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Chapter 29. Psychrometrics

Practice Problems

1.

A room contains air at 80°F (27°C) dry-bulb and 67°F (19°C) wet-bulb. The total pressure is 1 atm. Assuming a specific heat capacity for steam of 0.4 Btu/lbm/F, the specific heat of the room's atmosphere is

(A)

0.234 Btu/lbm-°F (0.979 kJ/kg·K)

(B)

0.237 Btu/lbm-°F (0.991 kJ/kg·K)

(C)

0.239 Btu/lbm-°F (0.999 kJ/kg·K)

(D)

0.242 Btu/lbm-°F (1.012 kJ/kg·K)

2.

1000 ft^3/min (0.5 m^3/s) of air at 50°F (10°C) dry-bulb and 95% relative humidity are mixed with 1500 ft^3/min (0.75 m^3/s) of air at 76°F (24°C) dry-bulb and 45% relative humidity. The specific humidity of the mixture is most nearly

(A)

0.008 lbm/lbm (0.008 kg/kg)

(B)

0.009 lbm/lbm (0.009 kg/kg)

(C)

0.010 lbm/lbm (0.010 kg/kg)

(D)

0.011 lbm/lbm (0.011 kg/kg)

3.

95°F (35°C) dry-bulb, 75°F (24°C) wet-bulb air passes through a cooling tower and leaves at 85°F (29°C) dry-bulb and 90% relative humidity. The change in moisture content per cubic foot (meter) of air is most nearly

(A)

1.8×10^{-4} lbm/ft^3 (2.7×10^{-3} kg/m^3)

(B)

3.3×10^{-4} lbm/ft^3 (4.5×10^{-3} kg/m^3)
(C)

6.7×10^{-4} lbm/ft^3 (9.9×10^{-3} kg/m^3)

(D)

9.2×10^{-4} lbm/ft^3 (14×10^{-3} kg/m^3)
4.

An air washer receives 1800 ft^3/min (0.85 m^3/s) of air at 70°F (21°C) and 40% relative humidity and discharges the air at 75% relative humidity. A recirculating water spray with a constant temperature of 50°F (10°C) is used. What mass of makeup water is required per minute?

(A)

0.127 lbm/min (0.00141 kg/s)

(B)

0.267 lbm/min (0.00296 kg/s)

(C)

0.374 lbm/min (0.00415 kg/s)

(D)

0.961 lbm/min (0.01067 kg/s)

5.

An air washer receives 1800 ft^3/min (0.85 m^3/s) of air. Air is received at 70°F (21°C) and 40% relative humidity and discharges at 75% relative humidity. The air washer recirculates a spray of saturated steam at atmospheric pressure. The mass of makeup water required is most nearly

(A)

0.801 lbm/min (0.0056 kg/s)

(B)

1.437 lbm/min (0.01005 kg/s)

(C)

1.907 lbm/min (0.01333 kg/s)

(D)

3.541 lbm/min (0.02476 kg/s)

6.

During performances, a theater experiences a sensible heat load of 500,000 Btu/hr (150 kW) and a moisture load of 175 lbm/hr (80 kg/h). Air enters the theater at 65°F (18°C) and 55% relative humidity and is removed when it reaches 75°F (24°C) or 60% relative humidity, whichever comes first. What is the relative humidity of the air leaving the theater?

(A)

38%
(B)

44%

(C)

58%

(D)

62%
7.

500 ft^3/min (0.25 m^3/s) of air at 80°F (27°C) dry-bulb and 70% relative humidity are removed from a room. 150 ft^3/min (0.075 m^3/s) pass through an air conditioner and leave saturated at 50°F (10°C). The remaining 350 ft^3/min (0.175 m^3/s) bypass the air conditioner and mix with the conditioned air at 1 atm. The heat load (in tons) of the air conditioner is most nearly

(A)

0.90 ton

(B)

1.3 ton

(C)

2.4 tons

(D)

2.9 tons

8.

A dehumidifier takes 5000 ft^3/min (2.36 m^3/s) of air at 95°F (35°C) dry-bulb and 70% relative humidity and discharges it at 60°F (16°C) dry-bulb and 95% relative humidity. The dehumidifier uses a wet R-12 refrigeration cycle operating between 100°F (saturated) (38°C) and 50°F (10°C). Find the quantity of heat removed from the air.

(A)

8345 Btu/min (143.0 kW)

(B)

8551 Btu/min (146.5 kW)

(C)

10,508 Btu/min (180.0 kW)

(D)

10,714 Btu/min (183.6 kW)

9.

1500 ft^3/min (0.71 m^3/s) of saturated 25 psia (170 kPa) air is heated from 200°F to 400°F (93°C to 204°C) in a constant pressure, constant moisture drying process. The heat required per unit mass of dry air is most nearly

(A)

31 Btu/lbm (71 kJ/kg)

(B)

57 Btu/lbm (130 kJ/kg)

(C)

99 Btu/lbm (230 kJ/kg)

(D)

120 Btu/lbm (280 kJ/kg)
10.

410 lbm/hr (0.052 kg/s) of dry 800°F (427°C) air pass through a scrubber to reduce particulate emissions. To protect the elastomeric seals in the scrubber, the air temperature is reduced to 350°F (177°C) by passing the air through a spray of 80°F (27°C) water. The pressure in the spray chamber is 20 psia (140 kPa). Approximately how much water is evaporated per hour?

(A)

18 lbm/hr (0.0023 kg/s)

(B)

27 lbm/hr (0.0035 kg/s)

(C)

31 lbm/hr (0.0040 kg/s)

(D)

39 lbm/hr (0.0050 kg/s)

11.

Combustion products leaving a gas turbine combustor are released at a temperature of 180°F into the atmosphere. The combustion products have a relative humidity of 20%. What is most nearly the dew point temperature of the combustion products?

(A)

110°F

(B)

120°F

(C)

130°F

(D)

140°F

Solutions

1.

Customary U.S. Solution

Locate the intersection of 80°F dry-bulb and 67°F wet-bulb on the psychrometric chart (see appendixMERM38A (also *NCEES Handbook* figure “Psychrometric Chart (U.S. Customary Units)”). Read the value of humidity and enthalpy.

$$\begin{aligned} \omega &= 0.0112 \text{ lbm moisture/lbm dry air} \\ &\quad (0.011 \text{ lbm/lbm}) \\ h &= 31.5 \text{ Btu/lbm dry air} \end{aligned}$$

c_p is gravimetrically weighted. c_p for air is 0.240 Btu/lbm-°F, and c_p for steam is approximately 0.40 Btu/lbm-°F.

$$\begin{aligned} G_{\text{air}} &= \frac{1}{1+0.0112} = 0.989 \\ G_{\text{steam}} &= \frac{0.0112}{1+0.0112} = 0.011 \\ c_{p,\text{mixture}} &= G_{\text{air}} c_{p,\text{air}} + G_{\text{steam}} c_{p,\text{steam}} \\ &= (0.989)\left(0.240 \ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right) \\ &\quad + (0.011)\left(0.40 \ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right) \\ &= 0.242 \text{ Btu/lbm-}^\circ\text{F} \end{aligned}$$

The answer is (D).

SI Solution

Locate the intersection of 27°C dry-bulb and 19°C wet-bulb on the psychrometric chart (see appendixMERM38B (also *NCEES Handbook* figure “Psychrometric Chart (SI Units)”). Read the value of humidity and enthalpy.

$$\begin{aligned} \omega &= \frac{10.5 \ \frac{\text{g}}{\text{kg dry air}}}{1000 \ \frac{\text{g}}{\text{kg}}} = 0.0105 \text{ kg/kg dry air} \\ &\quad (0.011 \text{ kg/kg}) \\ h &= 53.9 \text{ kJ/kg dry air} \end{aligned}$$

c_p is gravimetrically weighted. c_p for air is 1.0048 kJ/kg·K, and c_p for steam is approximately 1.675 kJ/kg·K.

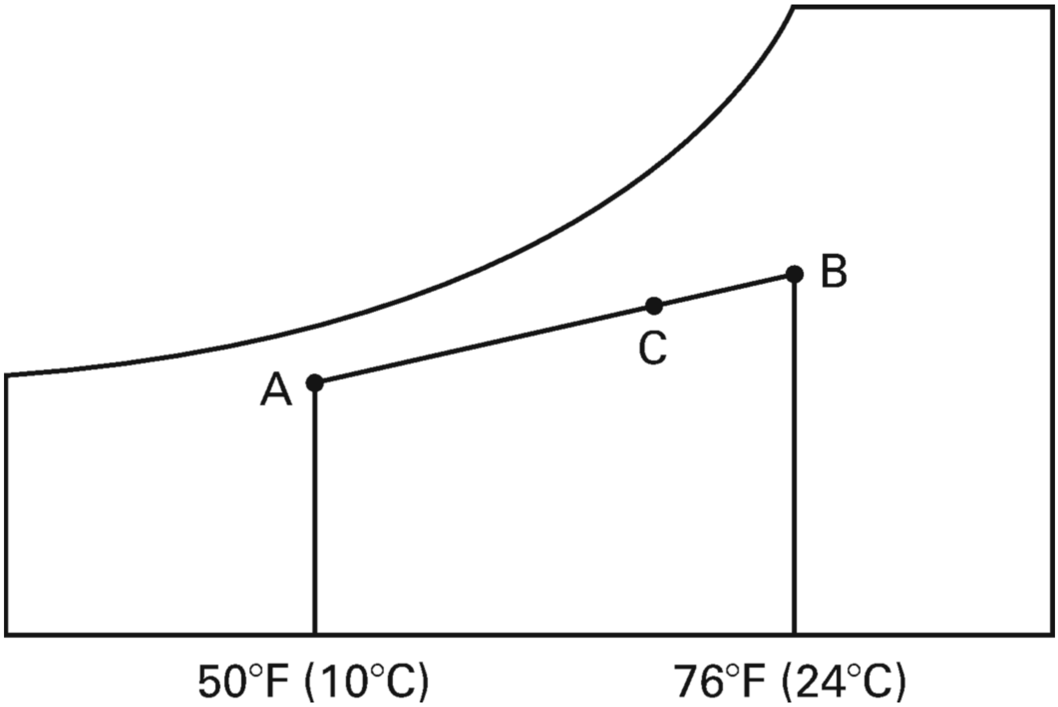
$$\begin{aligned} G_{\text{air}} &= \frac{1}{1+0.0105} = 0.990 \\ G_{\text{steam}} &= \frac{0.0105}{1+0.0105} = 0.010 \end{aligned}$$

$$\begin{aligned} c_{p,\text{mixture}} &= G_{\text{air}} c_{p,\text{air}} + G_{\text{air}} c_{p,\text{steam}} \\ &= (0.990)\left(1.0048 \ \frac{\text{kJ}}{\text{kg·K}}\right) \\ &\quad + (0.010)\left(1.675 \ \frac{\text{kJ}}{\text{kg·K}}\right) \\ &= 1.0115 \text{ kJ/kg·K} \quad (1.012 \text{ kJ/kg·K}) \end{aligned}$$

The answer is (D).

2.

Use the illustration shown for both the customary U.S. and SI solutions.



Customary U.S. Solution

Locate the two points on the psychrometric chart in appendixMERM38A (also *NCEES Handbook* figure "Psychrometric Chart (U.S. Customary Units)") and draw a line between them.

Reading from the chart (specific volumes),

$$\begin{aligned} \upsilon_A &= 13.0 \text{ ft}^3/\text{lbm} \\ \upsilon_B &= 13.7 \text{ ft}^3/\text{lbm} \end{aligned}$$

The density at each point is

$$\begin{aligned} \rho_A &= \frac{1}{\upsilon_A} = \frac{1}{13.0 \, \frac{\text{ft}^3}{\text{lbm}}} = 0.0769 \text{ lbm/ft}^3 \\ \rho_B &= \frac{1}{\upsilon_B} = \frac{1}{13.7 \, \frac{\text{ft}^3}{\text{lbm}}} = 0.0730 \text{ lbm/ft}^3 \end{aligned}$$

As in *NCEES Handbook:* Conservation of Mass, the mass flow at each point is

$$\begin{aligned} \dot{m}_A &= \rho_A \dot{V}_A = \left(0.0769 \, \frac{\text{lbm}}{\text{ft}^3}\right)\left(1000 \, \frac{\text{ft}^3}{\text{min}}\right) \\ &= 76.9 \text{ lbm/min} \\ \dot{m}_B &= \rho_B \dot{V}_B = \left(0.0730 \, \frac{\text{lbm}}{\text{ft}^3}\right)\left(1500 \, \frac{\text{ft}^3}{\text{min}}\right) \\ &= 109.5 \text{ lbm/min} \end{aligned}$$

The gravimetric fraction of flow A is

$$\frac{76.9 \, \frac{\text{lbm}}{\text{min}}}{76.9 \, \frac{\text{lbm}}{\text{min}} + 109.5 \, \frac{\text{lbm}}{\text{min}}} = 0.413$$

Since the scales are all linear,

$$\begin{aligned} 0.413 &= \frac{T_\mathrm{B} - T_\mathrm{C}}{T_\mathrm{B} - T_\mathrm{A}} \\ T_\mathrm{C} &= T_\mathrm{B} - (0.413)\left(T_\mathrm{B} - T_\mathrm{A}\right) \\ &= 76^\circ\mathrm{F} - (0.413)\left(76^\circ\mathrm{F} - 50^\circ\mathrm{F}\right) \\ &= 65.3^\circ\mathrm{F} \end{aligned}$$

$$\omega = \begin{array}{c} 0.0082 \text{ lbm moisture/lbm dry air} \\ (0.008 \text{ lbm/lbm}) \end{array}$$

The answer is (A).

SI Solution

Locate the two points on the psychrometric chart in appendixMERM38B (also *NCEES Handbook* figure "Psychrometric Chart (SI Units)"), and draw a line between them.

Reading from the chart (specific volumes),

$$\begin{aligned} \upsilon_\mathrm{A} &= 0.813 \text{ m}^3/\text{kg dry air} \\ \upsilon_\mathrm{B} &= 0.856 \text{ m}^3/\text{kg dry air} \end{aligned}$$

The density at each point is

$$\begin{aligned} \rho_\mathrm{A} &= \frac{1}{\upsilon_\mathrm{A}} = \frac{1}{0.813 \ \frac{\mathrm{m}^3}{\mathrm{kg}}} = 1.23 \text{ kg/m}^3 \\ \rho_\mathrm{B} &= \frac{1}{\upsilon_\mathrm{B}} = \frac{1}{0.856 \ \frac{\mathrm{m}^3}{\mathrm{kg}}} = 1.17 \text{ kg/m}^3 \end{aligned}$$

As in *NCEES Handbook:* Conservation of Mass, the mass flow at each point is

$$\begin{aligned} \dot{m}_\mathrm{A} &= \rho_\mathrm{A}\dot{V}_\mathrm{A} = \left(1.23 \ \frac{\mathrm{kg}}{\mathrm{m}^3}\right)\left(0.5 \ \frac{\mathrm{m}^3}{\mathrm{s}}\right) = 0.615 \text{ kg/s} \\ \dot{m}_\mathrm{B} &= \rho_\mathrm{B}\dot{V}_\mathrm{B} = \left(1.17 \ \frac{\mathrm{kg}}{\mathrm{m}^3}\right)\left(0.75 \ \frac{\mathrm{m}^3}{\mathrm{s}}\right) = 0.878 \text{ kg/s} \end{aligned}$$

The gravimetric fraction of flow A is

$$\frac{0.615 \ \frac{\mathrm{kg}}{\mathrm{s}}}{0.615 \ \frac{\mathrm{kg}}{\mathrm{s}} + 0.878 \ \frac{\mathrm{kg}}{\mathrm{s}}} = 0.412$$

Since the scales are linear,

$$\begin{aligned} 0.412 &= \frac{T_\mathrm{B} - T_\mathrm{C}}{T_\mathrm{B} - T_\mathrm{A}} \\ T_\mathrm{C} &= T_\mathrm{B} - (0.412)\left(T_\mathrm{B} - T_\mathrm{A}\right) \\ &= 24^\circ\mathrm{C} - (0.412)\left(24^\circ\mathrm{C} - 10^\circ\mathrm{C}\right) \\ &= 18.2^\circ\mathrm{C} \end{aligned}$$

$$\begin{aligned} \omega &= \frac{8.0 \ \frac{\mathrm{g}}{\text{kg dry air}}}{1000 \ \frac{\mathrm{g}}{\mathrm{kg}}} \\ &= \begin{array}{c} 0.008 \text{ kg moisture/kg dry air} \\ (0.008 \text{ kg/kg}) \end{array} \end{aligned}$$

The answer is (A).
3.

Customary U.S. Solution

Refer to the psychrometric chart (see appendixMERM38A and *NCEES Handbook* figure "Psychrometric Chart (U.S. Customary Units)").

At point 1, properties of air at $T_{db} = 95°F$ and $T_{wb} = 75°F$ are

$$\begin{aligned} \omega_1 &= 0.0141 \text{ lbm moisture/lbm air} \\ h_1 &= 38.4 \text{ Btu/lbm air} \\ v_1 &= 14.3 \text{ ft}^3\text{/lbm air} \end{aligned}$$

At point 2, properties of air at $T_{db} = 85°F$ and 90% relative humidity are

$$\begin{aligned} \omega_2 &= 0.0237 \text{ lbm moisture/lbm air} \\ h_2 &= 46.6 \text{ Btu/lbm air} \end{aligned}$$

The enthalpy change is

$$\begin{aligned} \frac{h_2 - h_1}{v_1} &= \frac{46.6 \ \frac{\text{Btu}}{\text{lbm air}} - 38.4 \ \frac{\text{Btu}}{\text{lbm air}}}{14.3 \ \frac{\text{ft}^3}{\text{lbm air}}} \\ &= 0.573 \text{ Btu/ft}^3 \text{ air} \end{aligned}$$

The moisture added is

$$\begin{aligned} \frac{\omega_2 - \omega_1}{v_1} &= \frac{\begin{array}{r} 0.0237 \ \frac{\text{lbm moisture}}{\text{lbm air}} \\ -0.0141 \ \frac{\text{lbm moisture}}{\text{lbm air}} \end{array}}{14.3 \ \frac{\text{ft}^3}{\text{lbm air}}} \\ &= \begin{array}{c} 6.71 \times 10^{-4} \text{ lbm/ft}^3 \text{ air} \\ (6.7 \times 10^{-4} \text{ lbm/ft}^3) \end{array} \end{aligned}$$

The answer is (C).

SI Solution

Refer to the psychrometric chart (see appendixMERM38B and *NCEES Handbook* figure "Psychrometric Chart (SI Units)").

At point 1, properties of air at $T_{db} = 35°C$ and $T_{wb} = 24°C$ are

$$\begin{aligned} \omega_1 &= 14.3 \text{ g/kg air} \\ h_1 &= 71.8 \text{ kJ/kg air} \\ v_1 &= 0.8893 \text{ m}^3\text{/kg air} \end{aligned}$$

At point 2, properties of air at $T_{db} = 29°C$ and 90% relative humidity are

$$\begin{aligned} \omega_2 &= 23.1 \text{ g/kg air} \\ h_2 &= 88 \text{ kJ/kg air} \end{aligned}$$

The enthalpy change is

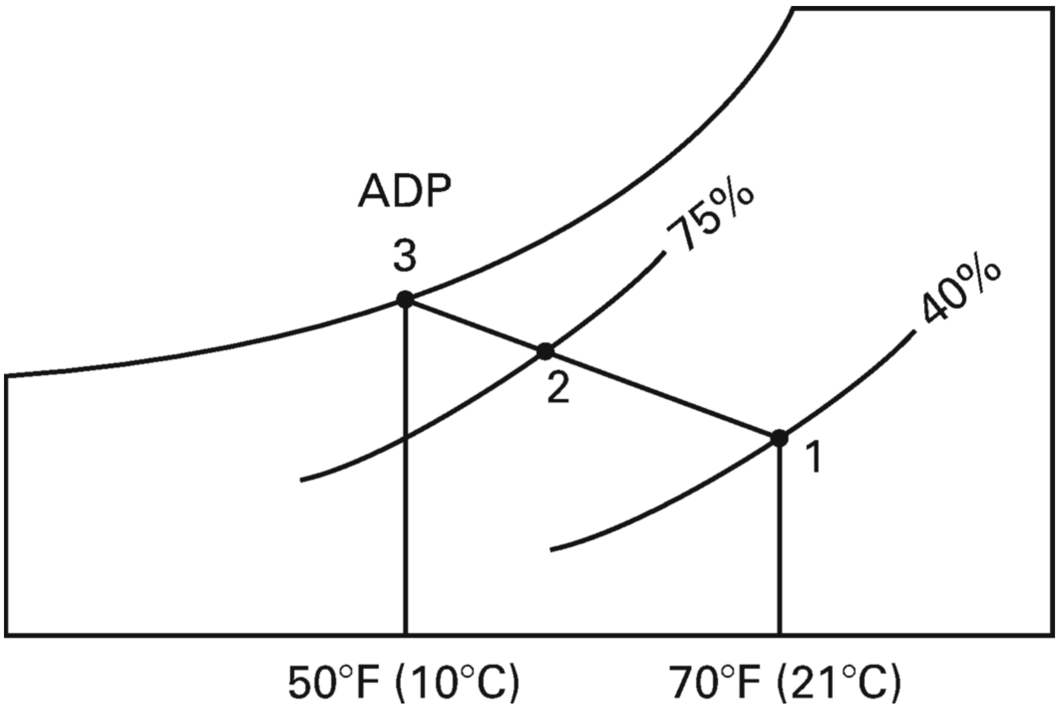
$$\frac{h_2 - h_1}{v_1} = \frac{88\ \frac{\text{kJ}}{\text{kg air}} - 71.8\ \frac{\text{kJ}}{\text{kg air}}}{0.8893\ \frac{\text{m}^3}{\text{kg air}}}$$
$$= 18.2\ \text{kJ/m}^3\ \text{air}$$

The moisture added is

$$\frac{\omega_2 - \omega_1}{v_1} = \frac{23.1\ \frac{\text{g}}{\text{kg air}} - 14.3\ \frac{\text{g}}{\text{kg air}}}{\left(0.8893\ \frac{\text{m}^3}{\text{kg air}}\right)\left(1000\ \frac{\text{g}}{\text{kg}}\right)}$$
$$= 9.9 \times 10^{-3}\ \text{kg/m}^3$$

The answer is (C).
4.

Use the illustration shown for both the customary U.S. and SI solutions.



Customary U.S. Solution

Refer to the psychrometric chart (see appendixMERM38A and *NCEES Handbook* figure "Psychrometric Chart (U.S. Customary Units)").

At point 1, properties of air at $T_{\text{db}} = 70°\text{F}$ and $\phi = 40\%$ are

$$h_1 = 23.6\ \text{Btu/lbm air}$$
$$\omega_1 = 0.00625\ \text{lbm moisture/lbm air}$$
$$v_1 = 13.48\ \text{ft}^3/\text{lbm air}$$

The mass flow rate of incoming air is

$$\dot{m}_{a,1} = \frac{\dot{V}_1}{v_1} = \frac{1800\ \frac{\text{ft}^3}{\text{min}}}{13.48\ \frac{\text{ft}^3}{\text{lbm air}}} = 133.53\ \text{lbm air/min}$$

Locate point 1 on the psychrometric chart.

Notice that the temperature of the recirculating water is constant but not equal to the air's entering wet-bulb temperature. Therefore, this is not an adiabatic process.

Locate point 3 as 50°F saturated condition (water being sprayed) on the psychrometric chart.

Draw a line from point 1 to point 3. The intersection of this line with 75% relative humidity defines point 2 as

$$\begin{aligned} h_2 &= 21.4 \text{ Btu/lbm air} \\ \omega_2 &= 0.0072 \text{ lbm moisture/lbm air} \\ T_{\text{db},2} &= 56^\circ\text{F} \\ T_{\text{wb},2} &= 51.8^\circ\text{F} \end{aligned}$$

The moisture (water) added is

$$\begin{aligned} \dot{m}_w &= \dot{m}_{a,1}(\omega_2 - \omega_1) \\ &= \left(133.53 \, \frac{\text{lbm air}}{\text{min}}\right) \\ &\quad \times \left(\begin{array}{r} 0.0072 \, \dfrac{\text{lbm moisture}}{\text{lbm air}} \\ -0.00625 \, \dfrac{\text{lbm moisture}}{\text{lbm air}} \end{array} \right) \\ &= 0.127 \text{ lbm/min} \end{aligned}$$

The answer is (A).

SI Solution

Refer to the psychrometric chart (see appendixMERM38B and *NCEES Handbook* figure "Psychrometric Chart (SI Units)").

At point 1, properties of air at $T_{\text{db}} = 21°\text{C}$ and $\phi = 40\%$ are

$$\begin{aligned} h_1 &= 36.75 \text{ kJ/kg air} \\ \omega_1 &= 6.2 \text{ g moisture/kg air} \\ v_1 &= 0.842 \text{ m}^3\text{/kg air} \end{aligned}$$

The mass flow rate of incoming air is

$$\begin{aligned} \dot{m}_{a,1} &= \frac{\dot{V}_1}{v_1} = \frac{0.85 \, \dfrac{\text{m}^3}{\text{s}}}{0.842 \, \dfrac{\text{m}^3}{\text{kg air}}} \\ &= 1.010 \text{ kg air/s} \end{aligned}$$

Locate point 1 on the psychrometric chart.

Notice that the temperature of the recirculating water is constant but not equal to the air's entering wet-bulb temperature. Therefore, this is not an adiabatic process.

Locate point 3 as 10°C saturated condition (water being sprayed) on the psychrometric chart.

Draw a line from point 1 to point 3. The intersection of this line with 75% relative humidity defines point 2 as

$$\begin{aligned} h_2 &= 34.1 \text{ kJ/kg air} \\ \omega_2 &= 7.6 \text{ g moisture/kg air} \\ T_{\text{db},2} &= 14.7^\circ\text{C} \\ T_{\text{wb},2} &= 12.0^\circ\text{C} \end{aligned}$$

The water added is

$$
\begin{aligned}
\dot{m}_w &= \dot{m}_{a,1}\left(\omega_2-\omega_1\right) \\
&= \frac{\left(1.010\ \frac{\text{kg air}}{\text{s}}\right)\left(\begin{array}{r} 7.6\ \frac{\text{g moisture}}{\text{kg air}} \\ -6.2\ \frac{\text{g moisture}}{\text{kg air}} \end{array}\right)}{1000\ \frac{\text{g}}{\text{kg}}} \\
&= 0.00141\ \text{kg/s}
\end{aligned}
$$

The answer is (A).
5.

Customary U.S. Solution

(See the SI solution for a trial-and-error solution procedure.)

From appendixMERM38A (also *NCEES Handbook* figure "Psychrometric Chart (U.S. Customary Units)"),

$$
\begin{aligned}
\omega_1 &= 0.00623\ \text{lbm moisture/lbm air} \\
h_1 &= 23.6\ \text{Btu/lbm air} \\
\dot{m}_{a,1} &= 133.53\ \text{lbm air/min}
\end{aligned}
$$

From the steam table in appendixMERM35E (also *NCEES Handbook* table "Saturated Steam (U.S. Units)—Temperature Table"), for 1 atm steam, $h_{\text{steam}} = 1150.3$ Btu/lbm.

From the conservation of energy equation,

$$
\dot{m}_{a,1}h_1+\dot{m}_{\text{steam}}h_{\text{steam}} = \dot{m}_{a,1}h_2
$$

$$
\begin{aligned}
&\left(133.53\ \frac{\text{lbm air}}{\text{min}}\right)\left(23.6\ \frac{\text{Btu}}{\text{lbm air}}\right) \\
&\quad +\dot{m}_{\text{steam}}\left(1150.3\ \frac{\text{Btu}}{\text{lbm}}\right) = \left(133.53\ \frac{\text{lbm air}}{\text{min}}\right)h_2 \quad [\text{Eq. 1}]
\end{aligned}
$$

Solve for $\dot{m}_{\text{steam}}$.

$$
\dot{m}_{\text{steam}} = 0.1161h_2-2.740 \qquad [\text{Eq. 3}]
$$

From a conservation of mass for the water,

$$
\dot{m}_{a,1}\omega_1+\dot{m}_{\text{steam}} = \dot{m}_{a,2}\omega_2
$$

$$
\begin{aligned}
&\left(133.53\ \frac{\text{lbm air}}{\text{min}}\right)\left(0.00623\ \frac{\text{lbm moisture}}{\text{lbm air}}\right) \\
&\quad +\dot{m}_{\text{steam}} = \left(133.53\ \frac{\text{lbm air}}{\text{min}}\right)\omega_2 \quad [\text{Eq. 2}]
\end{aligned}
$$

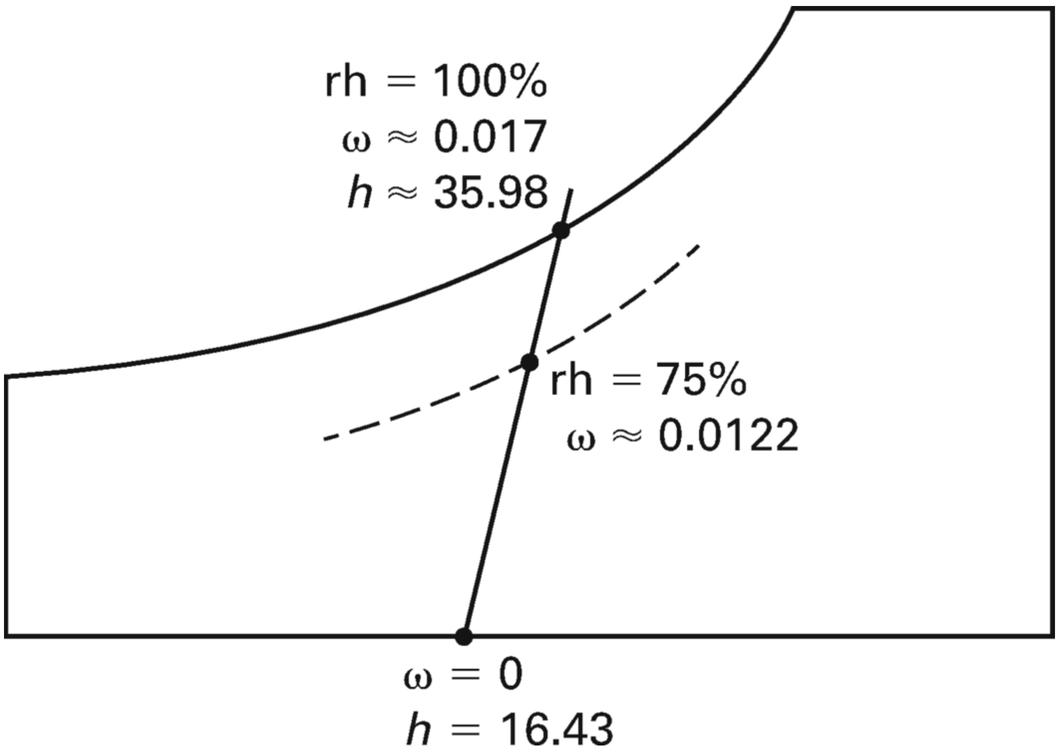
Solve for $\dot{m}_{\text{steam}}$.

$$
\dot{m}_{\text{steam}} = 133.53\omega_2-0.8319 \qquad [\text{Eq. 4}]
$$

Equate Eq. 3 and Eq. 4.

$$
\begin{aligned}
0.1161h_2-2.740 &= 133.53\omega_2-0.8319 \\
h_2 &= 1150.1\omega_2+16.43
\end{aligned}
$$

Plot this line on the psychrometric chart, and determine properties where it crosses the 75% relative humidity line.



At 75% relative humidity, from the psychrometric chart,

$$\begin{aligned}\omega_2 &= 0.0122 \text{ lbm moisture/lbm air}\\ h_2 &= 30.5 \text{ Btu/lbm}\\ T_{\text{db}} &= 72^\circ\text{F}\\ T_{\text{wb}} &= 66^\circ\text{F}\end{aligned}$$

The mass flow rate is

$$\dot{m}_{\text{steam}} = (0.1161)\left(30.5 \, \frac{\text{Btu}}{\text{lbm}}\right) - 2.740 = 0.801 \text{ lbm/min}$$

The answer is (A).

SI Solution

(See the customary U.S. solution for a graphical method.)

As in *NCEES Handbook* figure "Psychrometric Chart (SI Units),"

$$\begin{aligned}\omega_1 &= 6.2 \text{ g moisture/kg air}\\ h_1 &= 36.75 \text{ kJ/kg air}\\ \dot{m}_{a,1} &= 1.010 \text{ kg air/s}\end{aligned}$$

From the steam table in appendixMERM35F (also *NCEES Handbook* table "Saturated Steam (SI Units)—Temperature Table"), for 1 atm steam, $h_{\text{steam}} = 2675.4 \text{ kJ/kg}$.

From equationMERM38033, the conservation of energy equation,

$$\begin{aligned}\dot{m}_{a,1}h_1 + \dot{m}_{\text{steam}}h_{\text{steam}} &= \dot{m}_{a,1}h_2\\ \left(1.010 \, \frac{\text{kg air}}{\text{s}}\right)\left(36.75 \, \frac{\text{kJ}}{\text{kg air}}\right) & \\ +\dot{m}_{\text{steam}}\left(2675.4 \, \frac{\text{kJ}}{\text{kg}}\right) &= \left(1.010 \, \frac{\text{kg air}}{\text{s}}\right)h_2 \quad \text{[Eq. 1]}\end{aligned}$$

From equationMERM38034, a conservation of mass for the water,

$$\dot{m}_{a,1}\omega_1 + \dot{m}_{\text{steam}} = \dot{m}_{a,2}\omega_2$$

$$\frac{\left(1.010\ \frac{\text{kg air}}{\text{s}}\right)\left(6.2\ \frac{\text{g moisture}}{\text{kg air}}\right)}{\left(1000\ \frac{\text{kg}}{\text{g}}\right)} + \dot{m}_{\text{steam}} = \left(1.010\ \frac{\text{kg air}}{\text{s}}\right)\omega_2 \quad \text{[Eq. 2]}$$

Since no single relationship exists between ω_2, $\dot{m}_{\text{steam}}$, and h_2, a trial-and-error solution can be used. Once $\dot{m}_{\text{steam}}$ is selected, ω_2 and h_2 can be found from Eq. 1 and Eq. 2 as

$$h_2 = 36.75 + 2648.9\dot{m}_{\text{steam}}$$
$$\omega_2 = 0.0062 + 0.99\dot{m}_{\text{steam}}$$

Once h_2 and ω_2 are known, the relative humidity can be determined from the psychrometric chart. Continue the process until a relative humidity of 75% is achieved.

$\dot{m}_{\text{steam}}$ $\left(\frac{\text{kg}}{\text{s}}\right)$	ω_2 $\left(\frac{\text{kg moisture}}{\text{kg air}}\right)$	h_2 $\left(\frac{\text{kJ}}{\text{kg air}}\right)$	ϕ_2 (%)
0.005	0.0112	49.99	69.5
0.0055	0.0116	51.32	74.5
0.0056	0.0117	51.58	75.0

$$\dot{m}_{\text{steam}} = 0.0056\ \text{kg/s}$$
$$\omega_2 = \left(0.0117\ \frac{\text{kg moisture}}{\text{kg air}}\right)\left(1000\ \frac{\text{g}}{\text{kg}}\right) = 11.7\ \text{g moisture/kg air}$$
$$T_{\text{db}} = 21.3^\circ\text{C}$$
$$T_{\text{wb}} = 18.2^\circ\text{C}$$

The answer is (A).
6.

Customary U.S. Solution

From the psychrometric chart (see appendixMERM38A and *NCEES Handbook* figure "Psychrometric Chart (U.S. Customary Units)"), for incoming air at 65°F and 55% relative humidity, $\omega_1 = 0.0072$ lbm moisture/lbm air.

With sensible heating as a limiting factor, calculate the mass flow rate of air entering the theater from equationMERM38025 (ventilation rate).

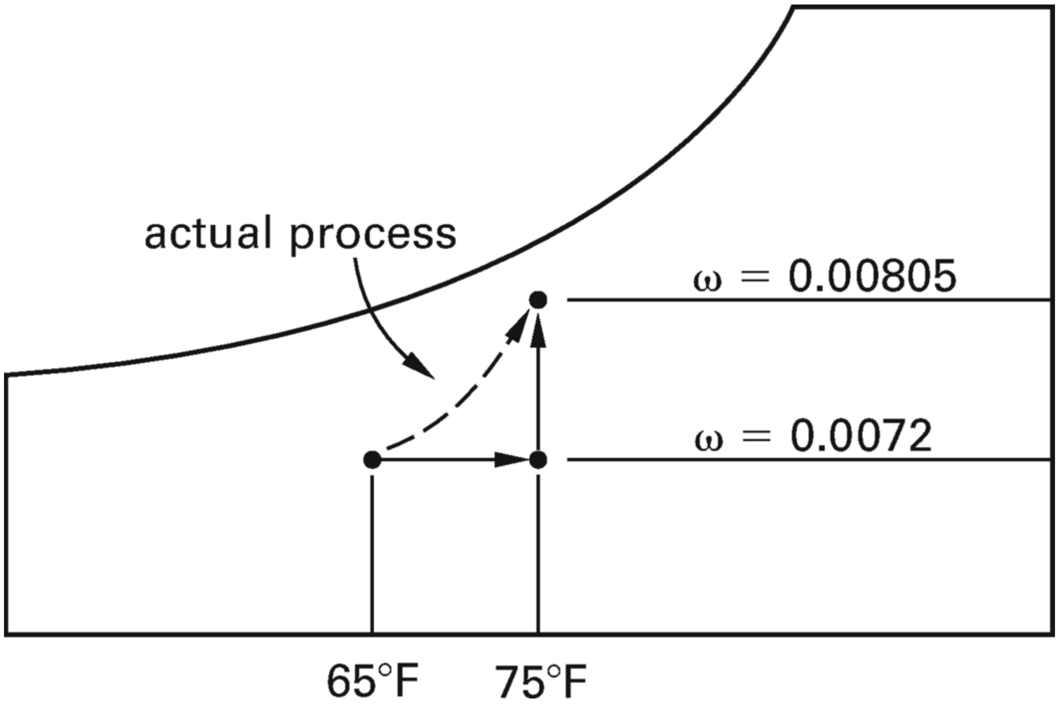
$$\dot{q} = \dot{m}_a\left(c_{p,\text{air}} + \omega c_{p,\text{moisture}}\right)(T_2 - T_1)$$

$$500{,}000\ \frac{\text{Btu}}{\text{hr}} = \dot{m}_a \times \left(\begin{array}{c} 0.240\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}} \\ +\,0.0072\ \frac{\text{lbm moisture}}{\text{lbm air}} \\ \times\left(0.444\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right)\end{array}\right) \times (75^\circ\text{F} - 65^\circ\text{F})$$

$$\dot{m}_a = 2.056 \times 10^5\ \text{lbm air/hr}$$

Assume that this air absorbs all the moisture. Then, the final humidity ratio is given by

$$
\begin{aligned}
\dot{m}_w &= \dot{m}_a\,(\omega_2 - \omega_1) \\
\omega_2 &= \left(\frac{\dot{m}_w}{\dot{m}_a}\right) + \omega_1 \\
&= \frac{175\ \dfrac{\text{lbm moisture}}{\text{hr}}}{2.056\times 10^5\ \dfrac{\text{lbm air}}{\text{hr}}} + 0.0072\ \frac{\text{lbm moisture}}{\text{lbm air}} \\
&= 0.00805\ \text{lbm moisture/lbm air}
\end{aligned}
$$



The final conditions are

$$
\begin{aligned}
T_{\text{db}} &= 75^\circ\text{F} \quad [\text{given}] \\
\omega_2 &= 0.00805\ \text{lbm moisture/lbm air}
\end{aligned}
$$

From the psychrometric chart (see appendixMERM38A and *NCEES Handbook* figure “Psychrometric Chart (U.S. Customary Units)”), the relative humidity is 44%. This is below 60%.

The answer is (B).

SI Solution

From the psychrometric chart (see appendixMERM38B and *NCEES Handbook* figure “Psychrometric Chart (SI Units)”), for incoming air at 18°C and 55% relative humidity, $\omega_1 = 7.1$ g moisture/kg air.

With sensible heating as a limiting factor, calculate the mass flow rate of air entering the theater from equationMERM38025 (ventilation rate).

$$
\begin{aligned}
\dot{q} &= \dot{m}_a\,(c_{p,\text{air}} + \omega c_{p,\text{moisture}})\,(T_2 - T_1) \\
(150\ \text{kW}) \times \left(1000\ \frac{\text{W}}{\text{kW}}\right) &= \dot{m}_a \left(\begin{array}{c} \left(1.005\ \dfrac{\text{kJ}}{\text{kg}\cdot{}^\circ\text{C}}\right)\left(1000\ \dfrac{\text{J}}{\text{kJ}}\right) \\ + \left(1.805\ \dfrac{\text{kJ}}{\text{kg}\cdot{}^\circ\text{C}}\right)\left(1000\ \dfrac{\text{J}}{\text{kJ}}\right) \\ \times \left(\dfrac{7.1\ \dfrac{\text{g moisture}}{\text{kg air}}}{1000\ \dfrac{\text{g}}{\text{kg}}}\right) \end{array}\right) \\
&\quad \times (24^\circ\text{C} - 18^\circ\text{C}) \\
\dot{m}_a &= 24.56\ \text{kg/s}
\end{aligned}
$$

Assume that this air absorbs all the moisture. Then, the final humidity ratio is given by

$$\begin{aligned}
\dot{m}_w &= \dot{m}_a\left(\omega_2 - \omega_1\right) \\
\omega_2 &= \frac{\dot{m}_w}{\dot{m}_a} + \omega_1 \\
&= \frac{80\ \frac{\text{kg}}{\text{h}}}{\left(24.56\ \frac{\text{kg}}{\text{s}}\right)\left(3600\ \frac{\text{s}}{\text{h}}\right)} + \frac{7.0\ \frac{\text{g moisture}}{\text{kg air}}}{1000\ \frac{\text{g}}{\text{kg}}} \\
&= 0.00790\ \text{kg moisture/kg air}
\end{aligned}$$

The final conditions are

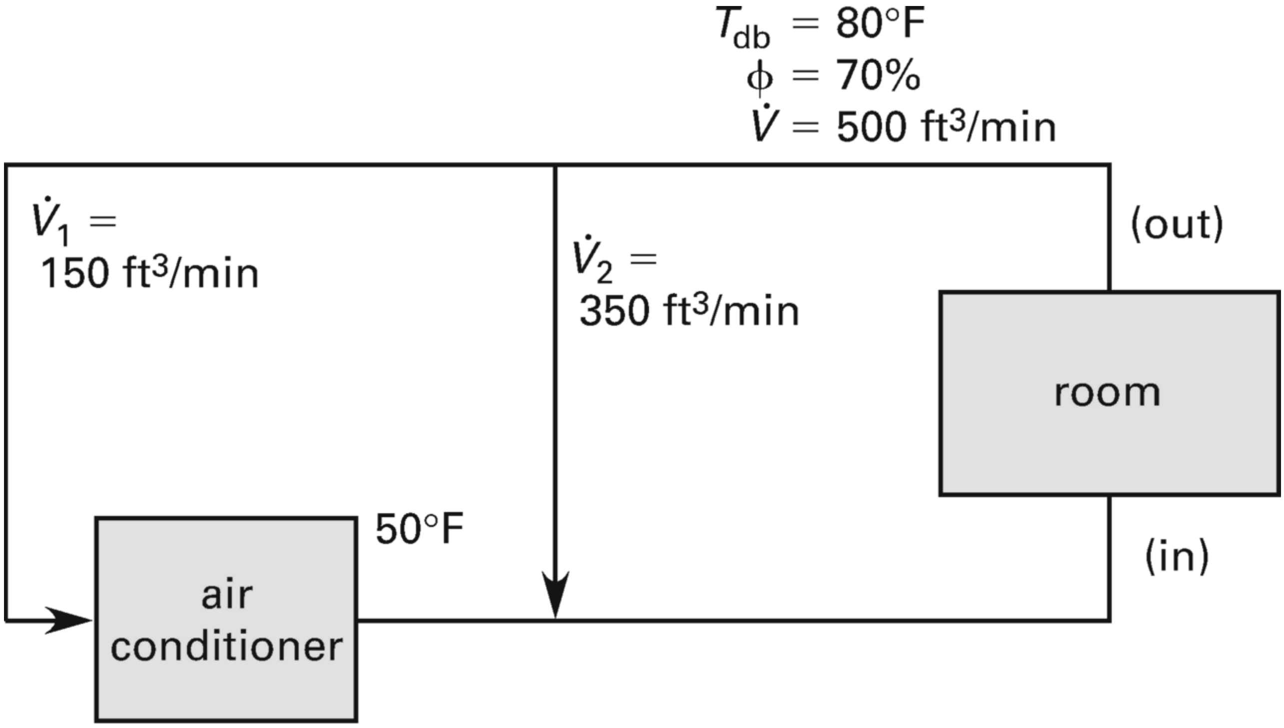
$$\begin{aligned}
T_{\text{db}} &= 24^\circ\text{C} \\
\omega_2 &= \left(0.00790\ \frac{\text{kg moisture}}{\text{kg air}}\right)\left(1000\ \frac{\text{g}}{\text{kg}}\right) \\
&= 7.9\ \text{g moisture/kg air}
\end{aligned}$$

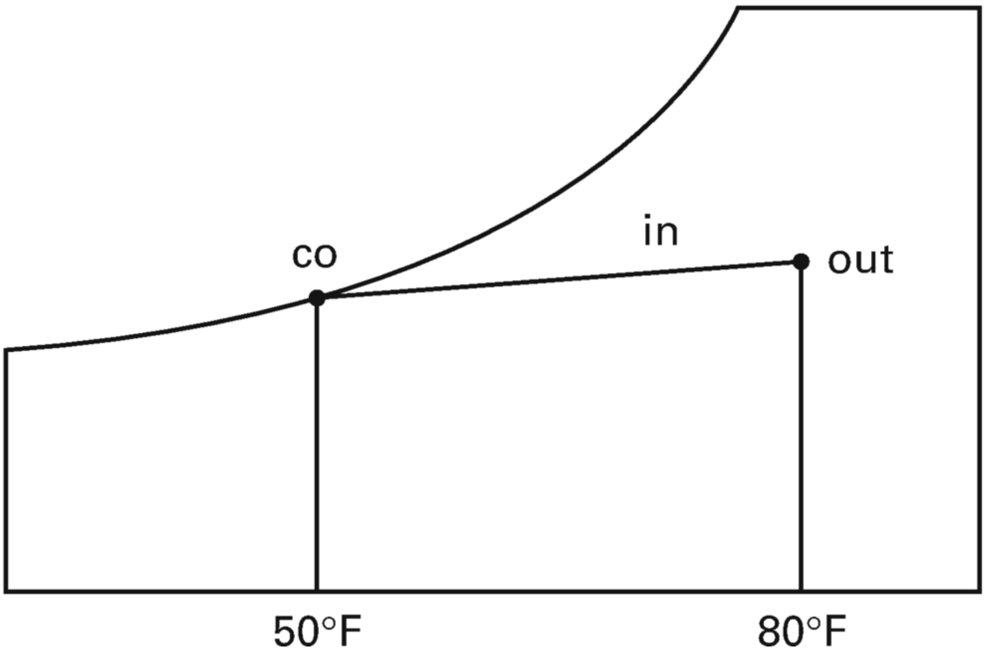
From the psychrometric chart (see *NCEES Handbook* figure “Psychrometric Chart (SI Units)”), the relative humidity is 44%. This is below 60%.

The answer is (B).

7.

Use the illustration shown for both customary U.S. and SI solutions.





Customary U.S. Solution

Locate point "out" (T_{db} = 80°F and ϕ = 70%) and point "co" (saturated at 50°F) on the psychrometric chart. At point "out" from appendixMERM38A (also *NCEES Handbook* figure "Psychrometric Chart (U.S. Customary Units)"),

$$\begin{aligned} v_{\text{out}} &= 13.95\ \text{ft}^3/\text{lbm air} \\ h_{\text{out}} &= 36.2\ \text{Btu/lbm air} \end{aligned}$$

At point "co," $h_{\text{co}} = 20.3\ \text{Btu/lbm air.}$

The air conditioner capacity is given by

$$
\begin{aligned}
\dot{Q} &= \dot{m}_{\text{air}}\left(h_{t,2}-h_{t,1}\right)=\dot{m}_1\left(h_{\text{out}}-h_{\text{co}}\right) \\
&= \left(10.75\ \frac{\text{lbm air}}{\text{min}}\right)\left(36.2\ \frac{\text{Btu}}{\text{lbm air}}-20.3\ \frac{\text{Btu}}{\text{lbm air}}\right) \\
&\quad\times\left(\frac{1\ \text{ton}}{200\ \frac{\text{Btu}}{\text{min}}}\right) \\
&= 0.85\ \text{ton} \quad (0.90\ \text{ton})
\end{aligned}
$$

The answer is (A).

SI Solution

Locate point "out" (T_{db} = 27°C, ϕ = 70%) and point "co" (saturated at 10°C) on the psychrometric chart. At point "out" from appendixMERM38B (also *NCEES Handbook* figure "Psychrometric Chart (SI Units)"),

$$
\begin{aligned}
\upsilon_{\text{out}} &= 0.872\ \text{m}^3/\text{kg air} \\
h_{\text{out}} &= 67.3\ \text{kJ}/\text{kg air}
\end{aligned}
$$

At point "co" from appendixMERM38B (also *NCEES Handbook* figure "Psychrometric Chart (SI Units)"), h_{co} = 29.26 kJ/kg air.

As in *NCEES Handbook:* Conservation of Mass, at mass flow rate through the air conditioner,

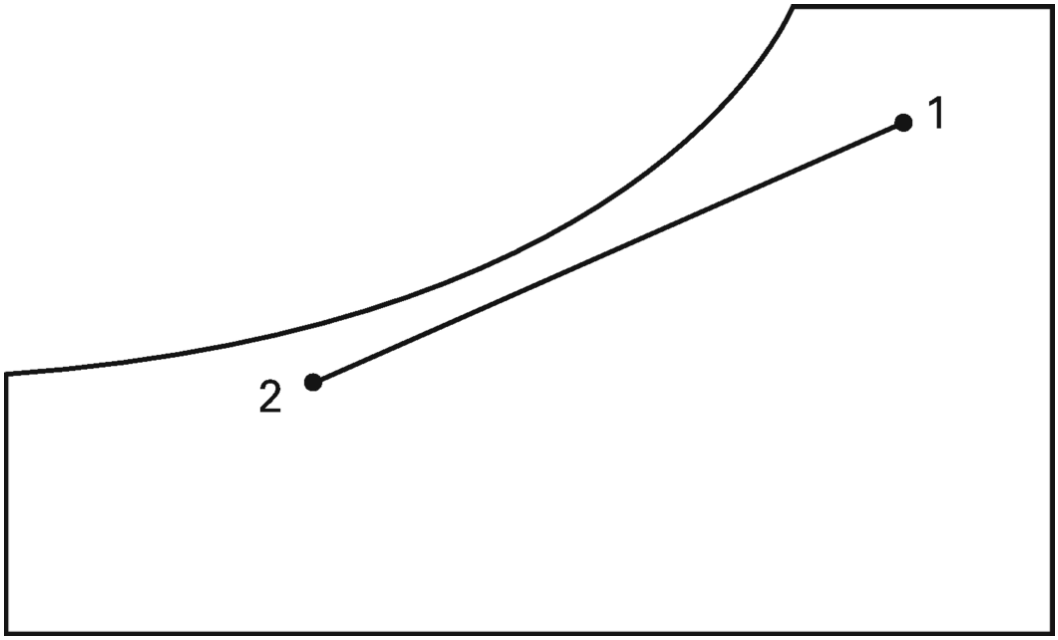
$$
\dot{m}_1=\frac{\dot{V}_1}{\upsilon}=\frac{0.075\ \frac{\text{m}^3}{\text{s}}}{0.872\ \frac{\text{m}^3}{\text{kg air}}}=0.0860\ \text{kg air}/\text{s}
$$

The air conditioner capacity is given by

$$
\begin{aligned}
\dot{Q} &= \dot{m}_{\text{air}}\left(h_{t,2}-h_{t,1}\right)=\dot{m}_1\left(h_{\text{out}}-h_{\text{co}}\right) \\
&= \left(0.0860\ \frac{\text{kg air}}{\text{s}}\right)\left(67.3\ \frac{\text{kJ}}{\text{kg air}}-29.26\ \frac{\text{kJ}}{\text{kg air}}\right) \\
&\quad\times\left(0.2843\ \frac{\text{ton}}{\text{kW}}\right) \\
&= 0.93\ \text{ton} \quad (0.90\ \text{ton})
\end{aligned}
$$

The answer is (A).
8.

Use the illustration shown for both customary U.S. and SI solutions.



Customary U.S. Solution

At point 1, from the psychrometric chart (see appendixMERM38A and *NCEES Handbook* figure "Psychrometric Chart (U.S. Customary Units)") at $T_{db} = 95°F$ and $\phi = 70\%$,

$$\begin{aligned} h_1 &= 50.7\ \text{Btu/lbm air} \\ v_1 &= 14.56\ \text{ft}^3/\text{lbm air} \\ \omega_1 &= 0.0253\ \text{lbm water/lbm air} \end{aligned}$$

At point 2, from the psychrometric chart (see appendixMERM38A and *NCEES Handbook* figure "Psychrometric Chart (U.S. Customary Units)") at $T_{db} = 60°F$ and $\phi = 95\%$,

$$\begin{aligned} h_2 &= 25.8\ \text{Btu/lbm air} \\ \omega_2 &= 0.0105\ \text{lbm water/lbm air} \end{aligned}$$

As in *NCEES Handbook:* Conservation of Mass, the air mass flow rate is

$$\dot{m}_a = \frac{\dot{V}}{v_1} = \frac{5000\ \dfrac{\text{ft}^3}{\text{min}}}{14.56\ \dfrac{\text{ft}^3}{\text{lbm air}}} = 343.4\ \text{lbm air/min}$$

From equationMERM38027, the quantity of heat removed is

$$\begin{aligned} \dot{q} &= \dot{m}_a\,(h_1 - h_2) \\ &= \left(343.4\ \frac{\text{lbm air}}{\text{min}}\right)\left(50.7\ \frac{\text{Btu}}{\text{lbm air}} - 25.8\ \frac{\text{Btu}}{\text{lbm air}}\right) \\ &= 8551\ \text{Btu/min} \end{aligned}$$

The answer is (B).

SI Solution

At point 1, from the psychrometric chart (see appendixMERM38B and *NCEES Handbook* figure "Psychrometric Chart (SI Units)") at $T_{db} = 35°C$ and $\phi = 70\%$,

$$h_1 = 99.9 \text{ kJ/kg air}$$
$$\upsilon_1 = 0.91 \text{ m}^3\text{/kg air}$$
$$\omega_1 = \frac{25.3 \frac{\text{g moisture}}{\text{kg air}}}{1000 \frac{\text{g}}{\text{kg}}} = 0.0253 \text{ kg moisture/kg air}$$

At point 2, from the psychrometric chart (see appendixMERM38B and *NCEES Handbook* figure "Psychrometric Chart (SI Units)") at $T_{\text{db}} = 16°\text{C}$ and $\phi = 95\%$,

$$h_2 = 43.4 \text{ kJ/kg air}$$
$$\omega_2 = \frac{10.8 \frac{\text{g moisture}}{\text{kg air}}}{1000 \frac{\text{g}}{\text{kg}}} = 0.0108 \text{ kg moisture/kg air}$$

As in *NCEES Handbook:* Conservation of Mass, the air mass flow rate is

$$\dot{m}_a = \frac{\dot{V}_1}{\upsilon_1} = \frac{\dot{V}_1}{\upsilon_{\text{out}}} = \frac{2.36 \frac{\text{m}^3}{\text{s}}}{0.91 \frac{\text{m}^3}{\text{kg air}}} = 2.593 \text{ kg air/s}$$

From equationMERM38027, the quantity of heat removed is

$$\begin{aligned}\dot{q} &= \dot{m}_a (h_1 - h_2) \\ &= \left(2.593 \frac{\text{kg air}}{\text{s}}\right)\left(99.9 \frac{\text{kJ}}{\text{kg air}} - 43.4 \frac{\text{kJ}}{\text{kg air}}\right) \\ &= 146.5 \text{ kW}\end{aligned}$$

The answer is (B).
9.

Customary U.S. Solution

The saturation pressure at 200°F from appendixMERM24A (also *NCEES Handbook* table "Saturated Steam (U.S. Units)—Temperature Table"), is $p_{\text{sat},1} = 11.538$ psia.

Since air is saturated (100% relative humidity), the water vapor pressure is equal to the saturation pressure.

$$p_{w,1} = p_{\text{sat},1} = 11.538 \text{ psia}$$

The partial pressure of the air is

$$\begin{aligned}p_{a,1} &= p_1 - p_{w,1} = 25 \text{ psia} - 11.538 \text{ psia} \\ &= 13.462 \text{ psia}\end{aligned}$$

Use equationMERM38007 (also *NCEES Handbook:* Air-Water Systems) to determine the humidity ratio.

$$\omega = 0.622 \left(\frac{p_{w,1}}{p_{a,1}}\right) = (0.622)\left(\frac{11.538 \text{ psia}}{13.462 \text{ psia}}\right) = 0.533$$

Since it is a constant pressure, constant moisture drying process, mole fractions and partial pressures do not change.

$$p_{w,2} = p_{w,1} = 11.538 \text{ psia}$$

The saturation pressure at 400°F from appendixMERM24A (also *NCEES Handbook* table "Saturated Steam (U.S. Units)—Temperature Table") is $p_{\text{sat},2} = 247.3$ psia.

The relative humidity at state 2 is

$$\phi_2 = \frac{p_{w,2}}{p_{\text{sat},2}} = \frac{11.538 \text{ psia}}{247.3 \text{ psia}} = 0.0467$$

Although the volume may change, the mass does not. The specific humidity remains constant.

$$\omega_2 = \omega_1 = 0.533 \text{ lbm water/lbm air}$$

The heat required consists of two parts.

As in *NCEES Handbook* table “Conversion Table for Temperature Units,” the absolute temperatures are

$$\begin{aligned} T_1 &= 200^\circ\text{F} + 460^\circ = 660^\circ\text{R} \\ T_2 &= 400^\circ\text{F} + 460^\circ = 860^\circ\text{R} \end{aligned}$$

As in *NCEES Handbook:* Temperature-Dependent Properties of Air (U.S. Customary Units), the heat capacity is 0.2424 Btu/lbm-°F. The heat absorbed by air is

$$\begin{aligned} q_1 &= h_2 - h_1 = c_p\,(T_2 - T_1) \\ &= \left(0.2424 \tfrac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right)(860^\circ\text{R} - 660^\circ\text{R}) \\ &= 48.48 \text{ Btu/lbm dry air} \end{aligned}$$

From the Mollier diagram (also *NCEES Handbook* figure “Temperature-Entropy (T-S) Diagram (U.S. Customary Units)”), for water, h_1 at 200°F and 11.529 psia is 1146 Btu/lbm (almost saturated).

Follow a constant 11.529 psia pressure curve up to 400°F.

$$h_2 = 1240 \text{ Btu/lbm}$$

The heat absorbed by the steam is

$$\begin{aligned} q_2 &= \omega\,(h_2 - h_1) \\ &= \left(0.532 \frac{\text{lbm water}}{\text{lbm air}}\right)\left(1240 \frac{\text{Btu}}{\text{lbm}} - 1146 \frac{\text{Btu}}{\text{lbm}}\right) \\ &= 50.01 \text{ Btu/lbm air} \end{aligned}$$

The total heat absorbed is

$$\begin{aligned} q_{\text{total}} &= q_1 + q_2 = 48.48 \frac{\text{Btu}}{\text{lbm air}} + 50.01 \frac{\text{Btu}}{\text{lbm air}} \\ &= 98.49 \text{ Btu/lbm air} \quad (99 \text{ Btu/lbm}) \end{aligned}$$

The answer is (C).

SI Solution

From appendixMERM24N (also *NCEES Handbook* table “Saturated Steam (SI Units)—Temperature Table”), the saturation pressure at 93°C is

$$p_{\text{sat},1} = (0.7884 \text{ bar})\left(100 \frac{\text{kPa}}{\text{bar}}\right) = 78.84 \text{ kPa}$$

Since air is saturated (100% relative humidity), water vapor pressure is equal to saturation pressure.

$$p_{w,1} = p_{\text{sat},1} = 78.84 \text{ kPa}$$

The partial pressure of air is

$$\begin{aligned} p_{a,1} &= p_1 - p_{w,1} = 170 \text{ kPa} - 78.84 \text{ kPa} \\ &= 91.16 \text{ kPa} \end{aligned}$$

Use equationMERM38007 (also *NCEES Handbook:* Air-Water Systems) to determine the humidity ratio.

$$\begin{aligned}\omega &= 0.622\left(\frac{p_{w,1}}{p_{a,1}}\right) = (0.622)\left(\frac{78.84\ \text{kPa}}{91.16\ \text{kPa}}\right)\\ &= 0.538\ \text{kg water/kg air}\end{aligned}$$

Since it is a constant pressure, constant moisture drying process, mole fractions and partial pressure do not change.

$$p_{w,2} = p_{w,1} = 78.84\ \text{kPa}$$

The saturation pressure at 204°C from appendixMERM24N (also *NCEES Handbook* table "Saturated Steam (SI Units)") is

$$p_{\text{sat},2} = (16.90\ \text{bar})\left(100\ \frac{\text{kPa}}{\text{bar}}\right) = 1690\ \text{kPa}$$

The relative humidity at state 2 is

$$\phi_2 = \frac{p_{w,2}}{p_{\text{sat},2}} = \frac{78.84\ \text{kPa}}{1690\ \text{kPa}} = 0.0467$$

Although the volume may change, the mass does not. The specific humidity remains constant.

$$\omega_2 = \omega_1 = 0.538\ \text{kg water/kg air}$$

The heat required consists of two parts.

The absolute temperatures are

$$\begin{aligned}T_1 &= 93^\circ\text{C} + 273^\circ = 366\text{K}\\ T_2 &= 204^\circ\text{C} + 273^\circ = 477\text{K}\end{aligned}$$

As in *NCEES Handbook:* Temperature-Dependent Properties of Air (SI Units), the heat capacity is 1.013 kJ/kg·K. The heat absorbed by air is

$$\begin{aligned}q_1 &= h_2 - h_1 = c_p\,(T_2 - T_1)\\ &= \left(1.013\ \tfrac{\text{kJ}}{\text{kg}\cdot\text{K}}\right)(477\text{K} - 366\text{K})\\ &= 112.44\ \text{kJ/kg}\end{aligned}$$

For water, h_1 at 93°C and 78.79 kPa is 2670 kJ/kg (almost saturated).

Follow a constant 78.79 kPa pressure curve up to 204°C.

$$h_2 = 2890\ \text{kJ/kg}$$

The heat absorbed by steam is

$$\begin{aligned}q_2 &= \omega\,(h_2 - h_1)\\ &= \left(0.537\ \frac{\text{kg water}}{\text{kg air}}\right)\left(2890\ \frac{\text{kJ}}{\text{kg}} - 2670\ \frac{\text{kJ}}{\text{kg}}\right)\\ &= 118.14\ \text{kJ/kg air}\end{aligned}$$

The total heat absorbed is

$$\begin{aligned}q_{\text{total}} &= q_1 + q_2 = 112.44\ \frac{\text{kJ}}{\text{kg air}} + 118.14\ \frac{\text{kJ}}{\text{kg air}}\\ &= 230.58\ \text{kJ/kg air}\quad (230\ \text{kJ/kg})\end{aligned}$$

The answer is (C).
10.

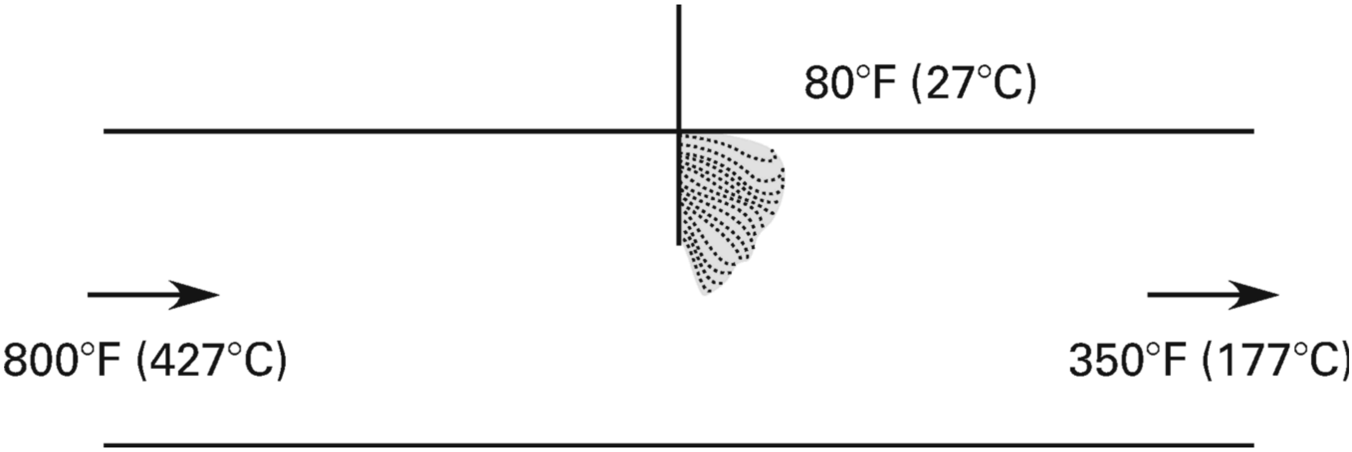
Customary U.S. Solution

As in *NCEES Handbook:* Temperature, the absolute air temperatures are

$$T_1 = 800^\circ\text{F} + 460^\circ = 1260^\circ\text{R}$$
$$T_2 = 350^\circ\text{F} + 460^\circ = 810^\circ\text{R}$$

From appendixMERM24A (also *NCEES Handbook* table "Physical Properties of Liquid Water (U.S. Units)"), the enthalpy of water at 80°F is $h_{w,1} = 48.07\ \text{Btu/lbm}\ \ (48\ \text{Btu/lbm})$.

From equationMERM38019(b) (also *NCEES Handbook:* Superheated Steam (U.S. Customary Units)), the enthalpy of steam at 350°F is 1216.4 Btu/lbm.



Air temperature is reduced from 800°F to 350°F, and this energy is used to change water at 80°F to steam at 350°F. From the energy balance equation,

$$\dot{m}_w\left(h_{w,2} - h_{w,1}\right) = \dot{m}_a\left(h_1 - h_2\right)$$
$$\dot{m} = \frac{\dot{m}_a\left(h_1 - h_2\right)}{h_{w,2} - h_{w,1}} = \frac{\dot{m}_a c_p (T_1 - T_2)}{h_{w,2} - h_{w,1}}$$
$$= \frac{\left(410\ \frac{\text{lbm}}{\text{hr}}\right)\left(0.25\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right) \times (1260^\circ\text{R} - 810^\circ\text{R})}{1216.4\ \frac{\text{Btu}}{\text{lbm}} - 48.07\ \frac{\text{Btu}}{\text{lbm}}}$$
$$= 39.4\ \text{lbm/hr water} \quad (39\ \text{lbm/hr})$$

The answer is (D).

SI Solution

As in *NCEES Handbook:* Temperature, the absolute temperatures are

$$T_1 = 427^\circ\text{C} + 273^\circ = 700\text{K}$$
$$T_2 = 177^\circ\text{C} + 273^\circ = 450\text{K}$$

From appendixMERM24N (also *NCEES Handbook* table "Physical Properties of Liquid Water (SI Units)"), the enthalpy of water at 27°C is $h_{w,1} = 113.19\ \text{kJ/kg}\ (113\ \text{kJ/kg})$.

From equationMERM38019(a) (also *NCEES Handbook* table "Superheated Steam (SI Units)"), the enthalpy of steam at 177°C is

$$h_{w,2} = 2820.5\ \text{kJ/kg}$$

Air temperature is reduced from 427°C to 177°C, and this energy is used to change water at 27°C to steam at 177°C. From the energy balance equation,

$$
\begin{aligned}
\dot{m} &= \frac{\dot{m}_a(h_1-h_2)}{h_{w,2}-h_{w,1}} = \frac{\dot{m}_a c_p(T_1-T_2)}{h_{w,2}-h_{w,1}} \\
&= \frac{\left(0.052\ \frac{\text{kg}}{\text{s}}\right)\left(1.04\ \frac{\text{kJ}}{\text{kg·K}}\right)(700\text{K}-450\text{K})}{2820.5\ \frac{\text{kJ}}{\text{kg}}-113.19\ \frac{\text{kJ}}{\text{kg}}} \\
&= 0.00502\ \text{kg/s} \quad (0.0050\ \text{kg/s})
\end{aligned}
$$

The answer is (D).
11.

Interpolating from appendixMERM24B (also *NCEES Handbook* table “Saturated Steam (U.S. Units)—Temperature Table”), the saturation pressure, p_{sat}, of 180°F water vapor is 7.515 psia. Use equationMERM38009 (also *NCEES Handbook:* Air-Water Systems) to find the partial pressure of the water vapor, p_w. The relative humidity, ϕ, is given as 20%.

$$
\begin{aligned}
\phi &= \frac{p_w}{p_{\text{sat}}} \\
p_w &= \phi p_{\text{sat}} = (0.20)\left(7.515\ \frac{\text{lbf}}{\text{in}^2}\right) \\
&= 1.5\ \text{lbf/in}^2
\end{aligned}
$$

From appendixMERM24B (also *NCEES Handbook:* Temperature-Dependent Properties of Air (U.S. Customary Units)), the dew point temperature corresponding to 1.5 lbf/in^2 is $115.64^\circ\text{F}\ \ (120^\circ\text{F})$.

The answer is (B).