Basics of HVAC (Heating, Ventilation, and Air Conditioning) Course

An Online Continuing Education Course for Engineers

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Introduction

Throughout my career as a Mechanical Engineer, I have been fortunate to have worked with Project Managers, Architects, Building Inspectors, and other professionals. These professionals are often very knowledgeable in their respective fields, but sometimes do not have much familiarity with HVAC (Heating, Ventilation, and Air Conditioning) or the basics of mechanical engineering, such as thermodynamics, fluid mechanics, and heat transfer. This has sometimes led to confusion, frustration, or misunderstandings during project planning, design, construction, or commissioning.

HVAC stands for Heating, Ventilation, and Air Conditioning. It is sometimes referred to as HVAC-R, with the "R" standing for Refrigeration. This is because the basics of Refrigeration are similar to the basics of Air Conditioning. But since Refrigeration is typically less applicable in other disciplines, this course will only cover Heating, Ventilation, and Air Conditioning.

This short, concise course is designed to be a good starting point for design and construction professionals who would like to learn more about HVAC and how that knowledge can be applied in their disciplines. This course is primarily focused on HVAC design as applicable to the United States of America, but may be helpful for those in other locations as well.

This course will cover the different kinds of heating systems common in HVAC. It will also discuss the basics of ventilation. Furthermore, it will cover air conditioning and the vapor compression cycle. Later on, this course will go over the different types of HVAC Equipment and HVAC Systems, as well as units common in HVAC. It will also cover basic concepts needed to understand the science behind HVAC.

Heating

Heating is the oldest and most important of the three elements of HVAC. Humans have been using fire for hundreds of thousands of years for heating themselves and for preparing food. Heating is the most important element for maintaining human health and providing for space and water heating, and has always been an important part of building design for this reason. Adequate space heating is also necessary for preventing freeze-thaw cycles and from water in plumbing and fire protection piping from freezing and causing water damage. Adequate space and water heating are required under building codes and are typically required for Use and Occupancy permits. Heating is often the most energy-intensive part of HVAC systems in the United States, especially in areas with cold winters.

There are three main ways to create heat:

- Combustion
- Electric Resistance
- Vapor Compression

Combustion

The simplest and oldest form of Heating is Combustion. Combustion is a chemical reaction that takes place when hydrocarbons (chemicals consisting of hydrogen and carbon atoms, H_xC_x) are exposed to oxygen (O_2) in the air at a certain temperature. In this reaction, the hydrocarbon's chemical bonds are broken and water vapor (H_2O) and carbon dioxide (CO_2) are produced, as well as a net increase in heat energy.

$$H_xC_x + O_2 = H_2O + CO_2 + Heat$$

Common hydrocarbons used for combustion are:

- Wood and other biomass
- Coal
- Petroleum products
  - Gasoline
  - Diesel Fuel
  - Fuel oil
- Natural Gas, also known as methane (CH_4)
- Municipal Solid Waste (MSW)
- Propane (C_3H_8)
- Ethanol

The main byproducts of this reaction are water vapor and carbon dioxide. However, there are other potential byproducts, including carbon monoxide, nitrous oxides, sulfur dioxide, and other products, depending on the makeup of the hydrocarbon. Simpler hydrocarbons, such as natural gas and propane, create fewer pollutants such as sulfur dioxide (the primary component in acid rain) and nitrogen oxides (NO_x). MSW, petroleum products, and coal can produce particulate matter, which is hazardous to human health and is regulated by laws such as the Clean Air Act. However, regardless of whether byproducts are produced, all of these combustion reactions produce carbon dioxide (CO_2) gas.

The two main types of combustion that are used for residential, commercial space, and water heating are Direct Vent and Power Vent. These differ primarily in their efficiency (η) which is the ratio of the amount of energy output divided by energy input:

$$\eta = (\frac{Output}{Input})x100\%$$

Direct vent is the oldest and most well-known. It uses the stack effect to vent the hot exhaust gases from the combustion up and away from the space using a flue or a chimney. It is the easiest way to vent, but there are drawbacks. For the stack effect to work properly, the exhaust gases must be hot, and so the efficiency of the combustion is usually a maximum of 80%. Also, due to the hot exhaust, the material of the chimney or flue must be resistant to heat to prevent fire. Therefore, ceramic chimneys were used in the past, and today typically stainless steel or aluminum is typically used. Older and larger combustion equipment can sometimes be modified to increase efficiency, such as reducing airflow intake (also known as "O_2 trim"), but typically this is not done for smaller pieces of equipment.

Power Vent is more common in newer combustion equipment, particularly in residential and small commercial applications. Power Vent does not rely on the stack effect to vent exhaust gases, and instead uses a small fan to push the exhaust gases away. This allows for higher efficiency (up to 95-98% efficient), but also, since the exhaust is at a lower temperature, it allows for different materials, such as PVC piping, to be used for the flue. It also allows for more flexible installation, where gases can be vented out the side of a building. Condensing boilers are an example of Power Vent equipment. They use the hot condensed water vapor (H_2O) in the exhaust gases to increase the efficiency of the combustion.

Combustion equipment is common in both air-side and water-side (hydronic) HVAC systems, as well as for heating hot water and steam. See pictures of some equipment below:

Power Vent Gas Furnace

Direct Vent Oil-Fired Boiler

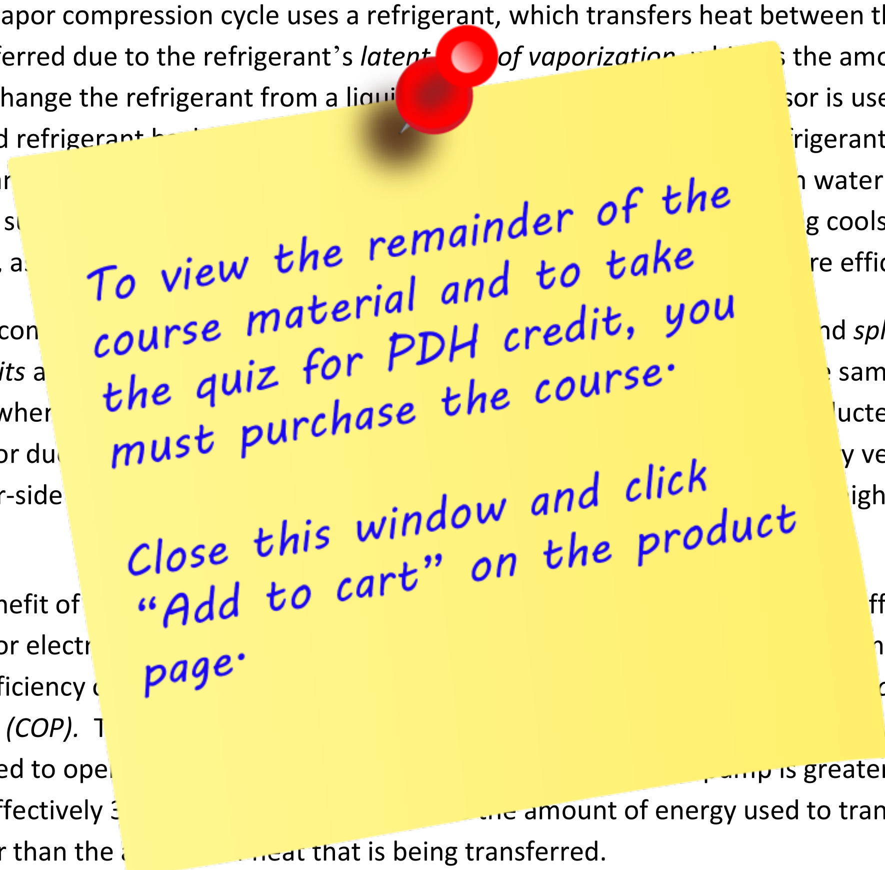
Electric Resistance

Another common way to create heat in an HVAC system is through electric resistance heating. Electric resistance heating elements are commonly used in toasters, hair dryers, or plug-in space heaters used in residential appliances. However, they are also used in larger pieces of HVAC equipment such as air handlers, duct heaters, and VAV boxes. It works by electrical current passing through a metal filament with high electrical resistance, and the electrical energy is transferred into heat. Because almost all of the electrical energy is transferred into heat energy, electric resistance heating is about 99% efficient, and no chimneys, flues, or vents are required since no exhaust gases are produced. Because of the lack of exhaust gases, no carbon emissions or pollutants are created from electric resistance heating.

Electric resistance equipment is more common in smaller air-side and water-side HVAC systems, but it is feasible for any application. However, electric resistance heating tends to be more expensive than combusting fossil fuels, so it is often avoided in larger systems or if cheap or reliable fossil fuels are available. Also, in larger HVAC equipment, the electrical infrastructure needed can be cost-prohibitive.

Vapor Compression (Heat Pumps)

The third common way for heating with HVAC equipment is through transferring heat through the vapor compression cycle. The vapor compression cycle is used for air conditioning and refrigeration, and can also be used for heating through what is called a heat pump. A heat pump is simply an air conditioner that uses the vapor compression cycle in reverse; instead of moving heat from inside a space to outside the space for cooling, it moves heat from outside the space to inside the space for heating. In order to do this, the vapor compression cycle uses a refrigerant, which transfers heat between the spaces. The heat is transferred due to the refrigerant's *latent* ... *of vaporization* ... the amount of energy required to change the refrigerant from a liqui... ...sor is used to condense the vaporized refrigerant ... ...rigerant. This cycle of condensing ar... ...n water in other applications, s... ...g cools down the human body, a... ...re efficiently.



Heat pumps con... ...nd *split systems*. *Packaged units* a... ...same unit. *Split systems* are wher... ...ucted units, such as air handlers or du... ...y versatile and can be used in air-side ... ...igh-temperature applications.

The main benefit of ... ...fficient than combustion or electr... ...nent have a maximum efficiency ... ...*cient of Performance (COP).* T... ...which is the energy needed to ope... ...is greater than 3, which means it is effectively 3... ...amount of energy used to transfer the heat is much smaller than the ... heat that is being transferred.

$$COP = \frac{HeatOutput}{WorkInput}$$

Most heat pumps are air-source, meaning heat is transferred into the outside air, but water-source or ground-source (geothermal) heat pumps are also available. One drawback of air-source heat pumps is that as the outside air temperature is colder, heat pumps are less efficient and require more electricity to transfer the same amount of heat. Therefore, they are sometimes paired with an electric resistance