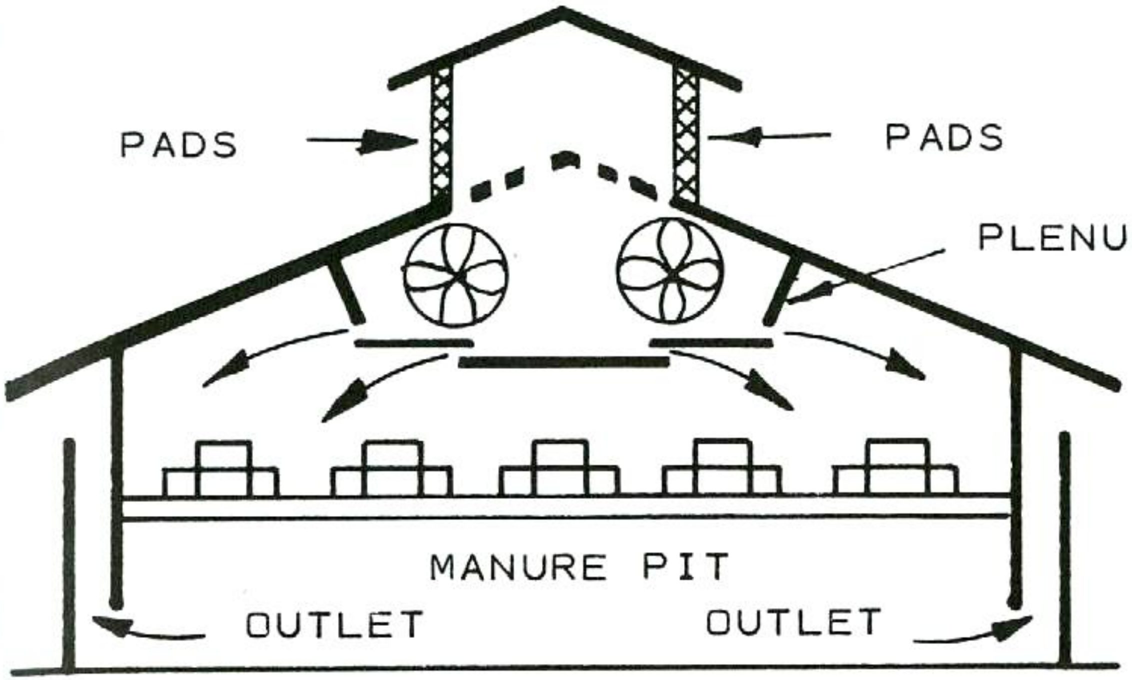
Ventilation of Agricultural Structures

Lecture 1: Introduction & Psychrometrics



Introduction

- Ventilation is a necessary part of the environmental control system of all livestock and plant structures.

- The purpose of the ventilation system is to provide an exchange of fresh environmental air based on climatic conditions and the environmental requirements of the biological units in the structure.

- The primary functions of the ventilation system vary with the particular application, climate, time of year, maturity of the biological system in the ventilated structure and with other factors.

- ventilation system design requires the integration of both the physical and biological sciences and the consideration of a wide range of complex interactions.

Introduction

- Determining ventilation rates and airflow distributions and are the two engineering design parameters that must be considered.

- These parameters must be integrated with biological, management, environmental, and structural parameters and designs must be formulated for widely varying climatic conditions.

- Furthermore, full understanding of the types and characteristics of ventilation and environmental control equipment is essential.

Properties of Moist Air

- The weight of water vapor that can be contained in the air varies with the air temperature.

- The water-vapor content ranges from zero for dry air to saturation or 100 percent relative humidity for a given temperature.

- The pressure, volume, weight, and the thermal properties of air-water vapor mixtures can be related by a series of laws which, though developed for a "perfect" gas, are applicable to processes involving air-water vapor mixtures under normal conditions with sufficient accuracy.

Perfect Gas Law

- The thermodynamic state of moist air can be established by the pressure and two other independent properties.

- The mathematical relationship among the properties of a perfect gas is:

$$Pv = mRT \quad [2.1]$$

where

P = the pressure of the gas, *N/m²*
v = the volume of the gas, m^3
m = the mass of the gas, kg
R = a gas constant, *J/kg* K
T = the absolute temperature of the gas, K

The behavior of a mixture of dry air and water vapor is near enough to that of a perfect gas to apply equation [2.1] with only negligible error at the temperature and pressure ranges for environmental control of most agricultural structures and processes. The gas constant for dry air, R = 287 *J/kg* K, and the gas constant of water vapor, R_w = 461 *J/kg* K, can be assumed as functionally accurate for this temperature and pressure range

DALTON'S LAW

- Water vapor in a mixture of dry air can be treated as a perfect gas. According to Dalton's Law, each component in a mixture of gases exerts its own partial pressure.

- The pressure exerted by each gas in a mixture of gases is independent of the presence of other gases, and the total pressure exerted by a mixture of gases equals the sum of the partial pressures:

$$P = P_a + P_w = \frac{m_a R_a T_a}{V_a} + \frac{m_w R_w T_w}{V_w} \quad [2.2]$$

DALTON'S LAW

➢ Assuming each component gas is uniformly diffused throughout the mixture, the components have equal volume and temperature, and equation [2.2] becomes:

$$P = \frac{T}{V}(m_a R_a + m_w R_w) \qquad [2.3]$$

➢ Since the volume and temperature of the mixture are equal, from equation [2.2] the following can be written:

$$\frac{P_w}{P_a} = \frac{m_w R_w}{m_a R_a} \qquad [2.4]$$

➢ Therefore, if the total pressure and the weight of water vapor are known, the partial pressures can be calculated.

HUMIDITY RATIO

- Humidity ratio is defined as the mass of water vapor in kilograms which is associated with a kilogram of dry air in an air-water vapor mixture.

- From equation [2.2], the humidity ratio (w) for an air-water vapor mixture may be written as (since the water vapor and the dry air have the same temperature and volume):

$$W = \frac{m_w}{m_a} = \frac{P_w V_w R_a T_a}{R_w T_w P_a V_a} = \frac{R_a P_w}{R_w P_a} \qquad [2.5]$$

- Substituting the numerical values for the gas constants, the humidity ratio becomes:

$$W = \frac{m_w}{m_a} = 0.622 \frac{P_w}{P_{at} - P_w} \qquad [2.6]$$

W = humidity ratio, *kg/kg* dry air

m_w = mass of water vapor, kg

P_{at} = atmospheric pressure, *N/m²*

m_a = mass of dry air, kg

P_w = pressure of water vapor, *N/m²*

RELATIVE HUMIDITY

➢ The relative humidity (Φ) is defined as the ratio of the partial pressure of the water vapor in moist air (P_W) to the vapor pressure, if the air were saturated with moisture at the same temperature (P_S). The relationship for relative humidity expressed as a percent is given by the equation:

$$\Phi(\%) = \frac{P_w}{P_s} \times 100\% \qquad [2.7]$$

➢ The vapor pressures for a space saturated with water vapor (P_S) can be found directly from any standard steam table.

SPECIFIC VOLUME

- Volume of a gas or mixture refers to the space occupied by a given quantity. In air-conditioning work, the volume is given as cubic meters per kilogram of dry air together with the mass of water vapor associated with it.

- The base of one kilogram of dry air is used because the kilograms of dry air entering and leaving an air-conditioning unit in a given time always remain constant after steady-flow conditions are established.

- The specific volume of air can be calculated by the application of the ideal gas law to the dry air alone:

$$V_a = \frac{m_a R_a T_a}{P_a} \qquad [2.8]$$

R_a = gas constant for dry air, 287 *J/kg K*
P_a = partial pressure of the dry air, *N/m²*
V_a = volume of 1 kg of dry air at its partial pressure, *m³/kg*
T_a = absolute temperature of the dry air, K
m_a = the mass of dry air, kg

TEMPERATURE

- Three different temperatures are used when referring to an air-water vapor mixture; namely, dry-bulb (db), wet-bulb (wb), and dew-point (dp) temperatures.

- The dry-bulb temperature is measured by a mercury-in-glass thermometer properly shielded from radiation, wiped dry beforehand, and given sufficient time to reach a steady-state reading.

- The wet-bulb temperature is a value indicated on an ordinary thermometer, the bulb of which has been wrapped with a wick moistened in water and placed in a moving stream of air.

- The dew-point temperature is defined as the temperature of an air-water vapor mixture at which moisture will start to condense out of the air as the air is cooled at constant pressure and constant water-vapor content (humidity ratio).

ENTHALPY

➢ The internal energy content of an air-water vapor mixture is called enthalpy, where the enthalpy is expressed as kJ/kg. The enthalpy, h_w, used in psychrometry is defined by the equation:

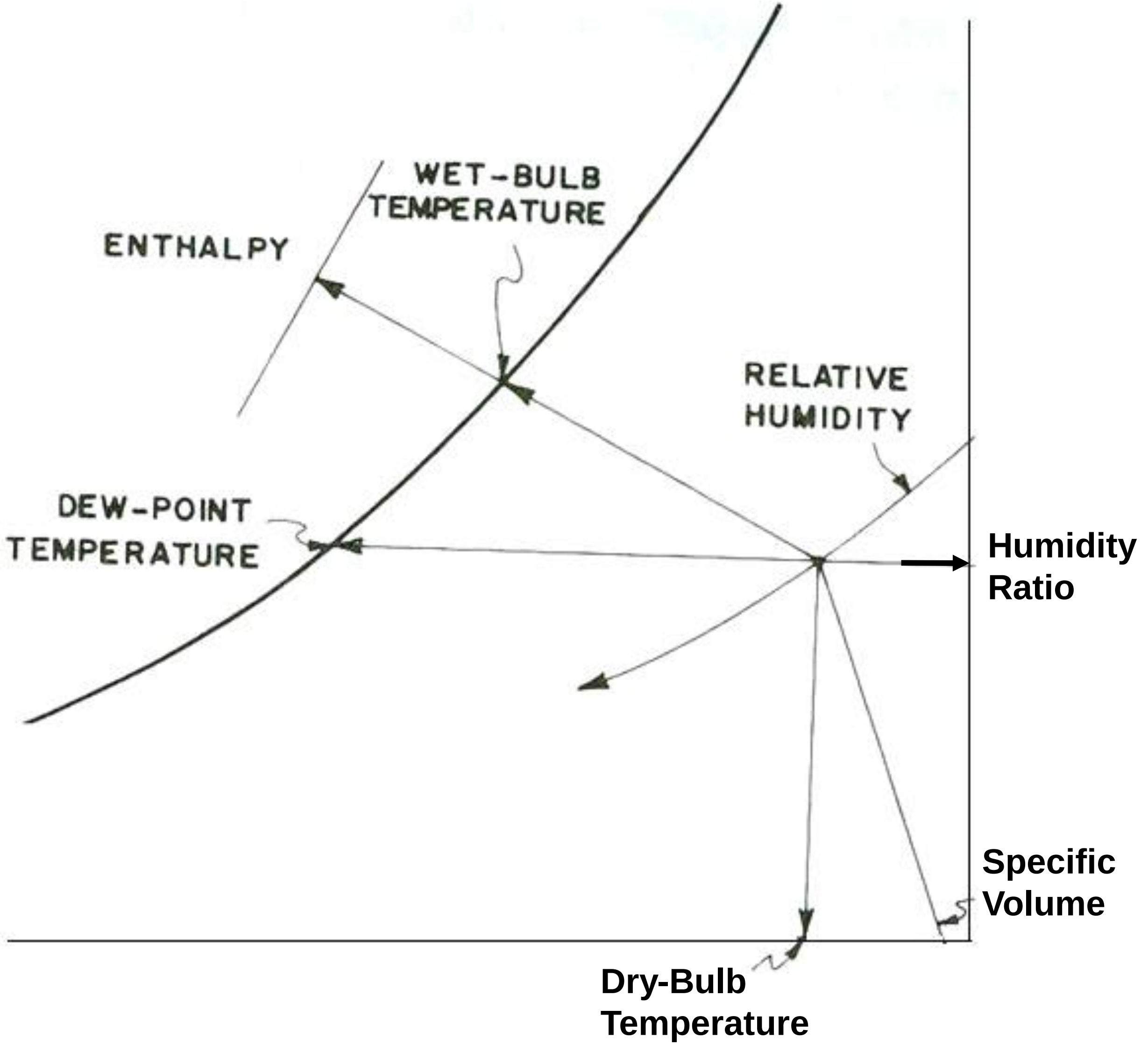
$$h_w = h_a + Wh_g \qquad [2.9]$$

h_a = enthalpy of dry air, kJ/kg
W = moisture content of air, kg/kg
h_g = enthalpy of water vapor, kJ/kg

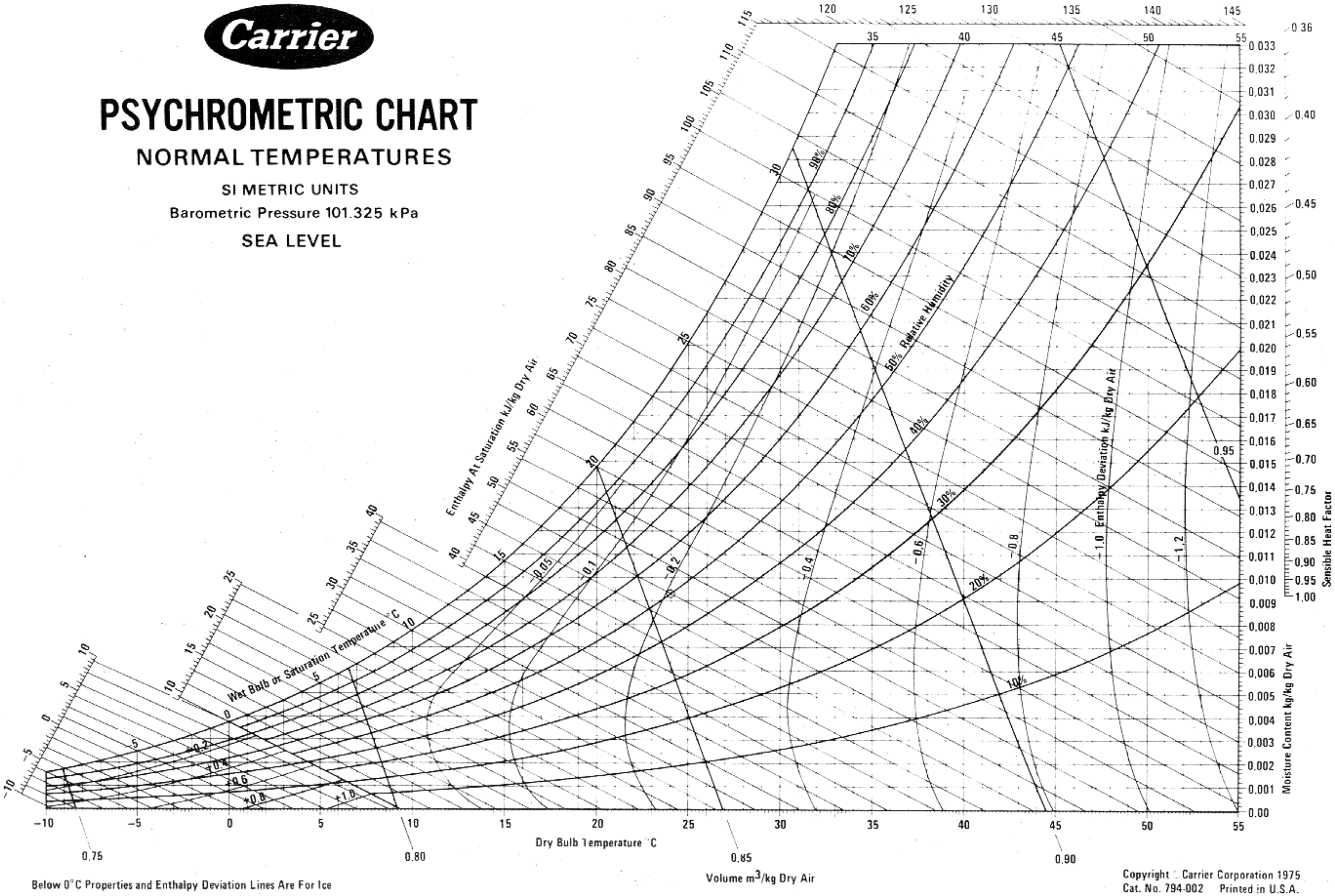
➢ The energy contained in the mixture can be present both as sensible heat (indicated by dry-bulb temperature) and latent heat of vaporization (energy content of the water vapor).

THE PSYCHROMETRIC CHART

- A psychrometric chart is a graphical representation of both the physical, and thermal properties of moist air.



THE PSYCHROMETRIC CHART



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- Air-conditioning processes include heating, cooling, humidifying or dehumidifying air-water vapor mixtures, either singly or in combination.

- **Sensible cooling** is cooling at constant humidity ratio.

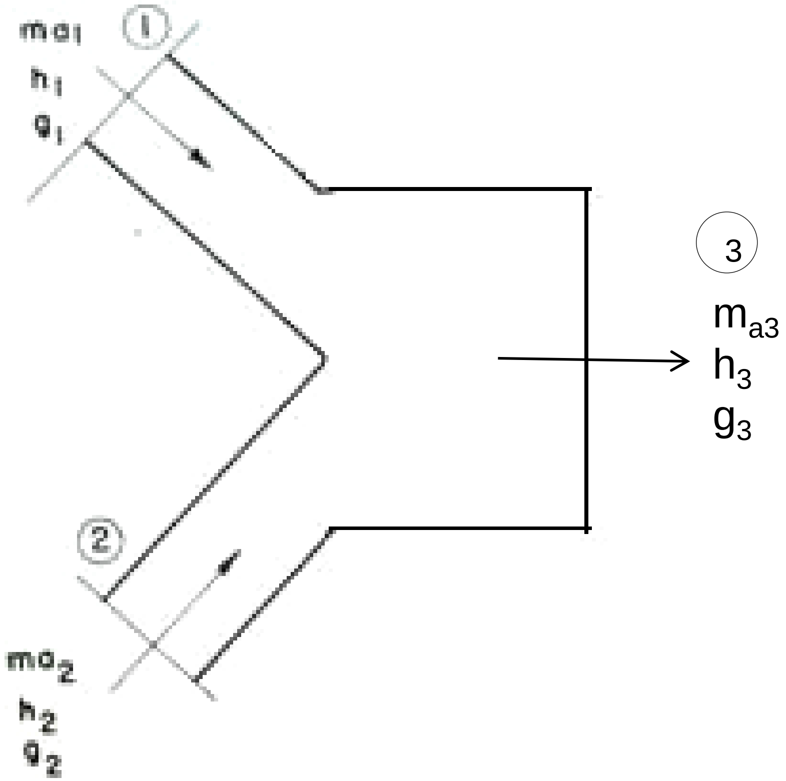
- **Evaporative cooling** is essentially an adiabatic saturation process (no heat gained or lost), and follows upward approximately along a constant wet-bulb temperature line. Air to be cooled is brought in contact with water at a temperature equal to the wet-bulb temperature of the air. The sensible heat of the initial air evaporates the water, lowering the air's dry-bulb temperature. Sensible heat is converted to latent heat in the added vapor, so the process is adiabatic.

AIR·WATER VAPOR MIXTURE PROCESSES

- **Heating and humidifying** of ventilating air occurs as it moves through livestock buildings. Animals and poultry produce heat and water vapor which are added to the ventilating air.

- **Cooling and dehumidifying** implies lowering both dry-bulb temperature and humidity ratio. The process path depends on the type of equipment used. In summer air conditioning, air passes over a cold finned-type evaporator coil of a refrigeration unit. The air is cooled below the dew-point temperature, and moisture condenses. Unless reheated or initially saturated, the final relative humidity of the moist air is always higher than at the start. Both sensible heat and latent heat are removed in the process.

➢ **Adiabatic mixing of moist air** is a common process in air conditioning where the mixing of moist air at two different conditions will take place to obtain a third state:



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