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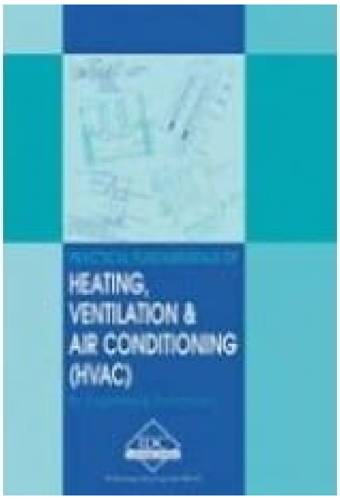
AC-E - Fundamentals of Heating, Ventilation & Air-Conditioning (HVAC)



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Short Description

This manual is designed for engineers and technicians from a wide range of abilities and backgrounds and will provide an excellent introduction to the fundamentals of heating, ventilation and air-conditioning. It commences with a review of psychrometric charts and then examines the factors that influence design choices, indoor air quality, load calculations and heating/ventilation and air-conditioning systems. Numerous tips and tricks throughout the manual make it very practical and topical to your applications.

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First Chapter
An Introduction to Practical Fundamentals of Heating, Ventilation & Airconditionning (HVAC)

1 Introduction

Objectives

After reading this chapter the student should be able to:

- Refresh his knowledge on the engineering basics
- Understand the laws of thermodynamics

1.1 General

Air conditioning for human comfort was considered a luxury a few decades ago, but now it has become a necessity in life. The air conditioning industry is rapidly developing throughout the world. More than 10 million window installations are being installed each year and residential central cooling installations are enjoying similar popularity.

Apart from reasons for comfort alone, air conditioning is commonly used nowadays in various industries such as food, automobiles, hotels, textiles and many more. On Earth, not only pollution from smoke is on the rise but pollution from dust is also playing havoc with our lives. Air conditioning plays a vital role in keeping out smoke and dust which could harm our health. Similarly, air conditioning has an important role to play in the preservation of food.

At present, there is hardly any sector of the economy that is not dependent on this industry. In fact in most areas of industry, HVAC systems are considered to be a basic necessity.

It is thus important to become part of this industry and this course is targeted at providing you with the basic knowledge and technology to play a role in designing, installing and commissioning HVAC systems.

The following gives an overview of the basic principles of thermodynamics, which play a key role in understanding HVAC systems.

1.2 Principles of Thermodynamics

1.2.1 Force, Newtons

In simple language, force is defined as a push or a pull. It is anything that has a tendency to set a body into motion, to bring a body to rest or change the direction of any motion.

1.2.2 Pressure, Pascals

Pressure is the force exerted per unit area. It may be described as the measure of intensity of a force exerted on any given point on the contact surface. Whenever a force is evenly distributed over a given area the pressure at any point on the surface is the same. It can be calculated by dividing the total force exerted by the area (on which the force is exerted).

Atmospheric pressure

The Earth is surrounded by an envelope of air called the atmosphere, which extends upward from the surface of the earth. Air has mass and due to gravity exerts a force called weight. The force per unit area is called pressure. This pressure exerted on the Earth's surface is known as atmospheric pressure.

Gauge pressure

Most pressure measuring instruments measure the difference between the pressure of a fluid and the atmospheric pressure. This is referred to as gauge pressure.

Absolute pressure

Absolute pressure is the sum of gauge pressure and atmospheric pressure.

Vacuum

If the pressure is lower than the atmospheric pressure, its gauge pressure is negative and the term vacuum is applied to the magnitude of the gauge pressure when the absolute pressure is zero (i.e. there is no air present whatsoever). The relationships among absolute pressure, gauge pressure, atmospheric pressure and vacuum are shown graphically in the Figure 1.1.

Figure 1.1

Relationship between absolute, gauge and vacuum pressures

In the above figure

P_a is the atmospheric pressure

P_{gauge} is the gauge pressure

P_{ab} is the absolute pressure

P_{vacuum} is the vacuum pressure

1.2.3 Density

It is defined as the mass of a substance divided by its volume or the mass per unit volume.

r = mass/volume

Specific Volume is defined as the reciprocal of density or volume per unit mass.

v = V/m

Specific Weight (Ws) is defined as the weight of a substance divided by its volume or the weight per unit volume.

Ws = m/V

1.2.4 Work

If a system undergoes a displacement under the action of a force, work is said to be done; the amount of work being equal to the product of force and the component of displacement parallel to the force. If a system as a whole exerts a force on its surrounding and a displacement takes place, the work that is done either by or on the system is said to be external work.

1.2.5 Energy

A body is said to possess energy when it is capable of doing work. In more general terms, energy is the capacity of a body for producing an effect. Energy is classified as

1. Stored Energy; examples are (a) Chemical energy in fuel and (b) Energy stored in dams
2. Energy in Transition: examples are (a) Heat and (b) Work

The following are the various forms of energy.

Potential energy (P.E)

It is the energy stored in the system due to its position in the gravitational force field. If a heavy object such as a building stone is lifted from the ground to the roof, the energy required to lift the stone is stored in it as potential energy. This stored potential energy remains unchanged as long as the stone remains in its position.

$P \times E = mgH$

Where

H = height of the object above the datum

Units

Kinetic Energy (K.E), Joules= Newton meter

If a body weighing one kg is moving with a velocity of v m/sec with respect to the observer, then the kinetic energy stored in the body is given by:

K.E =

This energy will remain stored in the body as long as it continues in motion at a constant velocity. When the velocity is zero, the kinetic energy is also zero.

Internal Energy

Molecules possess mass. They possess motion of transactional and rotational nature in liquid and gaseous states. Owing to the mass and motion these molecules have a large amount of kinetic energy stored in them. Any change in the temperature results in the change in the molecular kinetic energy since molecular velocity is a function of temperature.

Also the molecules are attracted towards each other by forces, which are very large in their solid state and tend to vanish once they are in a perfect gas state. In the melting of a solid or vaporization of a liquid it is necessary to overcome these forces. The energy required to bring about this change is stored in molecules as potential energy.

The internal energy is defined as the **total** energy of the body - chemical, nuclear, heat, gravitational, or any other type of energy. This energy is stored within the body which is denoted by the symbol ‘µ’. It is obvious from the above definition that it is impossible to measure the absolute value of the internal energy. However, we can measure the changes occurring in the internal energy. Since thermodynamics deals with the change in the internal energy of the system, it is important to know what causes the internal energy to change. The change in the internal energy can be caused by either due to absorption or release of heat in the system or the work done by or on the system., or if any matter enters or leaves the system.

1.2.6 Heat

Heat is one of the many forms of energy. This is evident from the fact that heat can be converted into other forms of energy and that other forms of energy can be converted into heat. Heat as molecular energy is universally accepted and heat as internal energy of the matter is thermodynamics.

Since all other forms of energy may be converted into heat, it is considered to be energy in its lowest form. The availability of heat energy to do work depends on temperature differential.

1.2.7 Heat capacity

It may be defined as the energy that must be added or removed from one kilogram of a substance to change its temperature by one degree Centigrade. In refrigeration technology heat capacity is used to determine how much heat should be removed to refrigerate various products.

1.2.7.1 Sensible heat (Q_S)

Heat which results in an increase or decrease in the temperature without it changing its phase is called sensible heat. A change in sensible heat is given by the equation when there is a change in temperature

$$Q_S = m \times C_S (T_2 - T_1)$$

Note: C_S is the heat capacity at constant pressure

m = mass of the substance in kg

$(T_2 – T_1)$ = Temperature difference in °C

1.2.7.2 Latent heat (QL)

Latent heat is the heat at which a substance changes its phase without any increase or decrease in the temperature. It is the amount of heat required to change the state of a substance.

$Q_L = m \times C_w(w_2 – w_1)$

Note: C_w is the heat capacity of moisture

m = mass of the substance in kg

$(w_2 – w_1)$ = change in moisture content in g/kg

1.2.7.3 Total heat (Q_T)

Total heat is the sum of sensible heat and latent heat. Heat measurements are taken above a specified datum. These measurements with water are at zero degrees C, since below this temperature water is solid. Refrigerant heat measurements are at $–40^0$C. For example: The sensible heat, latent heat and total heat for steam are shown in Figure 1.2 below.

$Q_T = Q_S + Q_L$

Figure 1. 2

Total Heat Chart Of $–40^0$C Ice To Steam at 100 ^{0}C

a-b is sensible heat, b-c is latent heat of fusion, c-d is Sensible heat, d-e is latent heat of vaporization, e-f is super heat.

1.3 Temperature and its measurement

Temperature is a property of matter. It is the measure of intensity of heat contained in matter and its relative value. A substance is said to be hot or cold when its temperature is compared with some other reference temperature. A high temperature indicates a high level of heat intensity or thermal pressure and a body is said to be hot.

Like other forms of energy heat can be measured because it has quantity and intensity. Heat is not visible but manifests itself in its effects on various substances either by changing its state or by creating relative degrees of sensation when in contact with the human body.

Since temperature is a measure of heat content, the temperature can be measured by measuring the effects of heat on different properties of matter as follows;

- Addition of heat increases the volume of the substance or pressure at constant volume. This property is used for measuring the temperature with the help of a mercury thermometer.
- With the increase in temperature, the resistivity of metals increases which is utilized in resistance thermometers
- If two junctions made of two dissimilar metals are maintained at different temperatures, a current flows in the circuit. This property is used in measuring with a thermocouple.
- When the temperature of a substance increases, the color also changes. This property is used for measuring the temperature in radiation pyrometers.

1.4 Pressure and temperature relationship

Water boils at 100^0C when the pressure on it is atmospheric at sea level. If the pressure is increased above the atmospheric pressure, i.e. in a deep mine shaft the boiling point increases and when the pressure is reduced below atmospheric, i.e. on top of a mountain, it reduces.

Boiling water does not necessarily have to be hot because if there is vacuum, water boils at a very low temperature. The same is true when it comes to other liquids, such as various refrigerants. These refrigerants have the same properties as water except their boiling point ranges are lower.

This pressure temperature relationship is used in most air conditioning and refrigeration systems.

1.5 Laws of Thermodynamics

1.5.1 First law of Thermodynamics and Energy Conservation

It is a fundamental principle that matter can neither be created nor destroyed though it may be made to take different forms. Similarly, energy cannot be created or destroyed. It can be converted from one form to another. The first law of thermodynamics states that the total energy in a system always remains constant.

This law is mainly based on observation and can be best studied with the help of observations.

In the following examples, we can see that heat, work, electricity and chemical energy are various forms of energy and they are mutually convertible.

- An electric Iron converts electricity into heat.
- An electric fan converts electricity into work.
- Water flowing through a turbine converts its potential energy into work.
- Churning of water converts work into heat.

The first law of thermodynamics can be represented by the equation:

$E_1 + Q_a – Q_t = E_2$

Where:

E_1 is the energy possessed by the system initially

E_2 is the energy possessed by the system after the work is done

Q_a is the energy added to the system

Q_t is the energy taken away from the system.

1.5.2 Second law of Thermodynamics

The second law of thermodynamics can be stated in a number of ways as:

- Heat flows from a body at higher temperature to a body at lower temperature irrespective of the mass and material of the body participating in the heat transfer. This heat flow is possible without the addition of external work.
- Work has the tendency to convert into heat but the heat cannot be

converted into work.
- Every engine or a refrigerator ejects heat to the surroundings.

With a brief discussion on the various thermodynamic principles, let us now study the fundamentals of Heating, Ventilation and Air conditioning in the next chapters.

1.6 Fundamentals of Heat Transfer

1.6.1 Modes of Transferring Heat

Heat is always transferred when a temperature difference exists between two bodies. There are three basic modes of heat transfer:

- *Conduction* involves the transfer of heat by the interactions of atoms or molecules of a material through which the heat is being transferred.
- *Convection* involves the transfer of heat by the mixing and motion of macroscopic portions of a fluid.
- *Radiation*, or radiant heat transfer, involves the transfer of heat by electromagnetic radiation that arises due to the temperature of a body.

1.6.2 Heat Flux

The rate at which heat is transferred is represented by the symbol. Common units for heat Q transfer rate is Watts. Sometimes it is important to determine the heat transfer rate per unit area, or *heat flux*, which has the symbol. Units for heat flux are W/m^2. The heat flux can be Q_{hf}determined by dividing the heat transfer rate by the area through which the heat is being transferred.

$$Q_{hf} = \frac{Q}{A}$$

Where: Q_{hf} = heat flux (W/m^2)

Q = heat transfer rate (W)

A = area (m^2)

1.6.3 Thermal Conductivity

The heat transfer characteristics of a solid material are measured by a property called the *thermal conductivity* (k) measured in W/m.K. It is a measure of a substance's ability to transfer heat through a solid by conduction. The thermal conductivity of most liquids and solids varies with temperature. For vapors, it depends upon pressure.

1 W/(m.K) = 1 W/(m.^{o}C) = 0.85984 kcal/(hr.m.^{o}C)

Table: 1.1

Thermal conductivity values for various materials at 300 K

Material	**Thermal conductivity W/m.K**
Copper	399
Gold	317
Aluminum	237
Iron	80.2
Carbon steel	43
Stainless Steel (18/8)	15.1
Glass	0.81
Plastics	0.2 – 0.3
Wood (shredded/cemented)	0.087
Cork	0.039
Water	0.6
Ethylene glycol	0.26
Hydrogen	0.18
Benzene	0.159
Air	0.026

1.6.4 Log Mean Temperature Difference (LMTD)

In heat exchanger applications, the inlet and outlet temperatures are commonly specified based on the fluid in the tubes. The temperature change that takes place across the heat exchanger from the entrance to the exit is not linear. A precise temperature change between two fluids across the heat exchanger is best represented by the *log mean temperature difference* (LMTD or DTlm).

$$D\,T_{LM} = \frac{(DT_2 - DT_1)}{\ln (DT_2 / DT_1)}$$

Where: DT2 = the larger temperature difference between the two fluid streams at either the entrance or the exit to the heat exchanger

DT1 = the smaller temperature difference between the two fluid streams at either the entrance or the exit to the heat exchanger

1.6.5 Convective Heat Transfer Coefficient

The convective heat transfer coefficient (h_c), defines, in part, the heat transfer due to convection. The convective heat transfer coefficient is sometimes referred to as a film coefficient and represents the thermal resistance of a relatively stagnant layer of fluid between a heat transfer surface and the fluid medium. Common units used to measure the convective heat transfer coefficient are (W/m^2K).

Table 1.2

Typical order-of magnitude values of convective heat transfer coefficients

Type of fluid and flow	**Convective heat transfer coefficient** **h_c, ($W/m^2\,K$)**
Air, free convection	6 – 30
Water, free convection	20 – 100
Air or superheated steam, forced convection	30 – 300
Oil, forced convection	60 – 1800
Water, forced convection	300 – 18000
Synthetic refrigerants, boiling	500 - 3000
Water, boiling	3000 – 60000
Synthetic refrigerants, condensing	1500 - 5000
Steam, condensing	6000 – 120000

1.6.7 Overall Heat Transfer Coefficient

In the case of combined heat transfer, it is common practice to relate the total rate of heat transfer Q the overall cross-sectional area for heat transfer (A_o), and the overall temperature difference (DT_o) using the overall heat transfer coefficient (U_o). The *overall heat transfercoefficient* combines the heat transfer coefficient of the two heat exchanger fluids and the thermal conductivity of the heat exchanger tubes. U_o is specific to the heat exchanger and the fluids that are used in the heat exchanger.

$$Q = U_o A_o DT_o$$

Where: Q = The rate of heat transfer (W)

U_o = the overall heat transfer coefficient ($W/m^2\ {}^oK$)

A_o = the overall cross-sectional area for heat transfer (m^2)

DT_o = the overall temperature difference (${}^oK$)

1.6.8 Bulk Temperature

The fluid temperature (T_b), referred to as the *bulk temperature*, varies according to the details of the situation. For flow adjacent to a hot or cold surface, T_b is the temperature of the fluid that is "far" from the surface, for instance, the center of the flow channel. For boiling or condensation, T_b is equal to the saturation temperature.

1.7 Fundamentals of Fluid Flow

Fluid flow is an important part of most industrial processes; especially those involving the transfer of heat. Frequently, when it is desired to remove heat from the point at which it is generated, some type of fluid is involved in the heat transfer process. Examples of this are the cooling water circulated through cooling coils in HVAC, the air flow past the heating and cooling coils, from fans and blowers, duct work, terminal units, packaged air conditioning units etc., Unlike solids, the particles of fluids move through piping and components at different velocities and are often subjected to different accelerations.

The basic principles of fluid flow include three concepts or principles:

1. The first is the principle of momentum (Equations of fluid forces)
2. The second is the conservation of energy (First Law of Thermodynamics).

3. The third is the conservation of mass (Continuity equation)

1.7.1 Properties of Fluids

A *fluid* is any substance which flows because its particles are not rigidly attached to one another. This includes liquids, gases and even some materials which are normally considered solids, such as glass. Fluids are materials which have no repeating crystalline structure.

There are several properties, including temperature, pressure, mass, specific volume, density, and Buoyancy.

- *Temperature* was defined as the relative measure of how hot or cold a material is. It can be used to predict the direction that heat will be transferred.
- *Pressure* was defined as the force per unit area. Common units for pressure are Pascal.
- *Mass* was defined as the quantity of matter contained in a body and is to be distinguished from weight, which is measured by the pull of gravity on a body.
- The *specific volume* of a substance is the volume per unit mass of the are substance. Typical units are m^3/kg .
- *Density*, on the other hand, is the mass of a substance per unit volume. Typical units are kg/m^3. Density and specific volume are the inverse of one another. Both density and specific volume is dependant on the temperature and somewhat on the pressure of the fluid. As the temperature of the fluid increases, the density decreases and the specific volume increases. Since liquids are considered incompressible, an increase in pressure will result in no change in density or specific volume of the liquid. In actuality, liquids can be slightly compressed at high pressures, resulting in a slight increase in density and a slight decrease in specific volume of the liquid.
- *Buoyancy* is defined as the tendency of a body to float or rise when submerged in a fluid. When a body is placed in a fluid, it is buoyed up by a force equal to the weight of the water that it displaces.
- *Compressibility* is the measure of the change in volume a substance undergoes when a pressure is exerted on the substance. Liquids are generally considered to be incompressible. For instance, a pressure of 1110 kg/cm^2 will cause a given volume of water to decrease by only 5% from its volume at atmospheric pressure. Gases on the other hand, are very compressible. The volume of a gas can be readily changed by exerting an external pressure on the gas.

1.7.2 Pascal’s Law

Pascal's law, or the Principle of transmission of fluid-pressure, states that "pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure ratio (initial difference) remains the same."

where

?*P* is the hydrostatic pressure (given in pascals in the SI system), or the difference in pressure at two points within a fluid column, due to the weight of the fluid;

? is the fluid density (in kilograms per cubic meter in the SI system);

g is acceleration due to gravity (normally using the sea level acceleration due to Earth’s gravity in metres per second squared);

?*h* is the height of fluid above the point of measurement, or the difference in elevation between the two points within the fluid column (in metres in SI).

1.7.3 Control Volume

In thermodynamics, a *control volume* was defined as a fixed region in space where one studies the masses and energies crossing the boundaries of the region. This concept of a control volume is also very useful in analyzing fluid flow problems. The boundary of a control volume for fluid flow is usually taken as the physical boundary of the part through which the flow is occurring.

The control volume concept is used in fluid dynamics applications, utilizing the continuity, momentum, and energy principles

1.7.4 Volumetric Flow Rate

The *volumetric flow rate* V of a system is a measure of the volume of fluid passing a point in the system per unit time. The volumetric flow rate can be calculated as the product of the cross sectional area (A) for flow and the average flow velocity (v).

V = A x v

The area is measured in square meter and velocity in meters per second, results in volumetric flow rate measured in cubic meter per second. Other common units for volumetric flow is liters per minute.

1.7.5 Mass Flow Rate

The *mass flow rate* (m) of a system is a measure of the mass of fluid passing a point in the system per unit time. The mass flow rate is related to the volumetric flow rate.

Mass flowrate = Density x Volumetric flowrate

m = r x V

The volumetric flow rate is in m^3/s and the density is kg/m^3 results in mass flow rate measured in kilograms per second

1.7.8 Conservation of Mass

In thermodynamics, we know that the energy can neither be created nor destroyed, only changed from one form to another form. The same is true for mass. Conservation of mass is a principle of engineering that states that all mass flow rates into a control volume are equal to all mass flow rates out of the control volume plus the rate of change of mass within the control volume.

$$m_{IN} = m_{OUT} + \frac{Dm}{Dt}$$

1.7.9 Steady-State Flow

Steady-state flow refers to the condition where the fluid properties at any single point in the system do not change over time. These fluid properties include temperature, pressure, and velocity. One of the most significant properties that is constant in a steady-state flow system is the system mass flow rate. This means that there is no accumulation of mass within any component in the system.

1.7.10 Continuity Equation

The continuity equation is simply a mathematical expression of the principle of conservation of mass. For a control volume that has a single inlet and a single outlet, the principle of conservation of mass states that, for steady-state flow, the mass flow rate into the volume must equal the mass flow rate out. The continuity equation for this situation is expressed by the following equation:

$$m_{IN} = m_{OUT}$$

$$r \times A \times v \text{ (inlet)} = r \times A \times v \text{ (Outlet)}$$

1.7.11 Head Loss

Head loss is a measure of the reduction in the total head (sum of elevation head, velocity head and pressure head) of the fluid as it moves through a fluid system. Head loss is unavoidable in real fluids. It is present because of: the friction between the fluid and the walls of the pipe; the friction between adjacent fluid particles as they move relative to one another; and the turbulence caused whenever the flow is redirected or affected in any way by such components as piping entrances and exits, pumps, valves, flow reducers, and fittings.

1.7.12 Frictional Loss

Frictional loss is that part of the total head loss that occurs as the fluid flows through straight pipes. The head loss for fluid flow is directly proportional to the length of pipe, the square of the fluid velocity, and a term accounting for fluid friction called the friction factor. The head loss is inversely proportional to the diameter of the pipe.

$$\text{Heat loss } \mu \ f \frac{Lv^2}{D}$$

1.7.13 Frictional Factor

The friction factor has been determined to depend on the Reynolds number for the flow and the degree of roughness of the pipe’s inner surface. The quantity used to measure the roughness of the pipe is called the relative roughness, which equals the average height of surface irregularities “**Î**”divided by the pipe diameter “D”

Î

Relative Roughness = ----------------

D

The value of the friction factor is usually obtained from the Moody Chart.

1.7.14 Darcy's Equation

The frictional head loss can be calculated using a mathematical relationship that is known as Darcy's equation for head loss. The equation takes two distinct forms. The first form of Darcy's equation determines the losses in the system associated with the length of the pipe.

$$H_f = f \frac{L}{D} \times \frac{v^2}{2g}$$

Where: f = friction factor (unitless)

L = length of pipe (meters)

D = diameter of pipe (meters)

v = fluid velocity (m/sec)

g = gravitational acceleration (m/sec^2)

1.7.15 Minor Losses

The losses that occur in pipelines due to bends, elbows, joints, valves, etc. are sometimes called *minor losses*. This is a misnomer because in many cases these losses are more important than the losses due to pipe friction, considered in the preceding section. For all minor losses in turbulent flow, the head loss varies as the square of the velocity. Thus a convenient method of expressing the minor losses in flow is by means of a loss coefficient (k). Values of the loss coefficient (k) for typical situations and fittings is found in standard handbooks. The form of Darcy's equation used to calculate minor losses of individual fluid system components is expressed by Equation:

$$v^2$$

$$H_f = k \, \frac{\qquad}{2g}$$

1.7.16 Equivalent Piping Length

Minor losses may be expressed in terms of the equivalent length (L_{eq}) of pipe that would have the same head loss for the same discharge flow rate. This relationship can be found by setting the two forms of Darcy's equation equal to each other.

$$H_f = f \, \frac{L}{D} \times \frac{v^2}{2g} = k \, \frac{v^2}{2g}$$

This yields two relationships that are useful.

$$L_{eq} = k \, \frac{D}{f} \quad \text{and} \quad k = f \, \frac{L_{eq}}{D}$$