Chapter 14
GAS-VAPOR MIXTURES AND AIR CONDITIONING

Dry and Atmospheric Air, Specific and Relative Humidity

14-1C Yes; by cooling the air at constant pressure.

14-2C Yes.

14-3C Specific humidity will decrease but relative humidity will increase.

14-4C Dry air does not contain any water vapor, but atmospheric air does.

14-5C Yes, the water vapor in the air can be treated as an ideal gas because of its very low partial pressure.

14-6C The partial pressure of the water vapor in atmospheric air is called vapor pressure.

14-7C The same. This is because water vapor behaves as an ideal gas at low pressures, and the enthalpy of an ideal gas depends on temperature only.

14-8C Specific humidity is the amount of water vapor present in a unit mass of dry air. Relative humidity is the ratio of the actual amount of vapor in the air at a given temperature to the maximum amount of vapor air can hold at that temperature.

14-9C The specific humidity will remain constant, but the relative humidity will decrease as the temperature rises in a well-sealed room.

14-10C The specific humidity will remain constant, but the relative humidity will decrease as the temperature drops in a well-sealed room.

14-11C A tank that contains moist air at 3 atm is located in moist air that is at 1 atm. The driving force for moisture transfer is the vapor pressure difference, and thus it is possible for the water vapor to flow into the tank from surroundings if the vapor pressure in the surroundings is greater than the vapor pressure in the tank.

14-12C Insulations on *chilled water lines* are always wrapped with *vapor barrier jackets* to eliminate the possibility of vapor entering the insulation. This is because moisture that migrates through the insulation to the cold surface will condense and remain there indefinitely with no possibility of vaporizing and moving back to the outside.

14-13C When the temperature, total pressure, and the relative humidity are given, the vapor pressure can be determined from the psychrometric chart or the relation $P_v = \phi P_{sat}$ where P_{sat} is the saturation (or boiling) pressure of water at the specified temperature and ϕ is the relative humidity.

14-14 A tank contains saturated air at a specified temperature and pressure. The mass of dry air, the specific humidity, and the enthalpy of the air are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis (*a*) The mass of dry air can be determined from the ideal gas relation for the dry air,

$$m_a = \frac{P_a V}{R_a T} = \frac{[(105-4.2469)\text{ kPa}](8\text{ m}^3)}{(0.287\text{ kJ/kg.K})(30+273.15\text{ K})} = \mathbf{9.264\ kg}$$

(*b*) The relative humidity of air is 100 percent since the air saturated. The vapor pressure is equal to the saturation pressure of water at 30ºC

$$P_v = P_g = P_{\text{sat @ 30°C}} = 4.2469\text{ kPa}$$

AIR
30°C
105 kPa
8 m^3

The specific humidity can be determined from

$$\omega = \frac{0.622 P_v}{P - P_v} = \frac{(0.622)(4.2469\text{ kPa})}{(105-4.2469)\text{ kPa}} = \mathbf{0.0262\ kg\ H_2O/kg\ dry\ air}$$

(*c*) The enthalpy of air per unit mass of dry air is determined from

$$\begin{aligned} h &= h_a + \omega h_v \cong c_p T + \omega h_{g\,@\,30°C} \\ &= (1.005\text{ kJ/kg}\cdot°\text{C})(30°\text{C}) + (0.0262)(2555.6\text{ kJ/kg}) = \mathbf{97.1\ kJ/kg\ dry\ air} \end{aligned}$$

14-15 A tank contains dry air and water vapor at specified conditions. The specific humidity, the relative humidity, and the volume of the tank are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis (*a*) The specific humidity can be determined form its definition,

$$\omega = \frac{m_v}{m_a} = \frac{0.3\text{ kg}}{21\text{ kg}} = \mathbf{0.0143\ kg\ H_2O/kg\ dry\ air}$$

21 kg dry air
0.3 kg H_2O vapor
30°C
100 kPa

(*b*) The saturation pressure of water at 30°C is

$$P_g = P_{\text{sat @ 30°C}} = 4.2469\text{ kPa}$$

Then the relative humidity can be determined from

$$\phi = \frac{\omega P}{(0.622+\omega)P_g} = \frac{(0.0143)(100\text{ kPa})}{(0.622+0.0143)(4.2469\text{ kPa})} = \mathbf{52.9\%}$$

(*c*) The volume of the tank can be determined from the ideal gas relation for the dry air,

$$P_v = \phi P_g = (0.529)(4.2469\text{ kPa}) = 2.245\text{ kPa}$$

$$P_a = P - P_v = 100 - 2.245 = 97.755\text{ kPa}$$

$$V = \frac{m_a R_a T}{P_a} = \frac{(21\text{ kg})(0.287\text{ kJ/kg}\cdot\text{K})(303\text{ K})}{97.755\text{ kPa}} = \mathbf{18.7\ m^3}$$

14-16 A tank contains dry air and water vapor at specified conditions. The specific humidity, the relative humidity, and the volume of the tank are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis (*a*) The specific humidity can be determined form its definition,

$$\omega = \frac{m_v}{m_a} = \frac{0.3\,\text{kg}}{21\,\text{kg}} = \mathbf{0.0143\,kg\,H_2O/kg\,dry\,air}$$

21 kg dry air
0.3 kg H_2O vapor
24°C
100 kPa

(*b*) The saturation pressure of water at 24°C is

$$P_g = P_{\text{sat @24°C}} = 2.986\,\text{kPa}$$

Then the relative humidity can be determined from

$$\phi = \frac{\omega P}{(0.622 + \omega)P_g} = \frac{(0.0143)(100\,\text{kPa})}{(0.622 + 0.0143)2.986\,\text{kPa}} = \mathbf{75.2\%}$$

(*c*) The volume of the tank can be determined from the ideal gas relation for the dry air,

$$P_v = \phi P_g = (0.752)(2.986\,\text{kPa}) = 2.245\,\text{kPa}$$

$$P_a = P - P_v = 100 - 2.245 = 97.755\,\text{kPa}$$

$$V = \frac{m_a R_a T}{P_a} = \frac{(21\,\text{kg})(0.287\,\text{kJ/kg}\cdot\text{K})(297\,\text{K})}{97.755\,\text{kPa}} = \mathbf{18.3\,m^3}$$

14-17 A room contains air at specified conditions and relative humidity. The partial pressure of air, the specific humidity, and the enthalpy per unit mass of dry air are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis (*a*) The partial pressure of dry air can be determined from

$$P_v = \phi P_g = \phi P_{\text{sat @ 20°C}} = (0.85)(2.3392\,\text{kPa}) = 1.988\,\text{kPa}$$

$$P_a = P - P_v = 98 - 1.988 = \mathbf{96.01\,kPa}$$

AIR
20°C
98 kPa
85% RH

(*b*) The specific humidity of air is determined from

$$\omega = \frac{0.622 P_v}{P - P_v} = \frac{(0.622)(1.988\,\text{kPa})}{(98 - 1.988)\,\text{kPa}} = \mathbf{0.0129\,kg\,H_2O/kg\,dry\,air}$$

(*c*) The enthalpy of air per unit mass of dry air is determined from

$$h = h_a + \omega h_v \cong c_p T + \omega h_g$$

$$= (1.005\,\text{kJ/kg}\cdot°\text{C})(20°\text{C}) + (0.0129)(2537.4\,\text{kJ/kg}) = \mathbf{52.78\,kJ/kg\,dry\,air}$$

14-18 A room contains air at specified conditions and relative humidity. The partial pressure of air, the specific humidity, and the enthalpy per unit mass of dry air are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis (*a*) The partial pressure of dry air can be determined from

$$P_v = \phi P_g = \phi P_{\text{sat @ 20°C}} = (0.85)(2.3392 \text{ kPa}) = 1.988 \text{ kPa}$$

$$P_a = P - P_v = 85 - 1.988 = \mathbf{83.01\ kPa}$$

AIR 20°C 85 kPa 85% RH

(*b*) The specific humidity of air is determined from

$$\omega = \frac{0.622 P_v}{P - P_v} = \frac{(0.622)(1.988 \text{ kPa})}{(85 - 1.988) \text{ kPa}} = \mathbf{0.0149\ kg\ H_2O/kg\ dry\ air}$$

(*c*) The enthalpy of air per unit mass of dry air is determined from

$$h = h_a + \omega h_v \cong c_p T + \omega h_g$$

$$= (1.005 \text{ kJ/kg}\cdot\text{°C})(20\text{°C}) + (0.0149)(2537.4 \text{ kJ/kg}) = \mathbf{57.90\ kJ/kg\ dry\ air}$$

14-19E A room contains air at specified conditions and relative humidity. The partial pressure of air, the specific humidity, and the enthalpy per unit mass of dry air are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis (*a*) The partial pressure of dry air can be determined from

$$P_v = \phi P_g = \phi P_{\text{sat @ 70°F}} = (0.85)(0.36334 \text{ psia}) = 0.309 \text{ psia}$$

$$P_a = P - P_v = 14.6 - 0.309 = \mathbf{14.291\ psia}$$

AIR 70°F 14.6 psia 85% RH

(*b*) The specific humidity of air is determined from

$$\omega = \frac{0.622 P_v}{P - P_v} = \frac{(0.622)(0.309 \text{ psia})}{(14.6 - 0.309) \text{ psia}} = \mathbf{0.0134\ lbm\ H_2O/lbm\ dry\ air}$$

(*c*) The enthalpy of air per unit mass of dry air is determined from

$$h = h_a + \omega h_v \cong c_p T + \omega h_g$$

$$= (0.24 \text{ Btu/lbm}\cdot\text{°F})(70\text{°F}) + (0.0134)(1091.8 \text{ Btu/lbm}) = \mathbf{31.43\ Btu/lbm\ dry\ air}$$

14-20 The masses of dry air and the water vapor contained in a room at specified conditions and relative humidity are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis The partial pressure of water vapor and dry air are determined to be

$$P_v = \phi P_g = \phi P_{\text{sat @ 23°C}} = (0.50)(2.811 \text{ kPa}) = 1.41 \text{ kPa}$$

$$P_a = P - P_v = 98 - 1.41 = 96.59 \text{ kPa}$$

ROOM 240 m^3 23°C 98 kPa 50% RH

The masses are determined to be

$$m_a = \frac{P_a \mathbf{V}}{R_a T} = \frac{(96.59 \text{ kPa})(240 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(296 \text{ K})} = \mathbf{272.9\ kg}$$

$$m_v = \frac{P_v \mathbf{V}}{R_v T} = \frac{(1.41 \text{ kPa})(240 \text{ m}^3)}{(0.4615 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(296 \text{ K})} = \mathbf{2.47\ kg}$$

Dew-point, Adiabatic Saturation, and Wet-bulb Temperatures

14-21C Dew-point temperature is the temperature at which condensation begins when air is cooled at constant pressure.

14-22C Andy's. The temperature of his glasses may be below the dew-point temperature of the room, causing condensation on the surface of the glasses.

14-23C The outer surface temperature of the glass may drop below the dew-point temperature of the surrounding air, causing the moisture in the vicinity of the glass to condense. After a while, the condensate may start dripping down because of gravity.

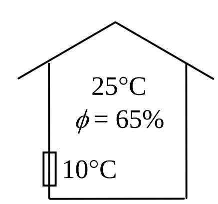
14-24C When the temperature falls below the dew-point temperature, dew forms on the outer surfaces of the car. If the temperature is below 0°C, the dew will freeze. At very low temperatures, the moisture in the air will freeze directly on the car windows.

14-25C When the air is saturated (100% relative humidity).

14-26C These two are approximately equal at atmospheric temperatures and pressure.

14-27 A house contains air at a specified temperature and relative humidity. It is to be determined whether any moisture will condense on the inner surfaces of the windows when the temperature of the window drops to a specified value.

Assumptions The air and the water vapor are ideal gases.



Analysis The vapor pressure P_v is uniform throughout the house, and its value can be determined from

$$P_v = \phi P_{g\,@\,25°\text{C}} = (0.65)(3.1698\ \text{kPa}) = 2.06\ \text{kPa}$$

The dew-point temperature of the air in the house is

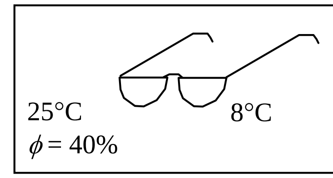
$$T_{\text{dp}} = T_{\text{sat}\,@\,P_v} = T_{\text{sat}\,@\,2.06\ \text{kPa}} = \mathbf{18.0°C}$$

That is, the moisture in the house air will start condensing when the temperature drops below 18.0°C. Since the windows are at a lower temperature than the dew-point temperature, some moisture **will condense** on the window surfaces.

14-28 A person wearing glasses enters a warm room at a specified temperature and relative humidity from the cold outdoors. It is to be determined whether the glasses will get fogged.

Assumptions The air and the water vapor are ideal gases.

Analysis The vapor pressure P_v of the air in the house is uniform throughout, and its value can be determined from



$$P_v = \phi P_{g\,@\,25°\text{C}} = (0.40)(3.1698\text{ kPa}) = 1.268\text{ kPa}$$

The dew-point temperature of the air in the house is

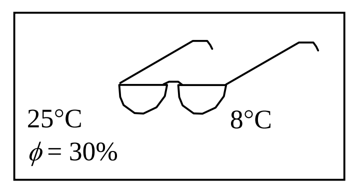
$$T_{\text{dp}} = T_{\text{sat}\,@\,P_v} = T_{\text{sat}\,@\,1.268\text{ kPa}} = \mathbf{10.5°C} \quad \text{(from EES)}$$

That is, the moisture in the house air will start condensing when the air temperature drops below 10.5°C. Since the glasses are at a lower temperature than the dew-point temperature, some moisture will condense on the glasses, and thus they **will get fogged**.

14-29 A person wearing glasses enters a warm room at a specified temperature and relative humidity from the cold outdoors. It is to be determined whether the glasses will get fogged.

Assumptions The air and the water vapor are ideal gases.

Analysis The vapor pressure P_v of the air in the house is uniform throughout, and its value can be determined from



$$P_v = \phi P_{g\,@\,25°\text{C}} = (0.30)(3.1698\text{ kPa}) = 0.95\text{ kPa}$$

The dew-point temperature of the air in the house is

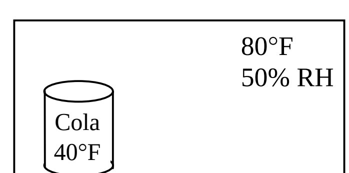
$$T_{\text{dp}} = T_{\text{sat}\,@\,P_v} = T_{\text{sat}\,@\,0.95\text{ kPa}} = \mathbf{6.2°C} \quad \text{(from EES)}$$

That is, the moisture in the house air will start condensing when the air temperature drops below 6.2°C. Since the glasses are at a higher temperature than the dew-point temperature, moisture will not condense on the glasses, and thus they **will not get fogged**.

14-30E A woman drinks a cool canned soda in a room at a specified temperature and relative humidity. It is to be determined whether the can will sweat.

Assumptions The air and the water vapor are ideal gases.

Analysis The vapor pressure P_v of the air in the house is uniform throughout, and its value can be determined from



$$P_v = \phi P_{g\,@\,80°\text{F}} = (0.50)(0.50745\text{ psia}) = 0.254\text{ psia}$$

The dew-point temperature of the air in the house is

$$T_{\text{dp}} = T_{\text{sat}\,@\,P_v} = T_{\text{sat}\,@\,0.254\text{ psia}} = \mathbf{59.7°F} \quad \text{(from EES)}$$

That is, the moisture in the house air will start condensing when the air temperature drops below 59.7°C. Since the canned drink is at a lower temperature than the dew-point temperature, some moisture will condense on the can, and thus it **will sweat.**

14-31 The dry- and wet-bulb temperatures of atmospheric air at a specified pressure are given. The specific humidity, the relative humidity, and the enthalpy of air are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis (*a*) We obtain the properties of water vapor from EES. The specific humidity ω_1 is determined from

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$

95 kPa 25°C T_{wb} = 17°C

where T_2 is the wet-bulb temperature, and ω_2 is determined from

$$\omega_2 = \frac{0.622 P_{g2}}{P_2 - P_{g2}} = \frac{(0.622)(1.938\text{ kPa})}{(95 - 1.938)\text{ kPa}} = 0.01295\text{ kg H}_2\text{O/kg dry air}$$

Thus, $$\omega_1 = \frac{(1.005\text{ kJ/kg}\cdot°\text{C})(17 - 25)°\text{C} + (0.01295)(2460.6\text{ kJ/kg})}{(2546.5 - 71.36)\text{ kJ/kg}} = \mathbf{0.00963\text{ kg H}_2\text{O/kg dry air}}$$

(*b*) The relative humidity ϕ_1 is determined from

$$\phi_1 = \frac{\omega_1 P_1}{(0.622 + \omega_1)P_{g1}} = \frac{(0.00963)(95\text{ kPa})}{(0.622 + 0.00963)(3.1698\text{ kPa})} = 0.457 \quad \text{or} \quad \mathbf{45.7\%}$$

(*c*) The enthalpy of air per unit mass of dry air is determined from

$$h_1 = h_{a1} + \omega_1 h_{v1} \cong c_p T_1 + \omega_1 h_{g1} = (1.005\text{ kJ/kg}\cdot°\text{C})(25°\text{C}) + (0.00963)(2546.5\text{ kJ/kg})$$
$$= \mathbf{49.65\text{ kJ/kg dry air}}$$

14-32 The dry- and wet-bulb temperatures of air in room at a specified pressure are given. The specific humidity, the relative humidity, and the dew-point temperature are to be determined.

Assumptions The air and the water vapor are ideal gases.

Analysis (*a*) We obtain the properties of water vapor from EES. The specific humidity ω_1 is determined from

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$

100 kPa 22°C T_{wb} = 16°C

where T_2 is the wet-bulb temperature, and ω_2 is determined from

$$\omega_2 = \frac{0.622 P_{g2}}{P_2 - P_{g2}} = \frac{(0.622)(1.819\text{ kPa})}{(100 - 1.819)\text{ kPa}} = 0.01152\text{ kg H}_2\text{O/kg dry air}$$

Thus, $$\omega_1 = \frac{(1.005\text{ kJ/kg}\cdot°\text{C})(16 - 22)°\text{C} + (0.01152)(2463.0\text{ kJ/kg})}{(2541.1 - 67.17)\text{ kJ/kg}} = \mathbf{0.00903\text{ kg H}_2\text{O/kg dry air}}$$

(*b*) The relative humidity ϕ_1 is determined from

$$\phi_1 = \frac{\omega_1 P_1}{(0.622 + \omega_1)P_{g1}} = \frac{(0.00903)(100\text{ kPa})}{(0.622 + 0.0091)(2.6452\text{ kPa})} = 0.541 \quad \text{or} \quad \mathbf{54.1\%}$$

(*c*) The vapor pressure at the inlet conditions is

$$P_{v1} = \phi_1 P_{g1} = \phi_1 P_{\text{sat @ 22°C}} = (0.541)(2.6452\text{ kPa}) = 1.432\text{ kPa}$$

Thus the dew-point temperature of the air is

$$T_{dp} = T_{\text{sat @ }P_v} = T_{\text{sat @1.432 kPa}} = \mathbf{12.3°C}$$

14-33 EES Problem 14-32 is reconsidered. The required properties are to be determined using EES at 100 and 300 kPa pressures.

Analysis The problem is solved using EES, and the solution is given below.

```
Tdb=22 [C]
Twb=16 [C]
P1=100 [kPa]
P2=300 [kPa]

h1=enthalpy(AirH2O;T=Tdb;P=P1;B=Twb)
v1=volume(AirH2O;T=Tdb;P=P1;B=Twb)
Tdp1=dewpoint(AirH2O;T=Tdb;P=P1;B=Twb)
w1=humrat(AirH2O;T=Tdb;P=P1;B=Twb)
Rh1=relhum(AirH2O;T=Tdb;P=P1;B=Twb)

h2=enthalpy(AirH2O;T=Tdb;P=P2;B=Twb)
v2=volume(AirH2O;T=Tdb;P=P2;B=Twb)
Tdp2=dewpoint(AirH2O;T=Tdb;P=P2;B=Twb)
w2=humrat(AirH2O;T=Tdb;P=P2;B=Twb)
Rh2=relhum(AirH2O;T=Tdb;P=P2;B=Twb)
```

SOLUTION

```
h1=45.09 [kJ/kga]
h2=25.54 [kJ/kga]
P1=100 [kPa]
P2=300 [kPa]
Rh1=0.541
Rh2=0.243
Tdb=22 [C]
Tdp1=12.3 [C]
Tdp2=0.6964 [C]
Twb=16 [C]
v1=0.8595 [m^3/kga]
v2=0.283 [m^3/kga]
w1=0.009029 [kgv/kga]
w2=0.001336 [kgv/kga]
```

14-34E The dry- and wet-bulb temperatures of air in room at a specified pressure are given. The specific humidity, the relative humidity, and the dew-point temperature are to be determined.

Assumptions The air and the water vapor are ideal gases.

14.7 psia
80°F
T_{wb} = 65°F

Analysis (*a*) The specific humidity ω_1 is determined from

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$

where T_2 is the wet-bulb temperature, and ω_2 is determined from

$$\omega_2 = \frac{0.622 P_{g2}}{P_2 - P_{g2}} = \frac{(0.622)(0.30578\text{ psia})}{(14.7 - 0.30578)\text{ psia}} = 0.01321\text{ lbm H}_2\text{O/lbm dry air}$$

Thus,

$$\omega_1 = \frac{(0.24\text{ Btu/lbm}\cdot°\text{F})(65-80)°\text{F} + (0.01321)(1056.5\text{ Btu/lbm})}{(1096.1 - 33.08)\text{ Btu/lbm}} = \mathbf{0.00974\ lbm\ H_2O/lbm\ dry\ air}$$

(*b*) The relative humidity ϕ_1 is determined from

$$\phi_1 = \frac{\omega_1 P_1}{(0.622 + \omega_1)P_{g1}} = \frac{(0.00974)(14.7\text{ psia})}{(0.622 + 0.00974)(0.50745\text{ psia})} = 0.447 \quad \text{or} \quad \mathbf{44.7\%}$$

(*c*) The vapor pressure at the inlet conditions is

$$P_{v1} = \phi_1 P_{g1} = \phi_1 P_{\text{sat @ 70°F}} = (0.447)(0.50745\text{ psia}) = 0.2268\text{ psia}$$

Thus the dew-point temperature of the air is

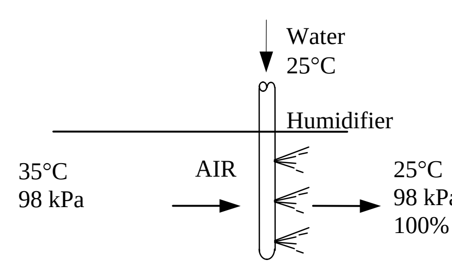
$$T_{\text{dp}} = T_{\text{sat @ }P_v} = T_{\text{sat @ 0.2268 psia}} = \mathbf{56.6°F} \qquad \text{(from EES)}$$

14-35 Atmospheric air flows steadily into an adiabatic saturation device and leaves as a saturated vapor. The relative humidity and specific humidity of air are to be determined.

Assumptions **1** This is a steady-flow process and thus the mass flow rate of dry air remains constant during the entire process $(\dot{m}_{a1} = \dot{m}_{a2} = \dot{m}_a)$. **2** Dry air and water vapor are ideal gases. **3** The kinetic and potential energy changes are negligible.

Analysis The exit state of the air is completely specified, and the total pressure is 98 kPa. The properties of the moist air at the exit state may be determined from EES to be

$$h_2 = 78.11\text{ kJ/kg dry air}$$
$$\omega_2 = 0.02079\text{ kg H}_2\text{O/kg dry air}$$



The enthalpy of makeup water is

$$h_{w2} = h_{f@\,25°\text{C}} = 104.83\text{ kJ/kg} \qquad \text{(Table A-4)}$$

An energy balance on the control volume gives

$$h_1 + (\omega_2 - \omega_1)h_w = h_2$$
$$h_1 + (0.02079 - \omega_1)(104.83\text{ kJ/kg}) = 78.11\text{ kJ/kg}$$

Pressure and temperature are known for inlet air. Other properties may be determined from this equation using EES. A hand solution would require a trial-error approach. The results are

$$h_1 = 77.66\text{ kJ/kg dry air}$$
$$\omega_1 = \mathbf{0.01654\ kg\ H_2O/kg\ dry\ air}$$
$$\phi_1 = \mathbf{0.4511}$$

Psychrometric Chart

14-36C They are very nearly parallel to each other.

14-37C The saturation states (located on the saturation curve).

14-38C By drawing a horizontal line until it intersects with the saturation curve. The corresponding temperature is the dew-point temperature.

14-39C No, they cannot. The enthalpy of moist air depends on ω, which depends on the total pressure.

14-40 [*Also solved by EES on enclosed CD*] The pressure, temperature, and relative humidity of air in a room are specified. Using the psychrometric chart, the specific humidity, the enthalpy, the wet-bulb temperature, the dew-point temperature, and the specific volume of the air are to be determined.

Analysis From the psychrometric chart (Fig. A-31) we read

(*a*) $\omega = 0.0181\,\text{kg H}_2\text{O / kg dry air}$

(*b*) $h = 78.4\ \text{kJ / kg dry air}$

(*c*) $T_{wb} = 25.5°\text{C}$

(*d*) $T_{dp} = 23.3°\text{C}$

(*e*) $v = 0.890\,\text{m}^3\text{ / kg dry air}$

14-41 EES Problem 14-40 is reconsidered. The required properties are to be determined using EES. Also, the properties are to be obtained at an altitude of 1500 m.

Analysis The problem is solved using EES, and the solution is given below.

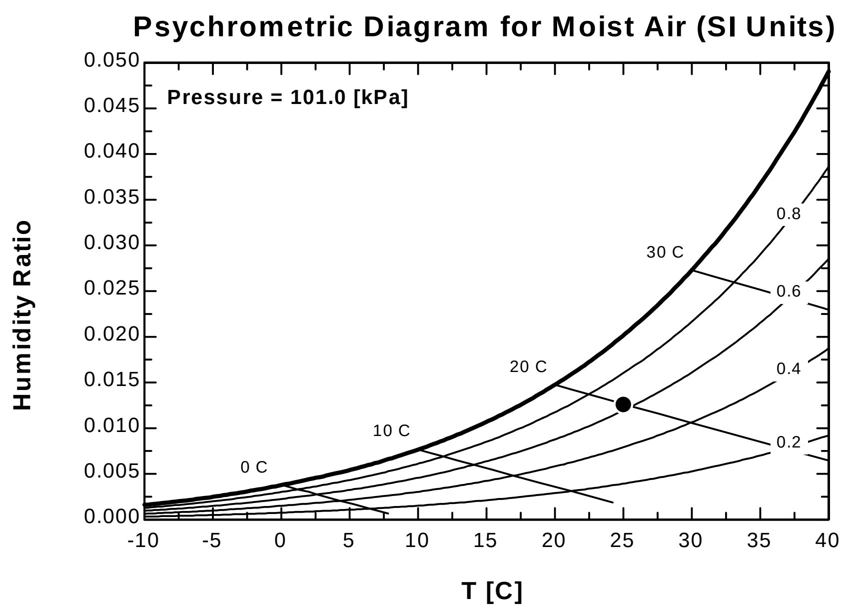
```
Tdb=32 [C]
Rh=0.60
P1=101.325 [kPa]
Z = 1500 [m]
P2=101.325*(1-0.02256*Z*convert(m,km))^5.256  "Relation giving P as a function of altitude"

    h1=enthalpy(AirH2O,T=Tdb,P=P1,R=Rh)
    v1=volume(AirH2O,T=Tdb,P=P1,R=Rh)
    Tdp1=dewpoint(AirH2O,T=Tdb,P=P1,R=Rh)
    w1=humrat(AirH2O,T=Tdb,P=P1,R=Rh)
    Twb1=wetbulb(AirH2O,T=Tdb,P=P1,R=Rh)

    h2=enthalpy(AirH2O,T=Tdb,P=P2,R=Rh)
    v2=volume(AirH2O,T=Tdb,P=P2,R=Rh)
    Tdp2=dewpoint(AirH2O,T=Tdb,P=P2,R=Rh)
    w2=humrat(AirH2O,T=Tdb,P=P2,R=Rh)
    Twb2=wetbulb(AirH2O,T=Tdb,P=P2,R=Rh)
```

SOLUTION

h1=78.37 [kJ/kg]
h2=87.85 [kJ/kg]
P1=101.3 [kPa]
P2=84.55 [kPa]
Rh=0.6
Tdb=32 [C]
Tdp1=23.26 [C]
Tdp2=23.26 [C]
Twb1=25.55 [C]
Twb2=25.27 [C]
v1=0.8895 [m^3/kg]
v2=1.072 [m^3/kg]
w1=0.01804 [kg/kg]
w2=0.02174 [kg/kg]
Z=1500 [m]



14-42 The pressure, temperature, and relative humidity of air in a room are specified. Using the psychrometric chart, the specific humidity, the enthalpy, the wet-bulb temperature, the dew-point temperature, and the specific volume of the air are to be determined.

Analysis From the psychrometric chart (Fig. A-31) we read

(*a*) $\omega = 0.0148 \text{ kg H}_2\text{O / kg dry air}$

(*b*) $h = 63.9 \text{ kJ / kg dry air}$

(*c*) $T_{\text{wb}} = 21.9°\text{C}$

(*d*) $T_{\text{dp}} = 20.1°\text{C}$

(*e*) $\boldsymbol{v} = 0.868 \text{ m}^3\text{ / kg dry air}$

14-43 EES Problem 14-42 is reconsidered. The required properties are to be determined using EES. Also, the properties are to be obtained at an altitude of 2000 m.

Analysis The problem is solved using EES, and the solution is given below.

```
Tdb=26 [C]
Rh=0.70
P1=101.325 [kPa]
Z = 2000 [m]
P2=101.325*(1-0.02256*Z*convert(m,km))^5.256  "Relation giving P as a function of altitude"

      h1=enthalpy(AirH2O,T=Tdb,P=P1,R=Rh)
      v1=volume(AirH2O,T=Tdb,P=P1,R=Rh)
      Tdp1=dewpoint(AirH2O,T=Tdb,P=P1,R=Rh)
      w1=humrat(AirH2O,T=Tdb,P=P1,R=Rh)
      Twb1=wetbulb(AirH2O,T=Tdb,P=P1,R=Rh)

      h2=enthalpy(AirH2O,T=Tdb,P=P2,R=Rh)
      v2=volume(AirH2O,T=Tdb,P=P2,R=Rh)
      Tdp2=dewpoint(AirH2O,T=Tdb,P=P2,R=Rh)
      w2=humrat(AirH2O,T=Tdb,P=P2,R=Rh)
      Twb2=wetbulb(AirH2O,T=Tdb,P=P2,R=Rh)
```

SOLUTION

h1=63.88 [kJ/kg]	h2=74.55 [kJ/kg]
P1=101.3 [kPa]	P2=79.49 [kPa]
Rh=0.7	Tdb=26 [C]
Tdp1=20.11 [C]	Tdp2=20.11 [C]
Twb1=21.87 [C]	Twb2=21.59 [C]
v1=0.8676 [m^3/kg]	v2=1.113 [m^3/kg]
w1=0.0148 [kg/kg]	w2=0.01899 [kg/kg]
Z=2000 [m]	

14-44E The pressure, temperature, and relative humidity of air in a room are specified. Using the psychrometric chart, the specific humidity, the enthalpy, the wet-bulb temperature, the dew-point temperature, and the specific volume of the air are to be determined.

Analysis From the psychrometric chart (Fig. A-31) we read

(*a*) $\omega = 0.0165 \text{ lbm H}_2\text{O / lbm dry air}$

(*b*) $h = 37.8 \text{ Btu / lbm dry air}$

(*c*) $T_{\text{wb}} = 74.3°\text{F}$

(*d*) $T_{\text{dp}} = 71.3°\text{F}$

(*e*) $\boldsymbol{v} = 14.0 \text{ ft}^3 \text{ / lbm dry air}$

14-45E EES Problem 14-44E is reconsidered. The required properties are to be determined using EES. Also, the properties are to be obtained at an altitude of 5000 ft.

Analysis The problem is solved using EES, and the solution is given below.

```
Tdb=82 [F]
Rh=0.70
P1=14.696 [psia]
Z = 5000 [ft]
Zeqv=Z*convert(ft,m)
P2=101.325*(1-0.02256*Zeqv/1000)^5.256*convert(kPa,psia)
"Relation giving P as a function of altitude"

    h1=enthalpy(AirH2O,T=Tdb,P=P1,R=Rh)
    v1=volume(AirH2O,T=Tdb,P=P1,R=Rh)
    Tdp1=dewpoint(AirH2O,T=Tdb,P=P1,R=Rh)
    w1=humrat(AirH2O,T=Tdb,P=P1,R=Rh)
    Twb1=wetbulb(AirH2O,T=Tdb,P=P1,R=Rh)

    h2=enthalpy(AirH2O,T=Tdb,P=P2,R=Rh)
    v2=volume(AirH2O,T=Tdb,P=P2,R=Rh)
    Tdp2=dewpoint(AirH2O,T=Tdb,P=P2,R=Rh)
    w2=humrat(AirH2O,T=Tdb,P=P2,R=Rh)
    Twb2=wetbulb(AirH2O,T=Tdb,P=P2,R=Rh)
```

SOLUTION

h1=37.78 [Btu/lbm]	h2=41.54 [Btu/lbm]
P1=14.7 [psia]	P2=12.23 [psia]
Rh=0.7	Tdb=82 [F]
Tdp1=71.25 [F]	Tdp2=71.25 [F]
Twb1=74.27 [F]	Twb2=73.89 [F]
v1=14.02 [ft^3/lbm]	v2=16.94 [ft^3/lbm]
w1=0.01647 [lbm/lbm]	w2=0.0199 [lbm/lbm]
Z=5000 [ft]	Zeqv=1524 [m]

14-46 The pressure and the dry- and wet-bulb temperatures of air in a room are specified. Using the psychrometric chart, the specific humidity, the enthalpy, the relative humidity, the dew-point temperature, and the specific volume of the air are to be determined.

Analysis From the psychrometric chart (Fig. A-31) we read

(*a*) $\omega = 0.0092 \text{ kg H}_2\text{O / kg dry air}$

(*b*) $h = 47.6 \text{ kJ / kg dry air}$

(*c*) $\phi = 49.6\%$

(*d*) $T_{\text{dp}} = 12.8°\text{C}$

(*e*) $v = 0.855 \text{ m}^3 \text{/ kg dry air}$

14-47 EES Problem 14-46 is reconsidered. The required properties are to be determined using EES. Also, the properties are to be obtained at an altitude of 3000 m.

Analysis The problem is solved using EES, and the solution is given below.

```
Tdb=24 [C]
Twb=17 [C]
P1=101.325 [kPa]
Z = 3000 [m]
P2=101.325*(1-0.02256*Z*convert(m,km))^5.256  "Relation giving P as function of altitude"

    h1=enthalpy(AirH2O,T=Tdb,P=P1,B=Twb)
    v1=volume(AirH2O,T=Tdb,P=P1,B=Twb)
    Tdp1=dewpoint(AirH2O,T=Tdb,P=P1,B=Twb)
    w1=humrat(AirH2O,T=Tdb,P=P1,B=Twb)
    Rh1=relhum(AirH2O,T=Tdb,P=P1,B=Twb)

    h2=enthalpy(AirH2O,T=Tdb,P=P2,B=Twb)
    v2=volume(AirH2O,T=Tdb,P=P2,B=Twb)
    Tdp2=dewpoint(AirH2O,T=Tdb,P=P2,B=Twb)
    w2=humrat(AirH2O,T=Tdb,P=P2,B=Twb)
    Rh2=relhum(AirH2O,T=Tdb,P=P2,B=Twb)
```

SOLUTION

```
h1=47.61 [kJ/kg]        h2=61.68 [kJ/kg]
P1=101.3 [kPa]          P2=70.11 [kPa]
Rh1=0.4956              Rh2=0.5438
Tdb=24 [C]              Tdp1=12.81 [C]
Tdp2=14.24 [C]          Twb=17 [C]
v1=0.8542 [m^3/kg]      v2=1.245 [m^3/kg]
w1=0.009219 [kg/kg]     w2=0.01475 [kg/kg]
Z=3000 [m]
```

Human Comfort and Air-Conditioning

14-48C It humidifies, dehumidifies, cleans and even deodorizes the air.

14-49C (*a*) Perspires more, (*b*) cuts the blood circulation near the skin, and (*c*) sweats excessively.

14-50C It is the direct heat exchange between the body and the surrounding surfaces. It can make a person feel chilly in winter, and hot in summer.

14-51C It affects by removing the warm, moist air that builds up around the body and replacing it with fresh air.

14-52C The spectators. Because they have a lower level of activity, and thus a lower level of heat generation within their bodies.

14-53C Because they have a large skin area to volume ratio. That is, they have a smaller volume to generate heat but a larger area to lose it from.

14-54C It affects a body's ability to perspire, and thus the amount of heat a body can dissipate through evaporation.

14-55C Humidification is to add moisture into an environment, dehumidification is to remove it.

14-56C The metabolism refers to the burning of foods such as carbohydrates, fat, and protein in order to perform the necessary bodily functions. The metabolic rate for an average man ranges from 108 W while reading, writing, typing, or listening to a lecture in a classroom in a seated position to 1250 W at age 20 (730 at age 70) during strenuous exercise. The corresponding rates for women are about 30 percent lower. Maximum metabolic rates of trained athletes can exceed 2000 W. We are interested in metabolic rate of the occupants of a building when we deal with heating and air conditioning because the metabolic rate represents the rate at which a body generates heat and dissipates it to the room. This body heat contributes to the heating in winter, but it adds to the cooling load of the building in summer.

14-57C The metabolic rate is proportional to the size of the body, and the metabolic rate of women, in general, is lower than that of men because of their smaller size. Clothing serves as insulation, and the thicker the clothing, the lower the environmental temperature that feels comfortable.

14-58C Sensible heat is the energy associated with a temperature change. The sensible heat loss from a human body increases as (*a*) the skin temperature increases, (*b*) the environment temperature decreases, and (*c*) the air motion (and thus the convection heat transfer coefficient) increases.

14-59C Latent heat is the energy released as water vapor condenses on cold surfaces, or the energy absorbed from a warm surface as liquid water evaporates. The latent heat loss from a human body increases as (*a*) the skin wetness increases and (*b*) the relative humidity of the environment decreases. The rate of evaporation from the body is related to the rate of latent heat loss by $\dot{Q}_{\text{latent}} = \dot{m}_{\text{vapor}} h_{fg}$ where h_{fg} is the latent heat of vaporization of water at the skin temperature.

14-60 An average person produces 0.25 kg of moisture while taking a shower. The contribution of showers of a family of four to the latent heat load of the air-conditioner per day is to be determined.

Assumptions All the water vapor from the shower is condensed by the air-conditioning system.

Properties The latent heat of vaporization of water is given to be 2450 kJ/kg.

Analysis The amount of moisture produced per day is

$$\begin{aligned}\dot{m}_{\text{vapor}} &= (\text{Moisture produced per person})(\text{No. of persons}) \\ &= (0.25\ \text{kg / person})(4\ \text{persons / day}) = 1\ \text{kg / day}\end{aligned}$$

Then the latent heat load due to showers becomes

$$\dot{Q}_{\text{latent}} = \dot{m}_{\text{vapor}} h_{fg} = (1\ \text{kg / day})(2450\ \text{kJ / kg}) = \mathbf{2450\ kJ / day}$$

14-61 There are 100 chickens in a breeding room. The rate of total heat generation and the rate of moisture production in the room are to be determined.

Assumptions All the moisture from the chickens is condensed by the air-conditioning system.

Properties The latent heat of vaporization of water is given to be 2430 kJ/kg. The average metabolic rate of chicken during normal activity is 10.2 W (3.78 W sensible and 6.42 W latent).

Analysis The total rate of heat generation of the chickens in the breeding room is

$$\dot{Q}_{\text{gen, total}} = \dot{q}_{\text{gen, total}}(\text{No. of chickens}) = (10.2\ \text{W / chicken})(100\ \text{chickens}) = \mathbf{1020\ W}$$

The latent heat generated by the chicken and the rate of moisture production are

$$\begin{aligned}\dot{Q}_{\text{gen, latent}} &= \dot{q}_{\text{gen, latent}}(\text{No. of chickens}) \\ &= (6.42\ \text{W/chicken})(100\ \text{chickens}) = 642\ \text{W} \\ &= 0.642\ \text{kW}\end{aligned}$$

$$\dot{m}_{\text{moisture}} = \frac{\dot{Q}_{\text{gen, latent}}}{h_{fg}} = \frac{0.642\ \text{kJ / s}}{2430\ \text{kJ / kg}} = 0.000264\ \text{kg / s} = \mathbf{0.264\ g / s}$$

14-62 A department store expects to have a specified number of people at peak times in summer. The contribution of people to the sensible, latent, and total cooling load of the store is to be determined.

Assumptions There is a mix of men, women, and children in the classroom.

Properties The average rate of heat generation from people doing light work is 115 W, and 70% of is in sensible form (see Sec. 14-6).

Analysis The contribution of people to the sensible, latent, and total cooling load of the store are

$$\dot{Q}_{\text{people, total}} = (\text{No. of people}) \times \dot{Q}_{\text{person, total}} = 135 \times (115\ \text{W}) = \mathbf{15{,}525\ W}$$

$$\dot{Q}_{\text{people, sensible}} = (\text{No. of people}) \times \dot{Q}_{\text{person, sensible}} = 135 \times (0.7 \times 115\ \text{W}) = \mathbf{10{,}868\ W}$$

$$\dot{Q}_{\text{people, latent}} = (\text{No. of people}) \times \dot{Q}_{\text{person, latent}} = 135 \times (0.3 \times 115\ \text{W}) = \mathbf{4658\ W}$$

14-63E There are a specified number of people in a movie theater in winter. It is to be determined if the theater needs to be heated or cooled.

Assumptions There is a mix of men, women, and children in the classroom.

Properties The average rate of heat generation from people in a movie theater is 105 W, and 70 W of it is in sensible form and 35 W in latent form.

Analysis Noting that only the sensible heat from a person contributes to the heating load of a building, the contribution of people to the heating of the building is

$$\dot{Q}_{\text{people, sensible}} = (\text{No. of people}) \times \dot{Q}_{\text{person, sensible}} = 500 \times (70\text{ W}) = 35{,}000\text{ W} = \mathbf{119{,}420\ Btu/h}$$

since 1 W = 3.412 Btu/h. The building needs to be heated since the heat gain from people is less than the rate of heat loss of 130,000 Btu/h from the building.

14-64 The infiltration rate of a building is estimated to be 1.2 ACH. The sensible, latent, and total infiltration heat loads of the building at sea level are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air infiltrates at the outdoor conditions, and exfiltrates at the indoor conditions. **3** Excess moisture condenses at room temperature of 24°C. **4** The effect of water vapor on air density is negligible.

Properties The gas constant and the specific heat of air are R = 0.287 kPa.m^3/kg.K and c_p = 1.005 kJ/kg·°C (Table A-2). The heat of vaporization of water at 24°C is $h_{fg} = h_{fg\,@\,24°\text{C}} = 2444.1\text{ kJ/kg}$ (Table A-4). The properties of the ambient and room air are determined from the psychrometric chart (Fig. A-31) to be

$$\left.\begin{array}{l} T_{\text{ambient}} = 32^{\circ}\text{C} \\ \phi_{\text{ambient}} = 50\% \end{array}\right\} w_{\text{ambient}} = 0.0150\text{ kg/kg dryair}$$

$$\left.\begin{array}{l} T_{\text{room}} = 24^{\circ}\text{C} \\ \phi_{\text{room}} = 50\% \end{array}\right\} w_{\text{room}} = 0.0093\text{ kg/kg dryair}$$

Analysis Noting that the infiltration of ambient air will cause the air in the cold storage room to be changed 1.2 times every hour, the air will enter the room at a mass flow rate of

$$\rho_{\text{ambient}} = \frac{P_0}{RT_0} = \frac{101.325\text{ kPa}}{(0.287\text{ kPa.m}^3\text{/kg.K})(32+273\text{ K})} = 1.158\text{ kg/m}^3$$

$$\dot{m}_{\text{air}} = \rho_{\text{ambient}} V_{\text{room}}\text{ACH} = (1.158\text{ kg/m}^3)(20\times 13\times 3\text{ m}^3)(1.2\text{ h}^{-1}) = 1084\text{ kg/h} = 0.301\text{ kg/s}$$

Then the sensible, latent, and total infiltration heat loads of the room are determined to be

$$\dot{Q}_{\text{infiltration, sensible}} = \dot{m}_{\text{air}} c_p (T_{\text{ambient}} - T_{\text{room}}) = (0.301\text{ kg/s})(1.005\text{ kJ/kg.°C})(32-24)\text{°C} = \mathbf{2.42\ kW}$$

$$\dot{Q}_{\text{infiltration, latent}} = \dot{m}_{\text{air}} (w_{\text{ambient}} - w_{\text{room}}) h_{fg} = (0.301\text{ kg/s})(0.0150-0.0093)(2444.1\text{ kJ/kg}) = \mathbf{4.16\ kW}$$

$$\dot{Q}_{\text{infiltration, total}} = \dot{Q}_{\text{infiltration, sensible}} + \dot{Q}_{\text{infiltration, latent}} = 2.42 + 4.16 = \mathbf{6.58\ kW}$$

Discussion The specific volume of the dry air at the ambient conditions could also be determined from the psychrometric chart at ambient conditions.

14-65 The infiltration rate of a building is estimated to be 1.8 ACH. The sensible, latent, and total infiltration heat loads of the building at sea level are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air infiltrates at the outdoor conditions, and exfiltrates at the indoor conditions. **3** Excess moisture condenses at room temperature of 24°C. **4** The effect of water vapor on air density is negligible.

Properties The gas constant and the specific heat of air are R = 0.287 kPa.m^3/kg.K and c_p = 1.005 kJ/kg·°C (Table A-2). The heat of vaporization of water at 24°C is $h_{fg} = h_{fg\,@\,24°\text{C}} = 2444.1\,\text{kJ/kg}$ (Table A-4). The properties of the ambient and room air are determined from the psychrometric chart (Fig. A-31) to be

$$\left.\begin{array}{l} T_{\text{ambient}} = 32^\circ\text{C} \\ \phi_{\text{ambient}} = 50\% \end{array}\right\} w_{\text{ambient}} = 0.0150\,\text{kg/kg dryair}$$

$$\left.\begin{array}{l} T_{\text{room}} = 24^\circ\text{C} \\ \phi_{\text{room}} = 50\% \end{array}\right\} w_{\text{room}} = 0.0093\,\text{kg/kg dryair}$$

Analysis Noting that the infiltration of ambient air will cause the air in the cold storage room to be changed 1.8 times every hour, the air will enter the room at a mass flow rate of

$$\rho_{\text{ambient}} = \frac{P_0}{RT_0} = \frac{101.325\,\text{kPa}}{(0.287\,\text{kPa.m}^3\text{/kg.K})(32+273\,\text{K})} = 1.158\,\text{kg/m}^3$$

$$\dot{m}_{\text{air}} = \rho_{\text{ambient}} V_{\text{room}}\text{ACH} = (1.158\,\text{kg/m}^3)(20\times 13\times 3\,\text{m}^3)(1.8\,\text{h}^{-1}) = 1084\,\text{kg/h} = 0.4514\,\text{kg/s}$$

Then the sensible, latent, and total infiltration heat loads of the room are determined to be

$$\dot{Q}_{\text{infiltration, sensible}} = \dot{m}_{\text{air}} c_p (T_{\text{ambient}} - T_{\text{room}}) = (0.4514\,\text{kg/s})(1.005\,\text{kJ/kg.°C})(32-24)\text{°C} = \mathbf{3.63\,kW}$$

$$\dot{Q}_{\text{infiltration, latent}} = \dot{m}_{\text{air}} (w_{\text{ambient}} - w_{\text{room}}) h_{fg} = (0.4514\,\text{kg/s})(0.0150-0.0093)(2444.1\,\text{kJ/kg}) = \mathbf{6.24\,kW}$$

$$\dot{Q}_{\text{infiltration, total}} = \dot{Q}_{\text{infiltration, sensible}} + \dot{Q}_{\text{infiltration, latent}} = 3.63 + 6.24 = \mathbf{9.87\,kW}$$

Discussion The specific volume of the dry air at the ambient conditions could also be determined from the psychrometric chart at ambient conditions.

Simple Heating and cooling

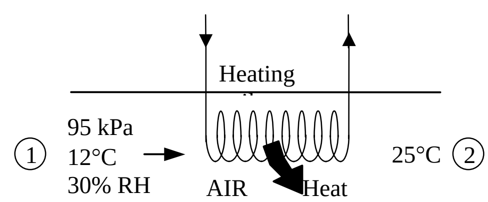
14-66C Relative humidity decreases during a simple heating process and increases during a simple cooling process. Specific humidity, on the other hand, remains constant in both cases.

14-67C Because a horizontal line on the psychrometric chart represents a ω = constant process, and the moisture content ω of air remains constant during these processes.

14-68 Air enters a heating section at a specified state and relative humidity. The rate of heat transfer in the heating section and the relative humidity of the air at the exit are to be determined.

Assumptions **1** This is a steady-flow process and thus the mass flow rate of dry air remains constant during the entire process. **2** Dry air and water vapor are ideal gases. **3** The kinetic and potential energy changes are negligible.

Analysis (*a*) The amount of moisture in the air remains constant ($\omega_1 = \omega_2$) as it flows through the heating section since the process involves no humidification or dehumidification. The inlet state of the air is completely specified, and the total pressure is 95 kPa. The properties of the air are determined to be



$$P_{v1} = \phi_1 P_{g1} = \phi_1 P_{\text{sat @12°C}} = (0.3)(1.403\,\text{kPa}) = 0.421\,\text{kPa}$$

$$P_{a1} = P_1 - P_{v1} = 95 - 0.421 = 94.58\,\text{kPa}$$

$$v_1 = \frac{R_a T_1}{P_{a1}} = \frac{(0.287\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(285\,\text{K})}{94.58\,\text{kPa}} = 0.8648\,\text{m}^3/\text{kg dry air}$$

$$\omega_1 = \frac{0.622\,P_{v1}}{P_1 - P_{v1}} = \frac{0.622(0.421\,\text{kPa})}{(95-0.421)\,\text{kPa}} = 0.002768\,\text{kg H}_2\text{O/kg dry air} \ (= \omega_2)$$

$$h_1 = c_p T_1 + \omega_1 h_{g1} = (1.005\,\text{kJ/kg}\cdot°\text{C})(12°\text{C}) + (0.002768)(2522.9\,\text{kJ/kg}) = 19.04\,\text{kJ/kg dry air}$$

and

$$h_2 = c_p T_2 + \omega_2 h_{g2} = (1.005\,\text{kJ/kg}\cdot°\text{C})(25°\text{C}) + (0.002768)(2546.5\,\text{kJ/kg}) = 32.17\,\text{kJ/kg dry air}$$

Also,

$$\dot{m}_{a1} = \frac{\dot{V}_1}{v_1} = \frac{6\,\text{m}^3/\text{min}}{0.8648\,\text{m}^3/\text{kg dry air}} = 6.938\,\text{kg/min}$$

Then the rate of heat transfer to the air in the heating section is determined from an energy balance on air in the heating section to be

$$\dot{Q}_{\text{in}} = \dot{m}_a(h_2 - h_1) = (6.938\,\text{kg/min})(32.17 - 19.04)\,\text{kJ/kg} = \mathbf{91.1\,kJ/min}$$

(*b*) Noting that the vapor pressure of air remains constant ($P_{v2} = P_{v1}$) during a simple heating process, the relative humidity of the air at leaving the heating section becomes

$$\phi_2 = \frac{P_{v2}}{P_{g2}} = \frac{P_{v2}}{P_{\text{sat@25°C}}} = \frac{0.421\,\text{kPa}}{3.1698\,\text{kPa}} = 0.133 \quad \text{or} \quad \mathbf{13.3\%}$$