and outdoor units to serve an individual room (Figure 9).

The individual systems are characterized by compact size, easy installation, and relatively low cost. However, they may have limited cooling or heating capacity and can be noisy.

Figure 9. Individual HVAC systems [11]

5.5.2. Space-Conditioning Systems or Space Systems

Space-Conditioning Systems are designed to condition a larger space, such as a building or a group of buildings (Figure 10). They are more powerful than individual room systems, offering better temperature control and air quality. Space Systems have their cooling, heating, and filtration performed predominantly in or above the conditioned space. The outdoor air is supplied by a separate outdoor ventilation system. They are more complex to install and require professional maintenance.

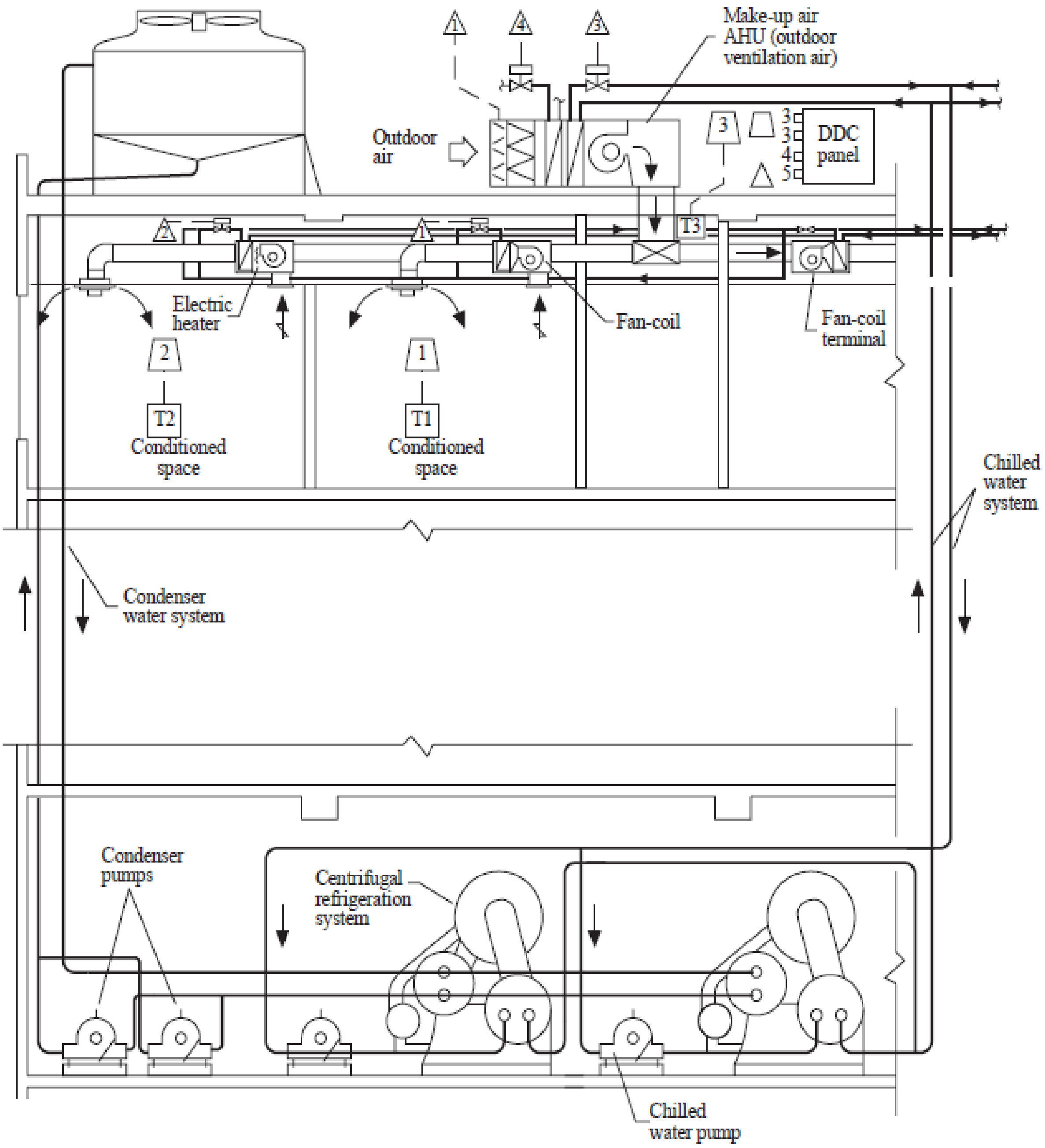


Figure 10. Space-Conditioning Systems

5.5.3. Unitary Packaged Systems or Packaged Systems

Unitary Packaged Systems are factory-built units that contain all the necessary components (evaporator, condenser, fan, and controls) in a single cabinet (Figure 11). They are characterized by easy installation, efficient operation, and relatively low maintenance. They are often used in commercial and industrial buildings.

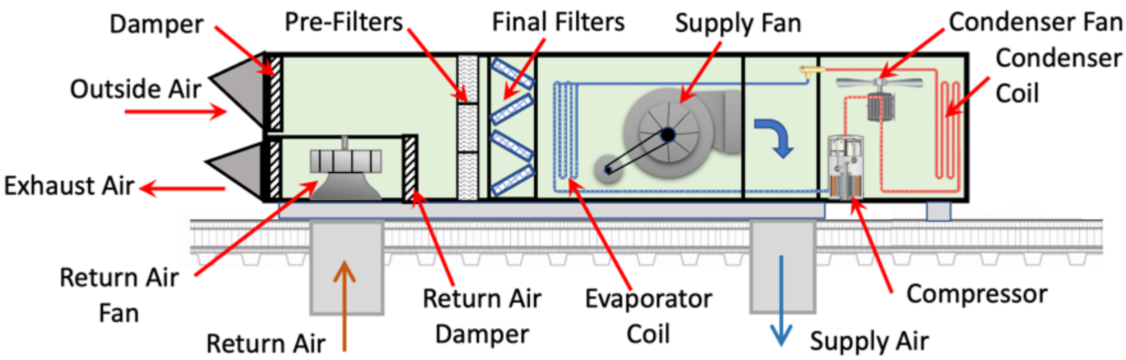


Figure 11. Packaged Systems [12]

5.5.4. Central Hydronic or Central Systems

A central system uses a central boiler or chiller to heat or cool water or another fluid, which is then circulated throughout the building to provide heating or cooling (Figure 12). As example there are central heating systems with radiators or baseboards, and central cooling systems with chilled water coils. For energy transport, the heat capacity of water is about 3400 times greater than that of air. This system is highly efficient, can provide even heating or cooling throughout a large building, and are often used in commercial and institutional settings. However, they can be more complex to install and maintain. Central systems are built-up systems assembled and installed on the site.

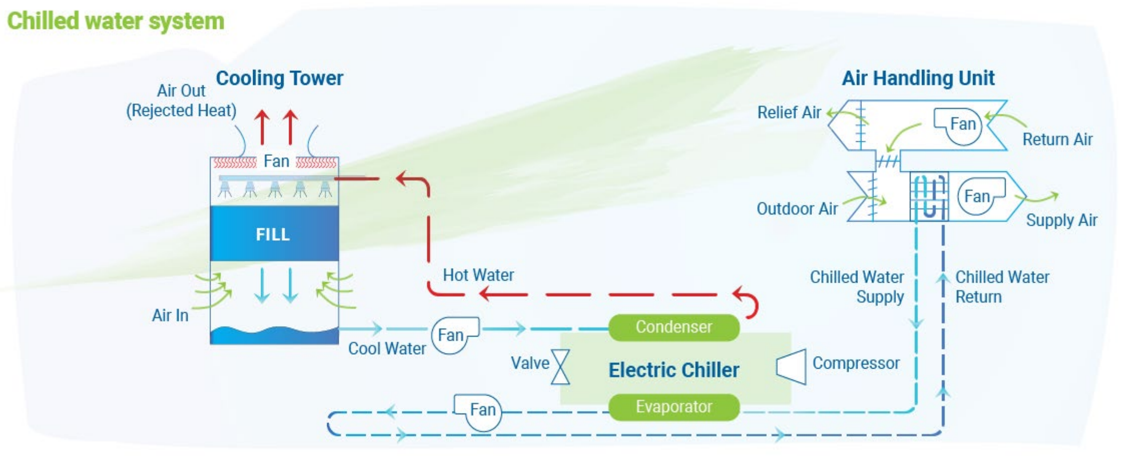


Figure 12. Central Hydronic System [13]

When selecting the most suitable HVAC system for your needs, several key factors like energy efficiency, cost considerations, indoor air quality should be carefully evaluated.

The Seasonal Energy Efficiency Ratio, for cooling systems, measures the system's efficiency over a cooling season. Heating Seasonal Performance Factor, for heating systems, measures the system's efficiency over a heating season. A higher SEER or HSPF rating indicates greater energy efficiency and lower operating costs. Comparing the efficiency ratings of different models can help identify the most energy-efficient options and potentially qualify for energy efficiency incentives.

There are three types of cost when referring to HVAC systems: initial installation cost, ongoing operating costs and maintenance and repair costs. The upfront cost of purchasing and installing an HVAC system can vary significantly depending on the size, type, and complexity of the system. Energy consumption is a major factor in the long-term operating costs of an HVAC system. Energy-efficient systems can help reduce these costs over time. Factor in the expected maintenance and repair costs associated with different HVAC systems. Some systems may require more frequent or expensive maintenance.

Additional factors when choosing the proper HVAC system can focus on the indoor air quality (especially when the installation building is a hospital), humidity control, system size, noise levels, reliability and warranty.

By carefully considering these factors, you can choose an HVAC system that meets your needs, improves your indoor comfort, and contributes to energy efficiency and environmental sustainability.

5.6– Innovative technologies for HVAC systems

5.6.1. HVAC systems with Variable Refrigerant Flow (VRF)

Variable Refrigerant Flow systems offer several advantages over traditional HVAC systems:

- **Ductless operation**: One of the most significant benefits of VRF systems is their ability to operate without extensive ductwork. This makes them ideal for retrofitting older buildings or spaces where ductwork installation is impractical or costly.
- **Precise refrigerant control**: VRF systems can precisely control the amount of refrigerant flowing to each individual evaporator unit. This allows for highly customized temperature control in different zones of a building.
- **Flexible evaporator configurations**: VRF systems can accommodate a variety of evaporator units, including different capacities and configurations. This flexibility enables them to meet the specific heating and cooling needs of various spaces.
- **Individualized comfort control**: With VRF systems, each zone or room can be independently controlled. This provides occupants with greater flexibility and comfort.
- **Simultaneous heating and cooling**: VRF systems can simultaneously heat and cool different areas of a building, making them ideal for applications where both heating and cooling are required.

- **Heat recovery**: VRF systems can recover heat from one zone and transfer it to another, improving energy efficiency and reducing operating costs.

VRF systems offer versatile cooling and heating solutions. For **cooling-only applications**, VRF systems are ideal for maintaining comfortable temperatures in various settings, such as offices, retail spaces, and residential buildings. These systems efficiently remove heat from indoor spaces, providing a pleasant and comfortable environment. In addition to cooling, VRF systems can also be configured as **heat pumps** (two-pipe systems – Figure 13), but not simultaneously. This allows them to both heat and cool spaces, making them suitable for regions with varying climates. By reversing the flow of refrigerant, VRF heat pumps can extract heat from the outside air and transfer it indoors, providing efficient heating during colder months.

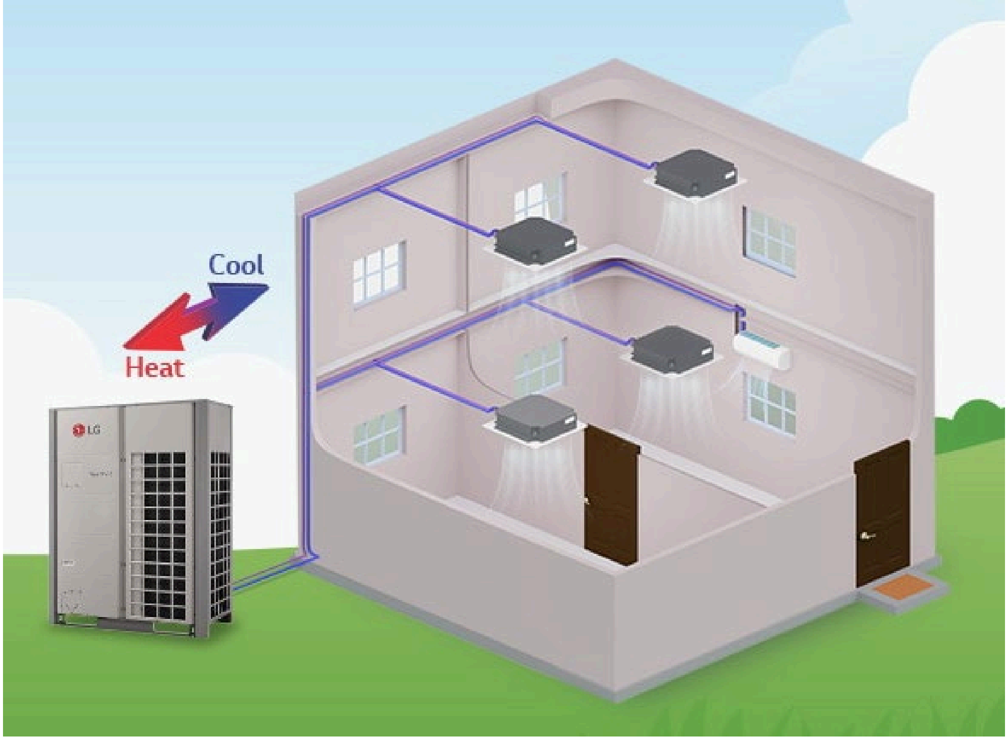


Figure 13. VRF with two-pipe systems

For even greater energy efficiency, **VRF systems can be used with heat recovery** (three-pipe systems – Figure 14). In this configuration, VRF systems can capture and reuse waste heat from one area of a building to heat another, significantly reducing energy consumption and operating costs. An indoor unit requiring cooling will open its liquid line and act as an evaporator, while an indoor unit requiring heating will open its hot gas and act as a condenser. This makes them an excellent choice for large commercial buildings and facilities that require both heating and cooling.

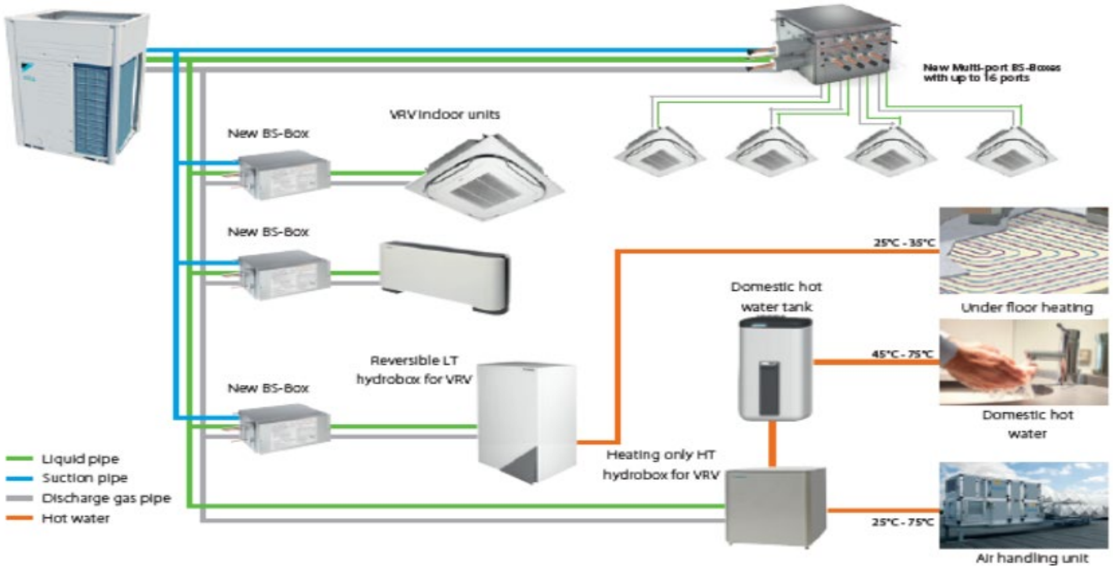


Figure 14. VRF with three-pipe systems [14]

5.6.2. Hybrid VRF systems

Hybrid VRF systems represent a recent advancement in HVAC technology, combining the efficiency of VRF systems with the benefits of water-based heating and cooling. As it can be depicted in Figure 15, these systems utilize a **2-pipe heat recovery** configuration, where refrigerant is replaced with water between the **Hybrid Branch Circuit Controller (HBCC)** and the indoor units.

This innovative design offers several advantages:

- **Reduced leak risk:** By using water instead of refrigerant for the final connection to indoor units, the system significantly minimizes the risk of refrigerant leaks. This not only protects the environment but also reduces the need for frequent leak detection and servicing.
- **Enhanced flexibility:** Hybrid VRF systems provide greater flexibility in system design and installation, as water pipes are generally easier to route and install compared to refrigerant lines.
- **Improved energy efficiency:** In some cases, using water for the final connection can enhance the overall system efficiency, especially in applications with long piping runs.
- **Cost savings:** The reduced need for refrigerant leak detection and servicing can result in long-term cost savings.

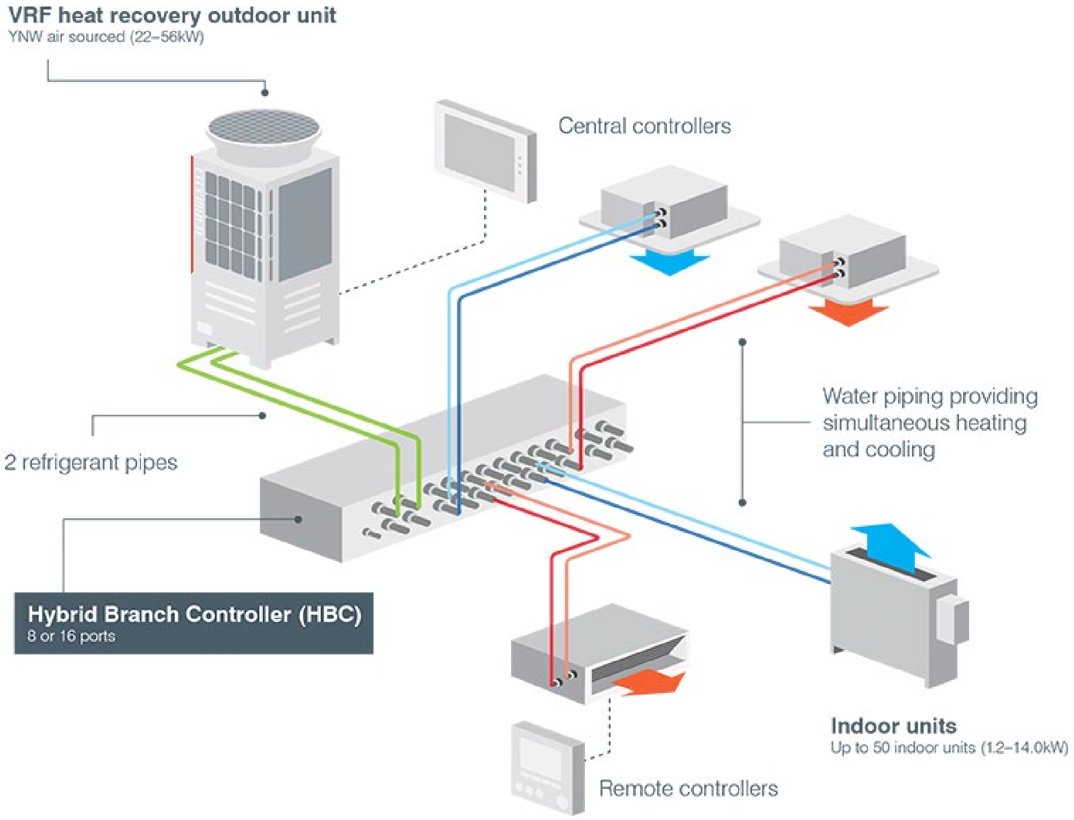


Figure 15. Hybrid VRF system [15]

Hybrid VRF systems with 2-pipe heat recovery offer a promising solution for those seeking a more sustainable, reliable, and cost-effective HVAC system. By combining the advantages of VRF technology with the benefits of water-based heating and cooling, these systems provide a valuable option for various commercial and residential applications.

5.6.3. HVAC system with ground-air heat exchanger

Underground heat exchangers offer a sustainable and energy-efficient solution for preconditioning ventilation air. By harnessing the relatively stable temperature of the earth, these systems can significantly reduce heating and cooling costs.

Underground heat exchangers utilize a network of pipes buried at a depth where the ground temperature remains relatively constant throughout the year. At depths of 1,5 to 2,0 m below the surface, the earth’s temperature is a constant (7-12ºC) throughout the year. This constant temperature can be either warmer or cooler than the ambient air, depending on the location and season. In winter, the air can be warmed by up to 17°C, while in summer, it can be cooled by as much as 14°C before reaching the air handling unit. This preconditioning of the air dramatically reduces the workload on traditional heating and cooling systems, resulting in substantial energy cost savings.

When ventilation air is drawn into the building, it passes through the underground heat exchanger pipes (Figure 16). The heat from or to the ground is transferred to or from the ventilation air, preheating or precooling it before it enters the building.

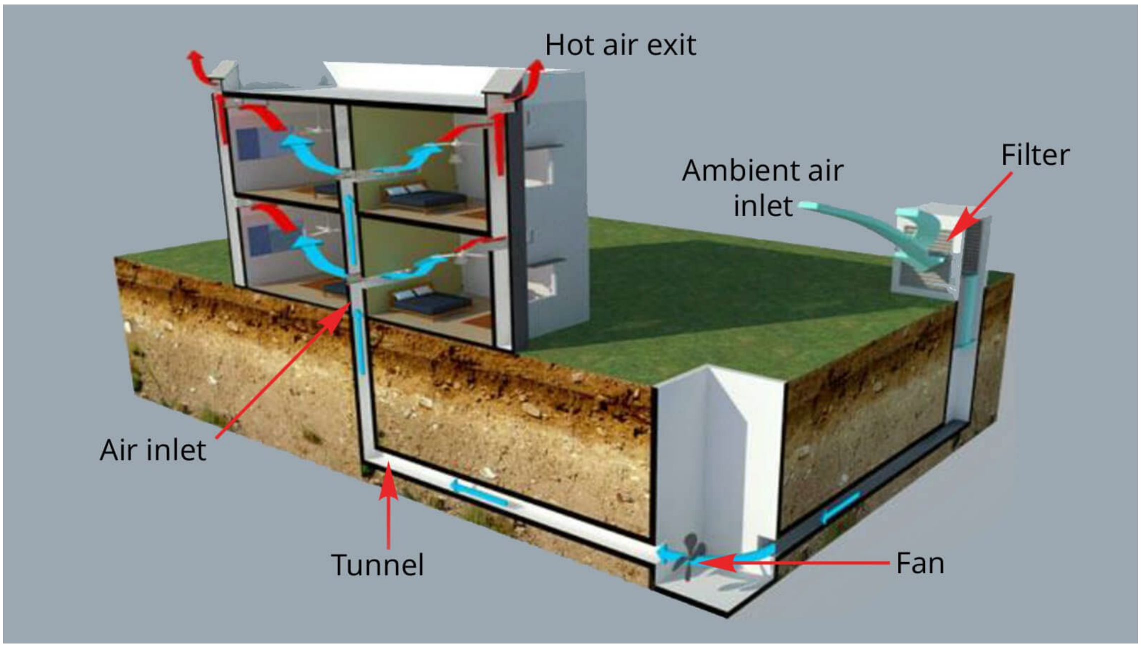


Figure 16. Working principle of HVAC system with ground-air heat exchanger

By preconditioning the ventilation air, underground heat exchangers reduce the energy required by traditional heating or cooling systems to maintain a comfortable indoor temperature. This can result in substantial energy cost savings and a reduced carbon footprint.

5.7– Maintenance and optimization of HVAC systems

5.7.1. Preventive Maintenance

Regular maintenance is crucial for ensuring the optimal performance, efficiency, and longevity of HVAC systems. A well-structured preventive maintenance schedule should include the following tasks:

- **Filter replacements:** Regularly replace air filters to prevent clogs and improve air quality.
- **Coil cleaning:** Clean evaporator and condenser coils to enhance heat transfer.
- **Lubrication:** Lubricate moving parts, such as fan motors and bearings, to reduce wear and tear.
- **Electrical inspections:** Check for loose connections, damaged wires, and other electrical issues.

- **Refrigerant checks:** Monitor refrigerant levels and inspect for leaks to maintain optimal system performance.
- **Safety inspections:** Check for carbon monoxide leaks, gas leaks, and other safety hazards.

When HVAC systems malfunction, effective troubleshooting can help identify and resolve issues promptly. Common troubleshooting techniques include power check, filters inspection, checking for obstructions and component test. If the problems persist, consult a qualified HVAC technician for expert diagnosis and repair.

5.7.2. Strategies for Improving System Performance

- **Regular maintenance:** Adhere to a preventive maintenance schedule to prevent problems and optimize efficiency.
- **Energy-efficient upgrades:** Consider upgrading to a more energy-efficient system or installing energy-saving components.
- **Proper sizing:** Ensure the HVAC system is appropriately sized for the space to avoid undercooling or overheating.
- **Duct sealing:** Seal leaky ducts to prevent energy loss and improve system efficiency.
- **Thermostat programming:** Use programmable thermostats to optimize heating and cooling schedules and reduce energy consumption.
- **Regular inspections:** Conduct regular inspections to identify potential issues and address them promptly.

By following these strategies, you can maintain the optimal performance of your HVAC system, improve energy efficiency, and reduce operating costs.

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6 - Deliverables

To evaluate the success of the tutorial, students will have to answer an online questionnaire.

7- What we have learned

The role of HVAC systems in regulating temperature, humidity, and air quality.

Advantages, disadvantages, and applications of various energy vectors.

Components, functions and interactions within HVAC systems.

Current types and innovative technologies of HVAC systems.

Maintaining and Optimizing HVAC Systems.