43.17 A $20,000 ft^2$ factory uses LED lighting with a power density of $0.7 W/ft^2$ for the LED strips plus 15% for drivers. The space contains eight 93% efficient $7.5hp$ motors operating at an average of 70% of their rated capacity. The machinery driven by the motors is located within the conditioned space. There are 120 factory employees performing light machine work. What is the total internal heat gain?

A. $180,000 \frac{Btu}{hr}$

B. $185,000 \frac{Btu}{hr}$

C. $280,000 \frac{Btu}{hr}$

D. $330,000 \frac{Btu}{hr}$

Calculate the heat gain from the lighting. Convert units to $\frac{Btu}{hr}$:

$$\dot{Q}_{lighting} = \left(20000 ft^2\right)\left(.7\frac{W}{ft^2}\right)(1.15)\left(3.412\frac{\frac{Btu}{hr}}{W}\right) = 54,933\frac{Btu}{hr}$$

Calculate the heat gain for the motors. Note the entire electrical load (operating at 70% of its capacity) counts as heat gain since the equipment powered is *within* the conditioned space, regardless of whether the power turns into mechanical work or heat loss. The motor efficiency need not be accounted for. Convert units to $\frac{Btu}{hr}$:

$$\dot{Q}_{motors} = (8)(7.5hp)(.7)\left(745.7\frac{W}{hp}\right)\left(3.412\frac{\frac{Btu}{hr}}{W}\right) = 106,862\frac{Btu}{hr}$$

Look up Human Cooling Loads in the Reference Handbook and find the value for light machine work. Calculate the heat gain for the workers:

$$\dot{Q}_{people} = (120 people)\left(1000\frac{\frac{Btu}{hr}}{person}\right) = 120,000\frac{Btu}{hr}$$

Calculate the total heat gain:

$$\dot{Q}_{total} = \dot{Q}_{lighting} + \dot{Q}_{motors} + \dot{Q}_{people}$$

$$\dot{Q}_{total} = 54,933\frac{Btu}{hr} + 106,862\frac{Btu}{hr} + 120,000\frac{Btu}{hr} = 281,795\frac{Btu}{hr}$$

Answer C

43.18 Boston typically has 5,630 heating degree days in the winter based on a non-standard internal design temperature of $70°F$. A building in Boston designed for an inside temperature of $70°F$ and an outside temperature of $0°F$ loses $5\frac{MMBtu}{hr}$ on a design day. The building is heated with natural gas which has an average heating value of $1,000\frac{Btu}{ft^3}$ and an average cost of $0.90 per CCF. The boiler efficiency is 80%. What is the annual cost of heating?

A. $87,000

B. $94,000

C. $109,000

D. $117,000

Consider the units of degree days, $[°F \cdot days]$, i.e. $\Delta T \times time$. The rate of heat loss on a design day and the design ΔT are given. Write an expression for the quantity of heat lost during the heating season. Be sure the resulting units are in Btu.

$$\dot{Q} = \frac{Q}{t} \rightarrow Q = \dot{Q}t$$

There is no cookie-cutter formula for this problem. Multiplying the heating degree days with $\dot{Q}$ cancels time, leaving only energy and temperature. Dividing by the design ΔT eliminates temperature:

$$Q = \frac{HDD \times \dot{Q}}{\Delta T} = \frac{(5630deg \cdot days)\left(\frac{24hr}{1day}\right)\left(5,000,000\frac{Btu}{hr}\right)}{(70°F - 0°F)} = 9.65 \times 10^9 Btu$$

Note that degree days account for the heat loss and ΔT being *less than* design for a great deal of the season. Heating systems are designed for the maximum (or near maximum) demand for the location, which may only be required on a few days per year.

Calculate the cost of natural gas. Note the heating value is given in $\frac{Btu}{ft^3}$ and the cost is in $\frac{\$}{CCF}$, where $CCF = 100ft^3$. Also account for the efficiency of the system, which will drive costs higher than if the system was 100% efficient.

$$Cost = \frac{\left(\frac{9.65 \times 10^9 Btu}{1000\frac{Btu}{ft^3}}\right)\left(\frac{\$0.90}{100ft^3}\right)}{(.8)} = \$108,579$$

Answer C