Exercises on Air Conditioning Processes (Solutions)

1. Determine the quantity of heat required to raise 14 m^3/min of air at 20°C and 80 per cent relative humidity to 35°C. What is the final relative humidity?

   [Ans.: 4.27 kJ/s, RH = 34%]

SOLUTION

From the psychrometric chart at td_1 = 20°C and $Ø_1$ = 80%,

h_1 = 50 kJ/kg

v_1 = 0.847 m^3/kg

mass flow rate, $m = \dfrac{14m^3/min}{0.847m^3/kg} = 16.53$ kg/min

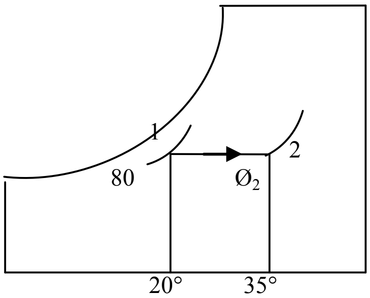
$Ø_2$ = 34%

h_2 = 65.5 kJ/kg

$Q = m (h_2 - h_1)$

$= 16.53 (65.5 - 50)$

= 256.20 kJ/min or 4.27 kJ/s



2. Determine the quantity of heat removed from 14 m^3/min of air when cooled from 37°C dry bulb and 21°C wet bulb temperatures to 15°C. What are the initial and final relative humidities?

   [Ans.: 6.04 kJ/s, initial RH = 23%, final RH = 85%]

SOLUTION

From the psychrometric chart at t_{d1} = 37°C and t_{w1} = 21°C,

$Ø_1$ = 23%

h_1 = 61 kJ/kg

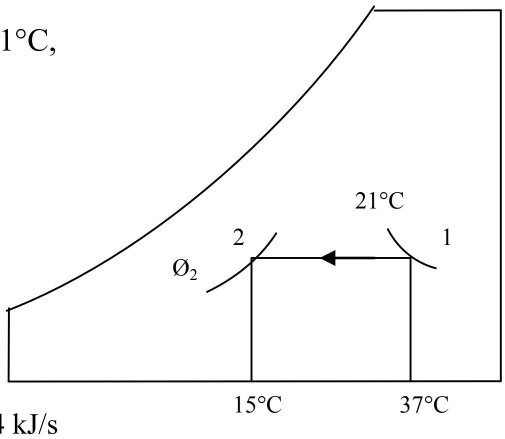
v_1 = 0.889 m^3/kg

mass flow rate, $m = \dfrac{14m^3/min}{0.889m^3/kg} = 15.75$ kg/min

$Ø_2$ = 85%

h_2 = 38 kJ/kg

$Q = m (h_2 - h_1) = 15.75 (38 - 61) = - 362.3$ kJ/min or – 6.04 kJ/s



3. How much heat and moisture must be added to 28 m^3/min of air at 24°C and 40% relative humidity to raise it to 38°C dry bulb and 27°C wet bulb temperature?

[Ans.: 22.73 kJ/s, 0.00581 kg/s]

SOLUTION

From the psychrometric chart at td_1 = 24°C and $Ø_1$ = 40%,

h_1 = 43 kJ/kg

W_1= 0.0075 kg/kg

v_1 = 0.852 m^3/kg

mass flow rate, m = $\frac{28m^3/\min}{0.852m^3/kg}$ = 32.86 kg/min

From the psychrometric chart at t_{d2} = 38°C and t_{w2} = 27°C,

h_2 = 84.5 kJ/kg

W_2= 0.0181 kg/kg

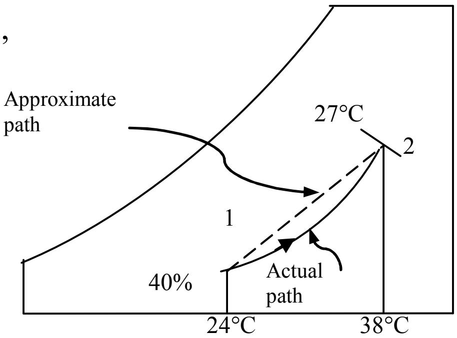
$Q = m (h_2 – h_1)$

= 32.86 (84.5 – 43) = 1364 kJ/min or 22.73 kJ/s

Moisure added = m (W_2 – W_1)

= 32.86 (0.0181 – 0.0075)

= 0.3483 kg/min or 0.00581 kg/s



4. How much heat and moisture must be removed to cool 28 m^3/min of air from 35°C dry bulb and 26°C wet bulb temperature to 21°C and 40% relative humidity?

[Ans.: 20.57 kJ/s, 0.0051 kg/s]

SOLUTION

From the psychrometric chart at t_{d1} = 35°C and t_{w1} = 26°C

h_1 = 80 kJ/kg

W_1= 0.0175 kg/kg

v_1 = 0.896 m^3/kg

mass flow rate, m = $\frac{28m^3/\min}{0.896m^3/kg}$ = 31.25 kg/min

From the psychrometric chart at t_{d2} = 21°C and $Ø_2$ =50%,

h_2 = 40.5 kJ/kg

W_2= 0.0077 kg/kg

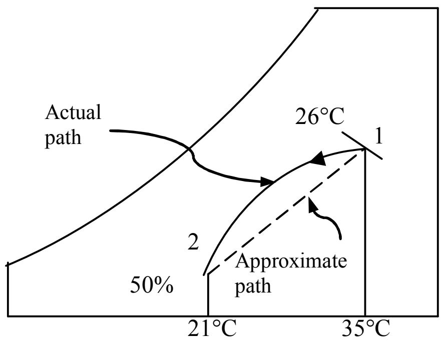
$Q = m (h_2 – h_1)$ = 31.25 (40.5 – 80)

= -1234.4 kJ/min or -20.57 kJ/s

Moisture removed = m (W_2 – W_1)

= 31.25 (0.0077 – 0.0175)

= 0.306 kg/min or 0.0051 kg/s



5. Air at 33°C dry bulb and 19°C wet bulb temperatures is cooled and humidified by passing it through an air washer in which the water is continuously recirculated. The air leaves the air washer at 23°C dry bulb temperature. Determine the moisture added per kg of dry air. What is the efficiency of the air washer?

[Ans.: 0.0041 kg/s, air washer efficiency = 71.43%]

SOLUTION

W_1= 0.0081 kg/kg

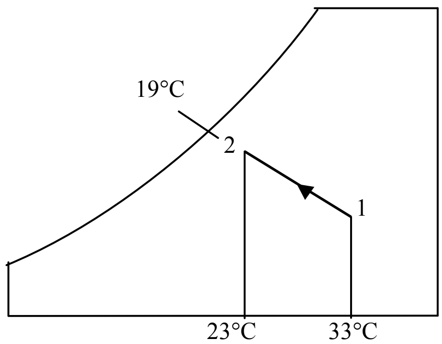
W_2= 0.0122 kg/kg

Moisture added = $W_2 - W_1$

= 0.0122- 0.0081

= 0.0041 kg/kg

Air washer efficiency = $\frac{33-23}{33-19}$ = 71.43%



6. Air at 24°C dry bulb and 15°C wet bulb temperatures enters dehumidifier and leaves at 41°C dry bulb and 19°C wet bulb temperatures. How much moisture has been removed per kilogram of dry air?

[Ans.: 0.0023 kg/kg]

SOLUTION

From the psychrometric chart at t_{d1} = 24°C and t_{w1} = 15°C

W_1= 0.0070 kg/kg

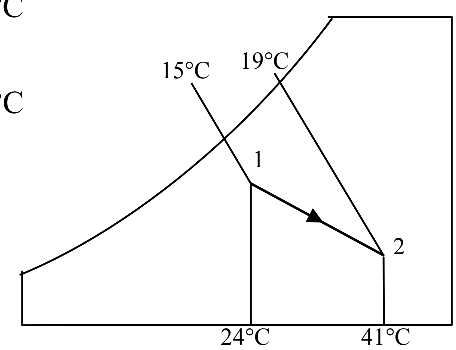
From the psychrometric chart at t_{d2} = 41°C and t_{w2} = 19°C

W_2= 0.0048 kg/kg

Moisture added = $W_1 - W_2$

= 0.0070 - 0.0048

= 0.0023 kg/kg



7. One half cubic meter per second of air at 15°C dry bulb and 13°C wet bulb temperatures are mixed with 0.20 m^3 per second of air at 25°C dry bulb and 18°C wet bulb temperatures. Determine (a) the dry bulb, wet bulb, and dew point temperatures of the mixture, and (b) the enthalpy of the mixture.

[Ans.: (a) DBT = 17.8°C, WBT = 14.6°C, DPT = 12.5°C; (b) 41 kJ/kg]

SOLUTION

From the psychrometric chart:

For the first stream

t_{d1} = 15°C t_{w1} = 13°C

W_1= 0.0085 kg/kg v_1 = 0.825 m^3/kg

For the second stream

$t_{d2} = 25°C$ $t_{w2} = 18°C$

$W_2 = 0.011$ kg/kg $v_2 = 0.858\ m^3/kg$

$$m_1 = \frac{V_1}{v_1} = \frac{0.50 m^3/s}{0.825 m^3/kg} = 0.606 \text{ kg/s}$$

$$m_2 = \frac{V_2}{v_2} = \frac{0.20 m^3/s}{0.858 m^3/kg} = 0.233 \text{ kg/s}$$

$$m_3 = m_1 + m_2 = 0.606 + 0.233 = 0.839 \text{ kg/s}$$

$$t_{d3} = \frac{m_1 t_{d1} + m_2 t_{d2}}{m_3} = \frac{0.606(15) + 0.233(25)}{0.839} = 17.8°C$$

$$W_3 = \frac{m_1 W_1 + m_2 W_2}{m_3} = \frac{0.606(0.0085) + 0.233(0.011)}{0.839}$$

$$= 0.0092 \text{ kg/kg}$$

From the psychrometric chart at $t_{d3} = 17.8°C$ and

$W_3 = 0.0092$ kg/kg

$t_{w3} = 14.6°C$

$t_{dp3} = 12.5°C$

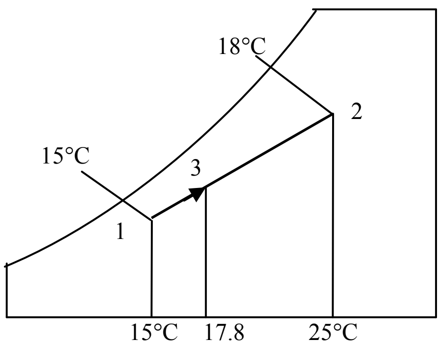
$h_3 = 41$ kJ/kg

Alternate solution

$t_{w3} = 14.6°C$

$t_{dp3} = 12.5°C$

$h_3 = 41$ kJ/kg



8. Outdoor air at 35°C dry bulb and 24°C wet bulb temperatures is to be mixed with room air at 26°C dry bulb and 50 per cent relative humidity. The final mixture is to consist of one-third outdoor air and two-thirds return air from the room. Find the resulting dry bulb and wet bulb temperatures of the mixture.

[Ans.: DBT = 29°C, WBT = 20.7°C]

SOLUTION

$t_{d1} = 35°C$

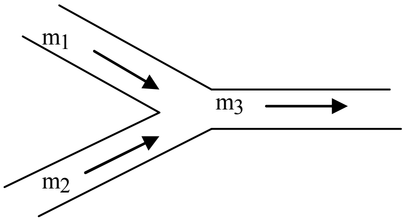
$t_{w1} = 24°C$

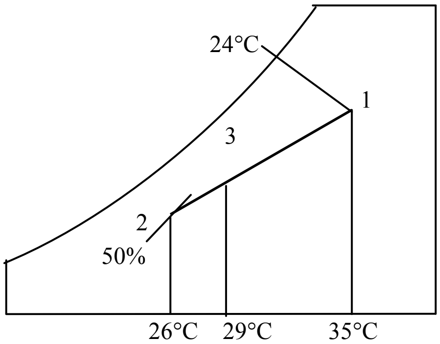
$t_{d2} = 26°C$

$Ø_2 = 50\%$

$m_1 = \frac{1}{3} m_3$

$m_2 = \frac{2}{3} m_3$





$$t_{d3} = \frac{m_1 t_{d1} + m_2 t_{d2}}{m_3} = \frac{(1/3)m_3(35) + (2/3)m_3(26)}{m_3} = 29°C$$

t_{w3} = 20.7°C

Alternate solution:

Divide line 1-2 into three equal parts. Point 3 is one-third of the line from point 2. Then read t_{d3} and t_{w3}.

9. A lecture theatre is to be maintained at a temperature of 25°C dry bulb and 19°C wet bulb temperatures. The sensible heat load is 88 kW and 58 kg per hour or moisture must be removed. Air is supplied to the lecture theatre at 18°C. Determine (a) the mass flow rate of supply air, (b) the relative humidity, dew point, and wet bulb temperatures of the supply air, (c) the latent heat load, and (d) the sensible heat ratio.

[Ans.: (a) 12.49 kg/s; (b) RH = 77%, DPT = 14.2°C, WBT = 15.6°C; (c) 40.59 kW; (d) 0.684]

SOLUTION

(a) $Q_S = (1.0062)(m)(t_2 - t_1)$

$88 = (1.0062)(m)(25 - 18)$

$m = 12.49$ kg/s

(b) Moisture picked up = $\dfrac{58}{(3600)(12.49)} = 0.0013$kg/kg

From the psychrometric chart at t_{d2} = 25°C and t_{w2} = 19°C

W_2= 0.0114 kg/kg

Humidity ratio of supply air,

$W_1 = W_2 - 0.0013 = 0.0114 - 0.0013 = 0.0101$ kg/kg

From the psychrometric chart at t_1 = 18°C and

W_1= 0.0101 kg/kg,

$Ø_1$ =77%

t_{dp1} =14.2 °C

t_{w1} = 15.6 °C

(c) $Q_L = (2500)(m)(W_2 - W_1)$

$= (2500)(12.49)(0.014 - 0.0101)$

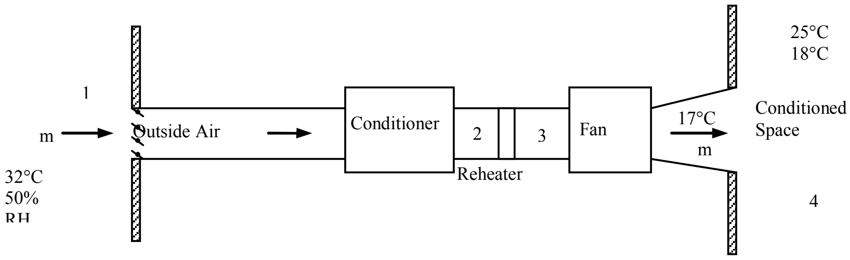
$= 40.59$kW

(d) SHR= $\dfrac{Q_S}{Q_S + Q_L} = \dfrac{88}{Q_L\, 88 + 40.59} = 0.6843$

10. In a space, the sensible heat load is 13.5 kW and the latent heat load is 3.4 kW. Outside air is at 32°C and 50 per cent relative humidity. The space is to be maintained at 25°C dry bulb and 18°C wet bulb temperatures. All outside air is supplied with reheater to satisfy the space conditions. The conditioned air leaves the supply fan at 17°C. Determine (a) the refrigeration load, (b) the capacity of the supply fan, and (c) the heat supplied in the reheater.

[Ans.: (a) 57.12 kW; (b) 1.40 m^3/s; (c) 5.88 kW]

SOLUTION



$Q_s = (1.0062)\ (m)\ (t_4 - t_3)$

$13.5 = (1.0062)\ (m)\ (25 - 17)$

$m = 1.68 kg/s$

Point 4: At t_4 = 25°C and t_{w4} = 18°C

$W_4 = 0.0101$ kg/kg

Point 3: $Q_L = (2500)\ (m)\ (W_4 - W_3)$

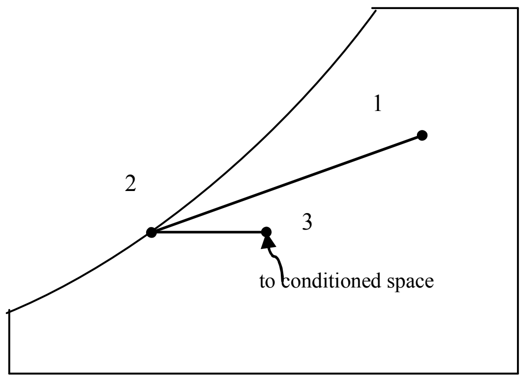
$3.4 = (2500)\ (1.68)\ (0.0101 - W_3)$

$W_3 = 0.0093$ kg/kg

At t_3 = 17°C and W_3 = 0.0093 kg/kg

$v_3 = 0.835\ m^3/kg$

$h_3 = 40.5$ kJ/kg



Point 2: At $W_2 = W_3$ = 0.0093 kg/kg and saturated,

$h_2 = 37$ kJ/kg

Point 1: At t_1 = 32°C and $Ø_1$ =50%,

$h_1 = 71$ kJ/kg

(a) Refrigeration load = $m\ (h_1 - h_2) = (1.68)\ (71 - 37) = 57.12$ kW

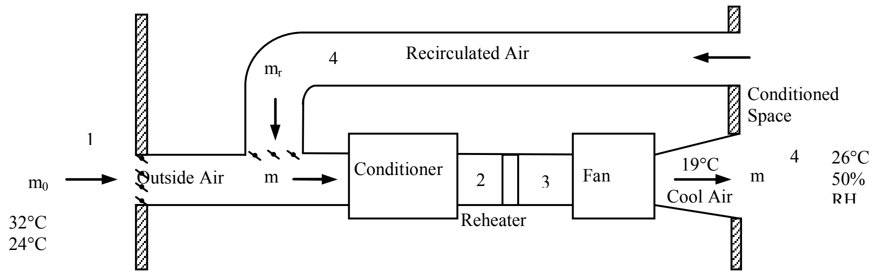
(b) Fan capacity = $m\ v_3 = (1.68)(0.835) = 1.40\ m^3/s$

(c) Heat supplied = $m\ (h_3 - h_2) = (1.68)\ (40.5 – 37) = 5.88$ kW

11. A space to be air conditioned has a sensible heat load of 36 kW and a latent heat load of 10.2 kW. The space is to be maintained at 26°C and 50 per cent relative humidity. Outside air is at 32°C dry bulb and 24°C wet bulb temperatures. The conditioned air will enter the space at 19°C. If 45 per cent of the supply air is fresh air and the rest is recirculated air, find (a) the volume flow rate of fresh air at supply conditions, (b) the apparatus dew point, and (c) the refrigeration load.

[Ans.: (a) 1.93 m^3/s; (b) 14°C; (c) 116 kW]

SOLUTION



$Q_s = (1.0062)(m)(t_4 - t_3)$

$36 = (1.0062)(m)(26 - 19)$

$m = 5.11$ kg/s

Point 4: At $t_4 = 26°C$ and $Ø_4 = 50\%$

$W_4 = 0.0106$ kg/kg, $h_4 = 53$ kJ/kg

Point 3: $Q_L = (2500)(m)(W_4 - W_3)$

$10.2 = (2500)(5.11)(0.0106 - W_3)$

$W_3 = 0.0098$ kg/kg

At $t_3 = 17°C$ and $W_3 = 0.0098$ kg/kg, $v_3 = 0.841\ m^3/kg$

Mass flow rate of outside air, $m_0 = (0.45)(m)$

$= (0.45)(5.11) = 2.30$ kg/s

(a) Volume flow rate of outside air, $V_0 = (m_0)(v_3)$

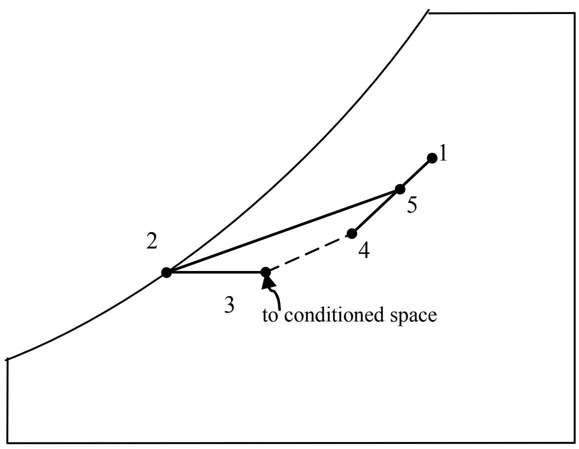
$= (2.30)(0.841) = 1.93\ m^3/kg$

Point 2: At $W_2 = W_3 = 0.0098$ kg/kg and saturated,

$h_2 = 39$ kJ/kg

$t_2 = 14°C$

(b) Apparatus dew point, $t_{dp2} = 14°C$



Point 1: At $t_1 = 32°C$ and $t_{w1} = 24°C$

$h_1 = 72.5$ kJ/kg

Mass flow rate of recirculated air,

$m_r = m - m_0 = 5.11 – 2.30 = 2.81$ kg/s

(c) Refrigeration load = $(m_r)(h_4 - h_2) + (m_0)(h_1 - h_2)$

= (2.81) (53 – 39) + (2.30) (72.5 – 39)

= 116.4 kW

Another solution:

$$h_5 = \frac{m_0 h_1 + m_r h_4}{m} = \frac{(2.30)(72.5) + (2.81)(53)}{5.11}$$

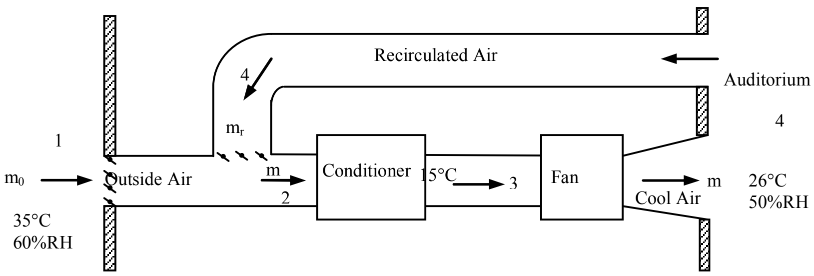
Refrigeration load = $(m)(h_5 - h_2)$

= (5.11) (61.7 – 39) = 116 kW

12. An auditorium is to be maintained at a temperature of 26°C dry bulb and 50% relative humidity. Air is to be supplied at a temperature not lower than 15°C dry bulb. The sensible heat gain is 110 kW and the latent heat gain is 37.5 kW. Take ventilating air as 25% by weight of the air from the room and is at 35°C dry bulb and 60% relative humidity. Determine the refrigeration capacity in tons of refrigeration (TR).

[Ans.: 68.5 TR]

SOLUTION



$Q_s = (1.0062)(m)(t_4 – t_3)$

$110 = (1.0062)(m)(26 - 15)$

$m = 9.938$ kg/s

Outside air supply, $m_0 = (0.45)(9.938) = 2.485$ kg/s

Point 4: At $t_4 = 26°C$ and $Ø_4 = 50\%$ RH

$h_4 = 53$ kJ/kg, $W_4 = 0.0106$ kg/kg

Point 3: $Q_L = (2500)(m)(W_4 – W_3)$

$37.5 = (2500)(9.938)(0.0106 – W_3)$

$W_3 = 0.00909$ kg/kg

At $t_3 = 15°C$ and $W_3 = 0.00909$ kg/kg

$h_3 = 38$ kJ/kg

Point 1: At $t_1 = 35°C$ and $Ø_1 = 60\%$ RH, $h_1 = 90$ kJ/kg

Return air, $m_r = m - m_0 = 9.938 - 2.485 = 7.453$ kg/s

Refrigeration load = $(m_0)(h_1 - h_3) + (m_r)(h_4 - h_3)$

$= (2.485)(90 - 38) + (7.453)(53 - 38)$

$= 241$ kJ/s

$= \frac{241}{3.52} = 68.5$ TR

Another solution:

$$h_2 = \frac{m_0 h_1 + m_r h_4}{m} = \frac{(2.485)(90) + (7.453)(53)}{5.11} = 62.25 \text{ kJ/kg}$$

Refrigeration load = $m(h_2 - h_3)$

$= (9.938)(62.25 - 38)$

$= 241$ kJ/s or 68.5 TR