

Table 7 Calculated Diffusion Coefficients for Water-Air at One Atmosphere

Temp, F	cm ² /sec	Temp, F	cm ² /sec	Temp, F	cm ² /sec
-100	0.130	40	0.228	140	0.311
-50	0.163	50	0.236	150	0.320
-40	0.169	60	0.243	200	0.365
-30	0.176	70	0.251	250	0.413
-20	0.183	80	0.260	300	0.463
-10	0.190	90	0.269	350	0.515
0	0.198	100	0.277	400	0.569
10	0.206	110	0.285	450	0.625
20	0.213	120	0.294	500	0.682
30	0.220	130	0.302		

the final dry-bulb temperature of the moist air and the rate of steam flow required in lb per hr.

Solution: Fig. 9 shows the schematic solution. By Table 3, the enthalpy of the steam $h_g = 1157.0$ Btu/lb water. Thus, from Equation 29, the condition line on the ASHRAE chart connecting States 1 and 2 must have a direction

$$\frac{\Delta h}{\Delta W} = 1157 \text{ Btu/lb water}$$

The condition line may be drawn through use of the $\Delta h/\Delta W$ protractor. The procedure is as follows: On the protractor establish the reference line by connecting the origin with the value $\Delta h/\Delta W = 1157$. Draw a second line parallel to the reference line and through the initial state-point of the moist air. This second line is the condition line. State 2 is established at the intersection of the condition line with the horizontal line extended from the saturation curve at 55 F ($t_s = 55$ F). Thus, $t_2 = 72.2$ F.

Values of W_1 and W_2 may be read from the chart. The required steam flow is

$$m_s = m_a(W_2 - W_1) = (200)(60)(0.00920 - 0.00070) = 102 \text{ lb steam/hr}$$

Absorption of Space Heat and Moisture Gains by Moist Air

The problem of air conditioning a space usually reduces to the determination of the quantity of moist air that must be applied and the necessary condition which it must have in order to remove given amounts of energy and water from the space and be withdrawn at a specified condition.

Fig. 10 schematically shows a space with incident rates of energy and moisture gains. The quantity q_s denotes the net

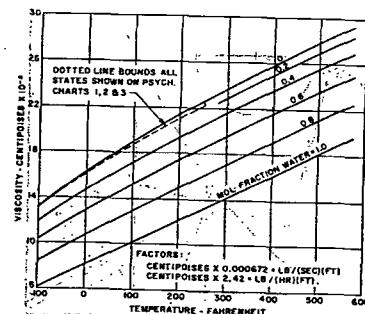


Fig. 12 Viscosity of Moist Air

sum of all rates of heat gain upon the space, arising from transfers through boundaries and from sources within the space. This heat gain involves addition of energy alone and does not include energy contributions due to addition of water (or water vapor). It is usually called the sensible heat gain. The quantity $\sum m_a$ denotes the net sum of all rates of moisture gain upon the space arising from transfers through boundaries and from sources within the space. Each pound of moisture injected into the space adds an amount of energy equal to its specific enthalpy.

Assuming steady-state conditions, the governing equations are:

$$m_a h_1 + q_s + \sum (m_a h_a) = m_a h_2$$

$$m_a W_1 + \sum m_a = m_a W_2$$

or

$$q_s + \sum (m_a h_a) = m_a (h_2 - h_1) \quad (30)$$

$$\sum m_a = m_a (W_2 - W_1) \quad (31)$$

It is to be noted that the left side of Equation 30 represents the total rate of energy addition to the space from all sources. By Equations 30 and 31

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{q_s + \sum (m_a h_a)}{\sum m_a} \quad (32)$$

according to which: on the ASHRAE chart and for a given state of the withdrawn air, all possible states (conditions) for the supply air must lie on a straight line drawn through the state-point of the withdrawn air and which has a direction specified by the numerical value of $(q_s + \sum (m_a h_a)) / \sum m_a$. This straight line is called the condition line for the given problem.

Example 8: Moist air is withdrawn from a room at 80 F dry-bulb temperature and 66 F thermodynamic wet-bulb temperature. The sensible rate of heat gain for the space is 30,000 Btu per hr. A rate of moisture gain of 10 lb per hr occurs from the occupants of the space. This moisture may be assumed as saturated water vapor at 90 F. Moist air is introduced into the room at a dry-bulb temperature of 60 F. Find the required thermodynamic wet-bulb temperature of the supply air and the required volume rate of flow of the supply air.

Solution: Fig. 11 shows the schematic solution. State 2 may be located on the ASHRAE chart. From Table 2, the specific enthalpy of the water vapor added is $h_g = 1100.44$ Btu/lb. From Equation 32

$$\frac{\Delta h}{\Delta W} = \frac{30,000 + (10)(1100.44)}{10} = 4100 \text{ Btu/lb water}$$

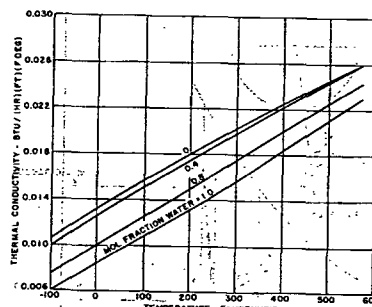


Fig. 13 Thermal Conductivity of Moist Air

With the $\Delta h/\Delta W$ protractor, establish a reference line of direction $\Delta h/\Delta W = 4100$ Btu/lb water. Parallel to this reference line, draw a straight line on the chart through State 2. The intersection of this line with the 60 F dry-bulb temperature line is State 1. Thus, $t_1 = 56.4$ F.

An alternate (and approximately correct) procedure in establishing the condition line is to use the sensible-total heat ratio of the protractor instead of the $\Delta h/\Delta W$ scale. The quantity $\Delta h/\Delta W$ is the ratio of the rate of sensible heat gain for the space to the rate of total energy gain for the space. Thus

$$\frac{\Delta h}{\Delta W} = \frac{q_s}{\sum m_a} = \frac{30,000}{10} = 0.732$$

$$\frac{\Delta h}{\Delta W} = \frac{q_s + \sum (m_a h_a)}{\sum m_a} = \frac{30,000 + (10)(1100.44)}{10} = 0.732$$

It may be observed that $\Delta h/\Delta W = 0.732$ on the protractor coincides closely with $\Delta h/\Delta W = 4100$ Btu/lb water.

The flow rate of dry air may be calculated from either Equation 30 or 31. From Equation 30

$$m_a = \frac{q_s + \sum (m_a h_a)}{h_2 - h_1} = \frac{30,000 + (10)(1100.44)}{(60)(30.73 - 24.00)} = 101.5 \text{ lb dry air/min}$$

At State 1, $m_a = 13.29$ cu ft/lb dry air. Thus

$$\text{Supply volume} = m_a v_1 = (101.5)(13.29) = 1349 \text{ cfm}$$

TRANSPORT PROPERTIES OF MOIST AIR

For certain scientific and experimental work, particularly in the field of heat transfer, a number of other properties of moist air are important. These are generally classified as Transport Properties and include: Diffusion Coefficient, Viscosity, Thermal Conductivity and Thermal Diffusion Factor. A recent paper² derives these properties by calculation. Table 7 and Figs. 12 and 13 summarize the author's results on the first three properties listed above. It will be noted from the indicated boundaries of Charts 1, 2 and 3 that the viscosity varies little from that of dry air at normal atmospheric pressure, and the thermal conductivity is essentially identical.

Conversion between mol fraction of water and humidity ratio may be accomplished by means of Equation 33.

$$W = .622 \left(\frac{z_w}{1 - z_w} \right) \quad (33)$$

LETTER SYMBOLS USED IN CHAPTER 3

- ϕ = degree of saturation W/W_s , dimensionless.
- ϕ = relative humidity, dimensionless.
- A = Coefficient in Equation 3, given by Table 5, cu ft per pound dry air.
- B = Coefficient in Equation 5, given by Table 5, Btu per pound dry air.
- C = Coefficient in Equation 7, given by Table 5, Btu per (pound dry air) (Fahrenheit degree absolute).
- D = enthalpy deviation, Btu per pound dry air.
- h = enthalpy of moist air, Btu per pound dry air.
- h = enthalpy correction term given by Equation 5 and to be added to Equation 4 for temperatures above 150 F, Btu per pound dry air.
- h_a = specific enthalpy of dry air, Btu per pound.
- $h_{a,s}$ = $h_a - h_g$, Btu per pound dry air.
- h_f = specific enthalpy of saturated liquid water, Btu per pound.
- $h_{f,s}$ = $h_f - h_g$, Btu per pound.
- h_g = specific enthalpy of saturated water vapor, Btu per pound.
- h_s = enthalpy of moist air at saturation, Btu per pound dry air.
- h_s^* = enthalpy of moist air at saturation at thermodynamic wet-bulb temperature, Btu per pound dry air.

- h_s = specific enthalpy of water vapor, Btu per pound.
- $h_{s,w}$ = specific enthalpy of condensed water (liquid or solid) at a pressure of 29.921 in. Hg, Btu per pound.
- h_w = specific enthalpy of water (any phase) added to or removed from moist air in a process, Btu per pound.
- m_a = mass flow of dry air, pounds per unit time.
- m_w = mass flow of water (any phase), pounds per unit time.
- n_a = mols of dry air.
- n_w = mols of water vapor.
- p = total pressure of moist air, inches Hg or pounds per square inch.
- p_a = partial pressure of dry air, inches Hg or pounds per square inch.
- p_s = reference pressure of 29.921 inches Hg in definition of U. S. Standard Atmosphere.
- $p_{s,w}$ = vapor pressure of water in moist air at saturation, inches Hg or pounds per square inch. Differs from the saturation pressure of pure water because of presence of the air.
- p_w = partial pressure of water vapor in moist air, inches Hg or pounds per square inch.
- $p_{w,s}$ = pressure of saturated pure water, inches Hg or pounds per square inch.
- q = rate of heat addition (or withdrawal), Btu per unit time.
- q_s = rate of addition (or withdrawal) of sensible heat, Btu per unit time.
- R = universal gas constant, 1544 foot-pounds per (Fahrenheit degree absolute) (mol).
- R_a = gas constant for dry air, 53.35 foot-pounds per (Fahrenheit degree absolute) (pound).
- s = entropy of moist air, Btu per (pound dry air) (Fahrenheit degree absolute).
- s = entropy correction term given by Equation 7 and to be added to Equation 6, Btu per (pound dry air) (Fahrenheit degree absolute).
- s = entropy correction term given by Equation 8 and to be added to Equation 6, Btu per (pound dry air) (Fahrenheit degree absolute).
- s_a = specific entropy of dry air, Btu per (pound) (Fahrenheit degree absolute).
- $s_{a,w}$ = $s_a - s_w$, Btu per (pound dry air) (Fahrenheit degree absolute).
- s_f = specific entropy of saturated liquid water, Btu per (pound) (Fahrenheit degree absolute).
- $s_{f,s}$ = $s_f - s_g$, Btu per (pound) (Fahrenheit degree absolute).
- s_g = specific entropy of saturated water vapor, Btu per (pound) (Fahrenheit degree absolute).
- s_w = specific entropy of condensed water (liquid or solid) at a pressure of 29.921 inches Hg, Btu per (pound) (Fahrenheit degree absolute).
- t = dry-bulb temperature of moist air, Fahrenheit degrees.
- t_d = dew-point temperature of moist air, Fahrenheit degrees.
- t^* = thermodynamic wet-bulb temperature of moist air, Fahrenheit degrees.
- T = absolute temperature, Fahrenheit degrees.
- T_s = reference temperature of 518.67 Fahrenheit degrees absolute in definition of U. S. Standard Atmosphere.
- v = volume of moist air, cubic feet per pound dry air.
- v = volume correction term given by Equation 3 and to be added to Equation 2 for temperatures above 150 F, cubic feet per pound dry air.
- v_a = specific volume of dry air, cubic feet per pound.
- $v_{a,s}$ = $v_a - v_w$, cubic feet per pound dry air.
- v_f = specific volume of saturated liquid water, cubic feet per pound.
- $v_{f,s}$ = $v_f - v_g$, cubic feet per pound.