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Chapter 30. Ventilation

Practice Problems

1.

An office room has floor dimensions of 60 ft by 95 ft (18 m by 29 m) and a ceiling height of 10 ft (3 m). Cool air is supplied from ceiling diffusers. 45 people occupy the office. What is most nearly the ventilation rate based on six air changes per hour?

(A)

1300 ft^3/min (35 m^3/min)

(B)

5700 ft^3/min (160 m^3/min)

(C)

13,000 ft^3/min (350 m^3/min)

(D)

34,000 ft^3/min (900 m^3/min)

2.

An auditorium is designed to seat 4500 people. The ventilation rate is 1.62×10^7 ft^3/hr (4.54×10^5 m^3/h) of outside air. The outside temperature is 0°F (−18°C) dry-bulb, and the outside pressure is 14.6 psia (100.6 kPa). Air leaves the auditorium at 70°F (21°C) dry-bulb. There is no recirculation. The furnace has a capacity of 1,250,000 Btu/hr (370 kW). The sensible heat generated by each person seated in the theater is 225 Btu/hr. Has the furnace been sized properly?

(A)

The furnace is less than half the required capacity.

(B)

The furnace is more than half the required capacity.

(C)

The furnace is less than twice the required capacity.

(D)

The furnace is more than twice the required capacity.

3.

The volumetric fraction of carbon dioxide in a submarine is measured to be 0.06%. What is most nearly the concentration measured in parts per million (ppm)?

(A)

0.6 ppm
(B)

60 ppm

(C)

600 ppm

(D)

6000 ppm
4.

A room is maintained at design conditions of 75°F (23.9°C) dry-bulb and 50% relative humidity. The air outside is at 95°F (35°C) dry-bulb and 75°F (23.9°C) wet-bulb. The outside air is conditioned and mixed with some room exhaust air. The mixed, conditioned air enters the room and increases 20°F (11.1°C) in temperature before being removed from the room. The sensible and latent loads are 200,000 Btu/hr (60 kW) and 50,000 Btu/hr (15 kW), respectively. Air leaves the coil at 50.8°F (10°C). The volume of air flowing through the coil is most nearly

(A)

4200 ft^3/min (120 m^3/min)

(B)

5800 ft^3/min (160 m^3/min)

(C)

7600 ft^3/min (220 m^3/min)

(D)

9300 ft^3/min (260 m^3/min)

5.

How should the pressurization (relative to the surroundings) in clean rooms and laboratories be maintained?

(A)

Clean rooms and laboratories should both be at positive pressures.

(B)

Clean rooms and laboratories should both be at negative pressures.

(C)

Clean rooms should be at positive pressures, while laboratories should be at negative pressures.

(D)

Clean rooms should be at negative pressures, while laboratories should be at positive pressures.

Solutions

1.

Customary U.S. Solution

The office volume is

$$V = (60\ \text{ft})\,(95\ \text{ft})\,(10\ \text{ft}) = 57{,}000\ \text{ft}^3$$

Based on six air changes per hour, the flow rate is

$$\begin{aligned}\dot{V} &= \frac{\left(57{,}000\ \dfrac{\text{ft}^3}{\text{air change}}\right)\left(6\ \dfrac{\text{air changes}}{\text{hr}}\right)}{60\ \dfrac{\text{min}}{\text{hr}}}\\ &= 5700\ \text{ft}^3/\text{min}\end{aligned}$$

The answer is (B).

SI Solution

The office volume is

$$V = (18\ \text{m})\,(29\ \text{m})\,(3\ \text{m}) = 1566\ \text{m}^3$$

Based on six air changes per hour, the flow rate is

$$\begin{aligned}\dot{V} &= \frac{\left(1566\ \dfrac{\text{m}^3}{\text{air change}}\right)\left(6\ \dfrac{\text{air changes}}{\text{h}}\right)}{60\ \dfrac{\text{min}}{\text{h}}}\\ &= 156.6\ \text{m}^3/\text{min} \quad (160\ \text{m}^3/\text{min})\end{aligned}$$

The answer is (B).
2.

Customary U.S. Solution

As in *NCEES Handbook* table “Conversion Table for Temperature Units,” the absolute temperature of outside air is

$$T = 0^\circ\text{F} + 460^\circ = 460^\circ\text{R}$$

From the ideal gas law, the density of outside air is

$$\begin{aligned}\rho &= \frac{pM}{RT} = \frac{\left(14.6\ \frac{\text{lbf}}{\text{in}^2}\right)\left(12\ \frac{\text{in}}{\text{ft}}\right)^2\left(29\ \frac{\text{lbm}}{\text{lbmol}}\right)}{\left(1545.35\ \frac{\text{ft-lbf}}{\text{lbmol-}^\circ\text{R}}\right)(460^\circ\text{R})}\\ &= 0.08567\ \text{lbm/ft}^3\end{aligned}$$

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

$$\begin{aligned}\dot{m} &= \dot{V}\rho = \left(1.62\times 10^7\ \frac{\text{ft}^3}{\text{hr}}\right)\left(0.08567\ \frac{\text{lbm}}{\text{ft}^3}\right)\\ &= 1.388\times 10^6\ \text{lbm/hr}\end{aligned}$$

Assume there can be no latent heat (no moisture) at 0°F.

From the problem statement, the sensible heat generated by each person seated in the theater is 225 Btu/hr. Therefore,

$$\dot{q}_{\text{in from people}} = \left(225\ \frac{\frac{\text{Btu}}{\text{hr}}}{\text{person}}\right)(4500\text{ persons})$$
$$= 1.01 \times 10^6\ \text{Btu/hr}$$

The air leaves the auditorium at 70°F. From appendixMERM35C (also *NCEES Handbook:* Temperature-Dependent Properties of Air (U.S. Customary Units)), the specific heat of dry air is 0.240 Btu/lbm-°F. (This remains fairly constant over normal temperature ranges.) Since $\dot{q}$ is known, the air temperature entering the auditorium is

$$\dot{q} = \dot{m}c_p\left(T_{\text{out,air}} - T_{\text{in,air}}\right)$$
$$T_{\text{in,air}} = T_{\text{out,air}} - \frac{\dot{q}}{\dot{m}c_p}$$
$$= 70^\circ\text{F} - \frac{1.01 \times 10^6\ \frac{\text{Btu}}{\text{hr}}}{\left(1.388 \times 10^6\ \frac{\text{lbm}}{\text{hr}}\right)\left(0.240\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right)}$$
$$= 67^\circ\text{F}$$

The heat needed to heat dry ventilation air from 0°F to 67°F is

$$\dot{q} = \dot{m}c_p\Delta T$$
$$= \left(1.388 \times 10^6\ \frac{\text{lbm}}{\text{hr}}\right)\left(0.240\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right)(67^\circ\text{F} - 0^\circ\text{F})$$
$$= 2.23 \times 10^7\ \text{Btu/hr}$$

Since 1.25×10^6 Btu/hr < 2.23×10^7 Btu/hr, the furnace is less than half the required capacity, so it is too small.

The answer is (A).

SI Solution

As in *NCEES Handbook* table "Conversion Table for Temperature Units," the absolute temperature of outside air is

$$T = -18^\circ\text{C} + 273^\circ = 255\text{K}$$

From the ideal gas law, the density of outside air is

$$\rho = \frac{pM}{RT} = \frac{(100.6\ \text{kPa})\left(29\ \frac{\text{kg}}{\text{kmol}}\right)}{\left(8.314\ \frac{\text{kJ}}{\text{kmol}\cdot\text{K}}\right)(255\text{K})} = 1.374\ \text{kg/m}^3$$

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

$$\dot{m} = \rho\dot{V} = \left(1.374\ \frac{\text{kg}}{\text{m}^3}\right)\left(4.54 \times 10^5\ \frac{\text{m}^3}{\text{h}}\right)$$
$$= 6.238 \times 10^5\ \text{kg/h}$$

Assume there can be no latent heat (no moisture) at −18°C.

From the problem statement, the sensible heat generated by people seated in the theater is

$$\left(225\ \frac{\frac{\text{Btu}}{\text{h}}}{\text{person}}\right)\left(0.293\ \frac{\text{W}}{\frac{\text{Btu}}{\text{h}}}\right) = 65.93\ \text{W/person}$$

Therefore,

$$\dot{q}_{\text{in from people}} = \frac{\left(65.93\ \frac{\text{W}}{\text{person}}\right)(4500\ \text{persons})}{1000\ \frac{\text{W}}{\text{kW}}}$$
$$= 296.7\ \text{kW}$$

The air leaves the auditorium at 21°C. From appendixMERM35D (also *NCEES Handbook:* Temperature-Dependent Properties of Air (SI Units)), the specific heat of dry air is $1.0048\ \text{kJ/kg·K}$. (This remains fairly constant over normal temperature ranges.) Since $\dot{q}$ is known, the air temperature entering the auditorium is

$$\dot{q} = \dot{m}c_p\left(T_{\text{out,air}} - T_{\text{in,air}}\right)$$
$$T_{\text{in,air}} = T_{\text{out,air}} - \frac{\dot{q}}{\dot{m}c_p}$$
$$= 21^\circ\text{C} - \frac{(296.7\ \text{kW})\left(3600\ \frac{\text{s}}{\text{h}}\right)}{\left(6.238\times10^5\ \frac{\text{kg}}{\text{h}}\right)\left(1.0048\ \frac{\text{kJ}}{\text{kg·K}}\right)}$$
$$= 19.3^\circ\text{C} \quad (19^\circ\text{C})$$

The heat needed to heat dry ventilation air from −18°C to 19.3°C is

$$\dot{q} = \dot{m}c_p\Delta T$$
$$= \frac{\left(6.238\times10^5\ \frac{\text{kg}}{\text{h}}\right)\left(1.0048\ \frac{\text{kJ}}{\text{kg·}^\circ\text{C}}\right)\times\left(19.3^\circ\text{C} - (-18^\circ\text{C})\right)}{3600\ \frac{\text{s}}{\text{h}}}$$
$$= 6494.28\ \text{kW} \quad (6.5\ \text{MW})$$

Since 370 kW < 6494 kW, the furnace is less than half the required capacity, so it is too small.

The answer is (A).

3.

Air contaminants are measured by volume, hence "ppm" are parts per million by volume (ppmv). In this problem, there are 0.06 volumes of carbon dioxide for every 100 volumes of air (i.e., 0.06 parts per 100 parts). In one million volumes of air, there would be $10^6/10^2 = 10^4$ more volumes of carbon dioxide.

$$(0.06\ \text{pphv})\left(10^4\ \frac{\text{ppmv}}{\text{pphv}}\right) = 600\ \text{ppmv} \quad (600\ \text{ppm})$$

The answer is (C).

4.

Customary U.S. Solution

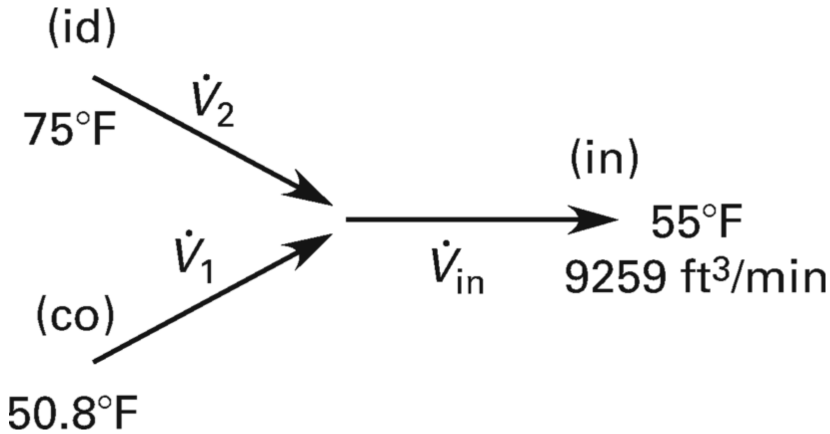
The mixed conditioned air enters the room at

$$T_{\text{db,in}} = 75^\circ\text{F} - 20^\circ\text{F} = 55^\circ\text{F}$$

From Eq. 30.13 (also *NCEES Handbook:* Latent and Sensible Heat and *NCEES Handbook:* Temperature-Dependent Properties of Air (U.S. Customary Units)), the volumetric flow rate of air entering the room is

$$\dot{V}_{\text{in,ft}^3/\text{min}} = \frac{\dot{q}_{s,\text{Btu/hr}}}{\left(1.08\ \frac{\text{Btu-min}}{\text{ft}^3\text{-hr-}^\circ\text{F}}\right)(T_{\text{id},^\circ\text{F}} - T_{\text{in},^\circ\text{F}})}$$
$$= \frac{200{,}000\ \frac{\text{Btu}}{\text{hr}}}{\left(1.08\ \frac{\text{Btu-min}}{\text{ft}^3\text{-hr-}^\circ\text{F}}\right)(75^\circ\text{F} - 55^\circ\text{F})}$$
$$= 9259\ \text{ft}^3/\text{min}$$

This is a mixing problem.



Using the lever rule, and since the temperature scales are all linear, the fraction of air passing through the coil is

$$\frac{T_{\text{id}} - T_{\text{in}}}{T_{\text{id}} - T_{\text{co}}} = \frac{75^\circ\text{F} - 55^\circ\text{F}}{75^\circ\text{F} - 50.8^\circ\text{F}} = 0.826$$
$$\dot{V}_1 = (0.826)\left(9259\ \frac{\text{ft}^3}{\text{min}}\right)$$
$$= 7648\ \text{ft}^3/\text{min} \quad (7600\ \text{ft}^3/\text{min})$$

The answer is (C).

SI Solution

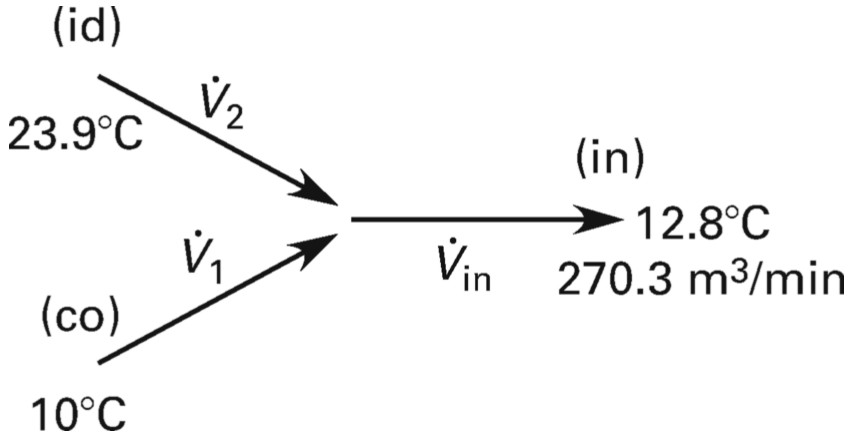
The mixed conditioned air enters the room at

$$T_{\text{db,in}} = 23.9^\circ\text{C} - 11.1^\circ\text{C} = 12.8^\circ\text{C}$$

From equationMERM3906 (also *NCEES Handbook:* Latent and Sensible Heat and *NCEES Handbook:* Temperature-Dependent Properties of Air (SI Units)),

$$\dot{V}_{\text{in,m}^3/\text{min}} = \frac{\dot{q}_{s,\text{kW}}}{\left(0.02\ \frac{\text{kJ}\cdot\text{min}}{\text{m}^3\cdot\text{s}\cdot^\circ\text{C}}\right)(T_{\text{id},^\circ\text{C}} - T_{\text{in},^\circ\text{C}})}$$
$$= \frac{60\ \text{kW}}{\left(0.02\ \frac{\text{kJ}\cdot\text{min}}{\text{m}^3\cdot\text{s}\cdot^\circ\text{C}}\right)(23.9^\circ\text{C} - 12.8^\circ\text{C})}$$
$$= 270.3\ \text{m}^3/\text{min}$$

This is a mixing problem.



Using the lever rule, and since the temperature scales are all linear, the fraction of air passing through the coil is

$$\begin{aligned}\frac{T_{\text{id}} - T_{\text{in}}}{T_{\text{id}} - T_{\text{co}}} &= \frac{23.9^\circ\text{C} - 12.8^\circ\text{C}}{23.9^\circ\text{C} - 10^\circ\text{C}} = 0.799 \\ \dot{V}_1 &= (0.799)\left(270.3\ \frac{\text{m}^3}{\text{min}}\right) \\ &= 216.0\ \text{m}^3/\text{min} \quad (220\ \text{m}^3/\text{min})\end{aligned}$$

The answer is (C).
5.

Clean rooms should be maintained at positive pressures with filtered forced air in order to prevent the incursion of airborne particles from the atmosphere. The intake air is filtered and cleaned, and the interior of the clean room is protected. Most laboratories should be maintained at negative pressures in order to keep airborne hazardous materials in the air distribution system. The exhaust is filtered and cleaned, and the environment is protected.

The answer is (C).