http://www.Drshokuhi.com

سایت آموزش مهندسی مکانیک

Special Topic: Heat Transfer from the Human Body

12-74C Yes, roughly one-third of the metabolic heat generated by a person who is resting or doing light work is dissipated to the environment by convection, one-third by evaporation, and the remaining one-third by radiation.

12-75C 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.

12-76C 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 wettedness 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.

12-77C The insulating effect of clothing is expressed in the unit **clo** with 1 clo = 0.155 m^2.°C/W = 0.880 ft^2.°F.h/Btu. Clothing serves as insulation, and thus reduces heat loss from the body by convection, radiation, and evaporation by serving as a resistance against heat flow and vapor flow. Clothing decreases heat gain from the sun by serving as a radiation shield.

12-78C (*a*) Heat is lost through the skin by convection, radiation, and evaporation. (*b*) The body loses both sensible heat by convection and latent heat by evaporation from the lungs, but there is no heat transfer in the lungs by radiation.

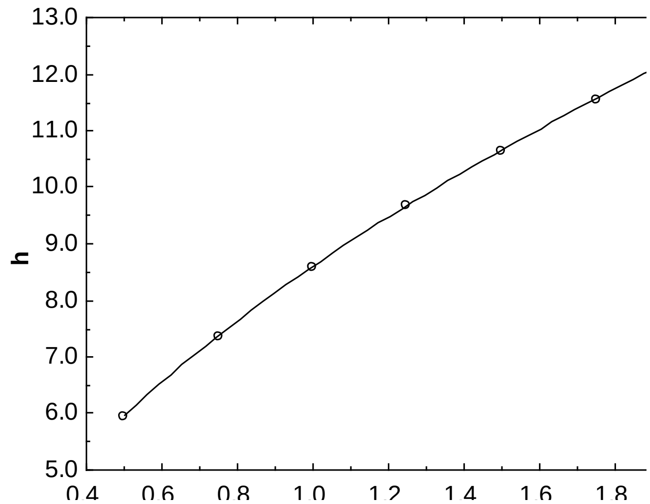
12-79C The *operative temperature* $T_{\text{operative}}$ is the average of the mean radiant and ambient temperatures weighed by their respective convection and radiation heat transfer coefficients, and is expressed as

$$T_{\text{operative}} = \frac{h_{\text{conv}} T_{\text{ambient}} + h_{\text{rad}} T_{\text{surr}}}{h_{\text{conv}} + h_{\text{rad}}} \cong \frac{T_{\text{ambient}} + T_{\text{surr}}}{2}$$

When the convection and radiation heat transfer coefficients are equal to each other, the operative temperature becomes the arithmetic average of the ambient and surrounding surface temperatures.

12-80 The convection heat transfer coefficient for a clothed person while walking in still air at a velocity of 0.5 to 2 m/s is given by $h = 8.6V^{0.53}$ where V is in m/s and h is in W/m^2.°C. The convection coefficients in that range vary from 5.96 W/m^2.°C at 0.5 m/s to 12.4 W/m^2.°C at 2 m/s. Therefore, at low velocities, the radiation and convection heat transfer coefficients are comparable in magnitude. But at high velocities, the convection coefficient is much larger than the radiation heat transfer coefficient.

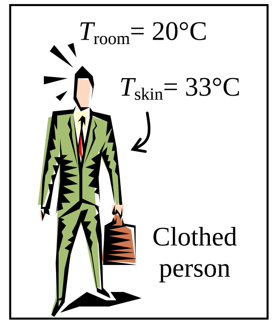
Velocity, m/s	$h = 8.6V^{0.53}$ W/m^2.°C
0.50	5.96
0.75	7.38
1.00	8.60
1.25	9.68
1.50	10.66
1.75	11.57
2.00	12.40



12-81 A man wearing summer clothes feels comfortable in a room at 22°C. The room temperature at which this man would feel thermally comfortable when unclothed is to be determined.

Assumptions **1** Steady conditions exist. **2** The latent heat loss from the person remains the same. **3** The heat transfer coefficients remain the same. **4** The air in the room is still (there are no winds or running fans). **5** The surface areas of the clothed and unclothed person are the same.

Analysis At low air velocities, the convection heat transfer coefficient for a standing man is given in Table 12-3 to be 4.0 W/m^2.°C. The radiation heat transfer coefficient at typical indoor conditions is 4.7 W/m^2.°C. Therefore, the heat transfer coefficient for a standing person for combined convection and radiation is



$$h_{combined} = h_{conv} + h_{rad} = 4.0 + 4.7 = 8.7 \text{ W/m}^2.°\text{C}$$

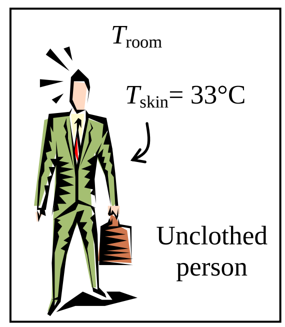
The thermal resistance of the clothing is given to be

$$R_{cloth} = 0.7 \text{ clo} = 0.7 \times 0.155 \text{ m}^2.°\text{C/W} = 0.109 \text{ m}^2.°\text{C/W}$$

Noting that the surface area of an average man is 1.8 m^2, the sensible heat loss from this person when clothed is determined to be

$$\dot{Q}_{sensible,clothed} = \frac{A_s(T_{skin} - T_{ambient})}{R_{cloth} + \dfrac{1}{h_{combined}}} = \frac{(1.8 \text{ m}^2)(33-20)°\text{C}}{0.109 \text{ m}^2.°\text{C/W} + \dfrac{1}{8.7 \text{ W/m}^2.°\text{C}}} = 104 \text{ W}$$

From heat transfer point of view, taking the clothes off is equivalent to removing the clothing insulation or setting R_{cloth} = 0. The heat transfer in this case can be expressed as



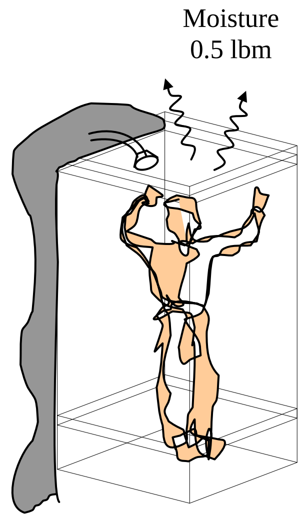
$$\dot{Q}_{sensible,unclothed} = \frac{A_s(T_{skin} - T_{ambient})}{\dfrac{1}{h_{combined}}} = \frac{(1.8 \text{ m}^2)(33-T_{ambient})°\text{C}}{\dfrac{1}{8.7 \text{ W/m}^2.°\text{C}}}$$

To maintain thermal comfort after taking the clothes off, the skin temperature of the person and the rate of heat transfer from him must remain the same. Then setting the equation above equal to 104 W gives

$$T_{ambient} = \mathbf{26.4°C}$$

Therefore, the air temperature needs to be raised from 22 to 26.4°C to ensure that the person will feel comfortable in the room after he takes his clothes off. Note that the effect of clothing on latent heat is assumed to be negligible in the solution above. We also assumed the surface area of the clothed and unclothed person to be the same for simplicity, and these two effects should counteract each other.

12-82E An average person produces 0.50 lbm 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 1050 Btu/lbm.

Analysis The amount of moisture produced per day is

$$m_{vapor} = \text{(Moisture produced per person)(No. of persons)}$$
$$= \text{(0.5 lbm/person)(4 persons/day)} = 2 \text{ lbm/day}$$

Then the latent heat load due to showers becomes

$$Q_{latent} = m_{vapor} h_{fg} = \text{(2 lbm/day)(1050 Btu/lbm)} = \mathbf{2100\ Btu/day}$$

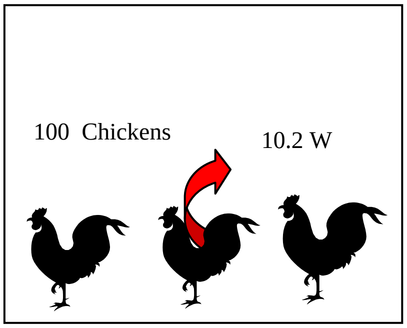
12-83 There are 100 chickens in a breeding room. The rate of total heat generation and the rate of moisture production in the room are to be determined.

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

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



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

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

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

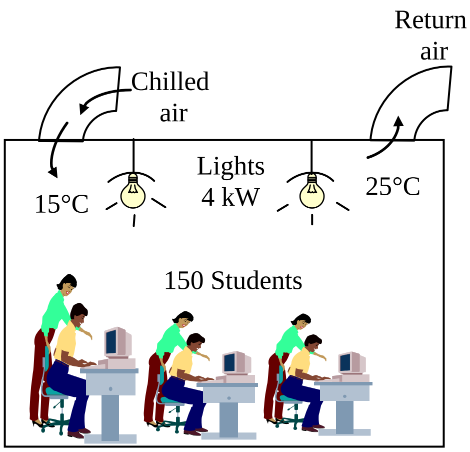
12-84 Chilled air is to cool a room by removing the heat generated in a large insulated classroom by lights and students. The required flow rate of air that needs to be supplied to the room is to be determined.

Assumptions **1** The moisture produced by the bodies leave the room as vapor without any condensing, and thus the classroom has no latent heat load. **2** Heat gain through the walls and the roof is negligible.

Properties The specific heat of air at room temperature is 1.00 kJ/kg·°C (Table A-15). The average rate of metabolic heat generation by a person sitting or doing light work is 115 W (70 W sensible, and 45 W latent).

Analysis The rate of sensible heat generation by the people in the room and the total rate of sensible internal heat generation are

$$\dot{Q}_{\text{gen,sensible}} = \dot{q}_{\text{gen,sensible}}(\text{No. of people})$$
$$= (70\ \text{W/person})(150\ \text{persons}) = 10{,}500\ \text{W}$$
$$\dot{Q}_{\text{total, sensible}} = \dot{Q}_{\text{gen,sensible}} + \dot{Q}_{\text{lighting}}$$
$$= 10{,}500 + 4000 = 14{,}500\ \text{W}$$



Then the required mass flow rate of chilled air becomes

$$\dot{m}_{\text{air}} = \frac{\dot{Q}_{\text{total, sensible}}}{C_p \Delta T}$$
$$= \frac{14.5\ \text{kJ/s}}{(1.0\ \text{kJ/kg}\cdot{}^\circ\text{C})(25-15)^\circ\text{C}} = \mathbf{1.45\ kg/s}$$

Discussion The latent heat will be removed by the air-conditioning system as the moisture condenses outside the cooling coils.

12-85 The average mean radiation temperature during a cold day drops to 18°C. The required rise in the indoor air temperature to maintain the same level of comfort in the same clothing is to be determined.

Assumptions **1** Air motion in the room is negligible. **2** The average clothing and exposed skin temperature remains the same. **3** The latent heat loss from the body remains constant. **4** Heat transfer through the lungs remain constant.

Properties The emissivity of the person is 0.95 (from Appendix tables). The convection heat transfer coefficient from the body in still air or air moving with a velocity under 0.2 m/s is h_{conv} = 3.1 W/m^2·°C (Table 12-3).

Analysis The total rate of heat transfer from the body is the sum of the rates of heat loss by convection, radiation, and evaporation,

$$\dot{Q}_{\text{body, total}} = \dot{Q}_{\text{sensible}} + \dot{Q}_{\text{latent}} + \dot{Q}_{\text{lungs}} = (\dot{Q}_{\text{conv}} + Q_{\text{rad}}) + \dot{Q}_{\text{latent}} + \dot{Q}_{\text{lungs}}$$

Noting that heat transfer from the skin by evaporation and from the lungs remains constant, the sum of the convection and radiation heat transfer from the person must remain constant.

$$\begin{aligned}
\dot{Q}_{\text{sensible,old}} &= hA_s(T_s - T_{\text{air,old}}) + \varepsilon A_s\sigma(T_s^4 - T_{\text{surr,old}}^4) \\
&= hA_s(T_s - 22) + 0.95A_s\sigma[(T_s + 273)^4 - (22+273)^4] \\
\dot{Q}_{\text{sensible,new}} &= hA_s(T_s - T_{\text{air,new}}) + \varepsilon A_s\sigma(T_s^4 - T_{\text{surr,new}}^4) \\
&= hA_s(T_s - T_{\text{air,new}}) + 0.95A_s\sigma[(T_s + 273)^4 - (18+273)^4]
\end{aligned}$$

Setting the two relations above equal to each other, canceling the surface area A_s, and simplifying gives

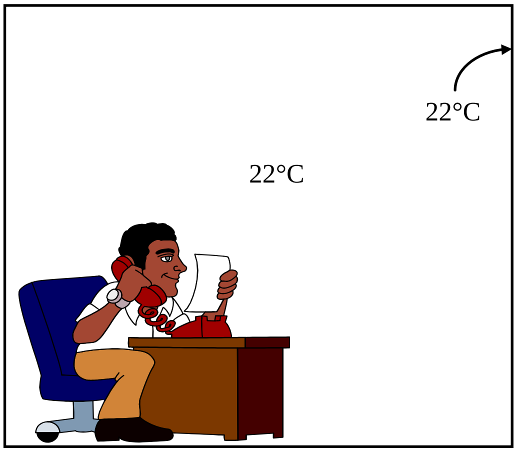
$$-22h - 0.95\sigma(22+273)^4 = -hT_{\text{air, new}} - 0.95\sigma(18+273)^4$$

$$3.1(T_{\text{air, new}} - 22) + 0.95 \times 5.67 \times 10^{-8}(291^4 - 295^4) = 0$$

Solving for the new air temperature gives

$$T_{\text{air, new}} = \mathbf{29.0°C}$$

Therefore, the air temperature must be raised to 29°C to counteract the increase in heat transfer by radiation.



12-86 The average mean radiation temperature during a cold day drops to 12°C. The required rise in the indoor air temperature to maintain the same level of comfort in the same clothing is to be determined.

Assumptions **1** Air motion in the room is negligible. **2** The average clothing and exposed skin temperature remains the same. **3** The latent heat loss from the body remains constant. **4** Heat transfer through the lungs remain constant.

Properties The emissivity of the person is 0.95 (from Appendix tables). The convection heat transfer coefficient from the body in still air or air moving with a velocity under 0.2 m/s is h_{conv} = 3.1 W/m^2·°C (Table 12-3).

Analysis The total rate of heat transfer from the body is the sum of the rates of heat loss by convection, radiation, and evaporation,

$$\dot{Q}_{\text{body, total}} = \dot{Q}_{\text{sensible}} + \dot{Q}_{\text{latent}} + \dot{Q}_{\text{lungs}} = (\dot{Q}_{\text{conv}} + Q_{\text{rad}}) + \dot{Q}_{\text{latent}} + \dot{Q}_{\text{lungs}}$$

Noting that heat transfer from the skin by evaporation and from the lungs remains constant, the sum of the convection and radiation heat transfer from the person must remain constant.

$$\begin{aligned}\dot{Q}_{\text{sensible,old}} &= hA_s(T_s - T_{\text{air,old}}) + \varepsilon A_s\sigma(T_s^4 - T_{\text{surr,old}}^4)\\ &= hA_s(T_s - 22) + 0.95A_s\sigma[(T_s + 273)^4 - (22+273)^4]\\ \dot{Q}_{\text{sensible,new}} &= hA_s(T_s - T_{\text{air,new}}) + \varepsilon A_s\sigma(T_s^4 - T_{\text{surr,new}}^4)\\ &= hA_s(T_s - T_{\text{air,new}}) + 0.95A_s\sigma[(T_s + 273)^4 - (12+273)^4]\end{aligned}$$

Setting the two relations above equal to each other, canceling the surface area A_s, and simplifying gives

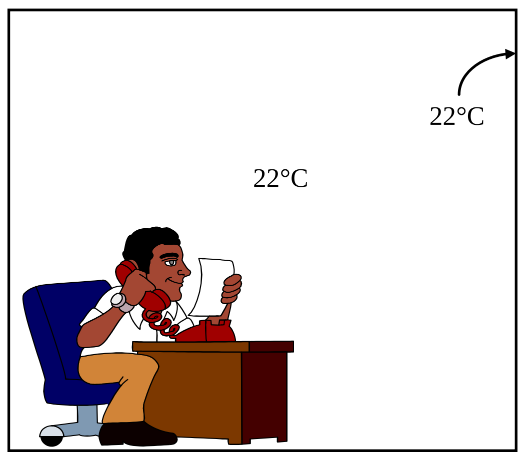
$$-22h - 0.95\sigma(22+273)^4 = -hT_{\text{air,new}} - 0.95\sigma(12+273)^4$$

$$3.1(T_{\text{air,new}} - 22) + 0.95\times5.67\times10^{-8}(285^4 - 295^4) = 0$$

Solving for the new air temperature gives

$T_{\text{air, new}}$ = **39.0°C**

Therefore, the air temperature must be raised to 39°C to counteract the increase in heat transfer by radiation.



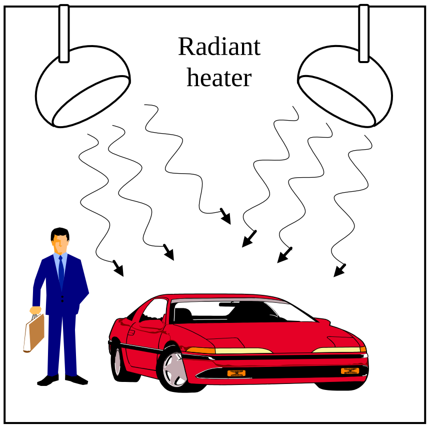
12-87 A car mechanic is working in a shop heated by radiant heaters in winter. The lowest ambient temperature the worker can work in comfortably is to be determined.

Assumptions **1** The air motion in the room is negligible, and the mechanic is standing. **2** The average clothing and exposed skin temperature of the mechanic is 33°C.

Properties The emissivity and absorptivity of the person is given to be 0.95. The convection heat transfer coefficient from a standing body in still air or air moving with a velocity under 0.2 m/s is h_{conv} = 4.0 W/m^2·°C (Table 12-3).

Analysis The equivalent thermal resistance of clothing is

$$R_{cloth} = 0.7 \text{ clo} = 0.7 \times 0.155 \text{ m}^2.°\text{C/W} = 0.1085 \text{ m}^2.°\text{C/W}$$



Radiation from the heaters incident on the person and the rate of sensible heat generation by the person are

$$\dot{Q}_{\text{rad, incident}} = 0.05 \times \dot{Q}_{\text{rad, total}} = 0.05(10 \text{ kW}) = 0.5 \text{ kW} = 500 \text{ W}$$

$$\dot{Q}_{\text{gen, sensible}} = 0.5 \times \dot{Q}_{\text{gen, total}} = 0.5(350 \text{ W}) = 175 \text{ W}$$

Under steady conditions, and energy balance on the body can be expressed as

$$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} = 0$$

$$\dot{Q}_{\text{rad from heater}} - \dot{Q}_{\text{conv+rad from body}} + \dot{Q}_{\text{gen, sensible}} = 0$$

or

$$\alpha\dot{Q}_{\text{rad,incident}} - h_{conv}A_s(T_s - T_{surr}) - \varepsilon A_s\sigma(T_s^4 - T_{surr}^4) + \dot{Q}_{\text{gen,sensible}} = 0$$

$$0.95(500\text{ W}) - (4.0 \text{ W/m}^2\cdot\text{K})(1.8\text{ m}^2)(306 - T_{surr})$$
$$-0.95(1.8\text{ m}^2)(5.67\times10^{-8} \text{ W/m}^2\cdot\text{K}^4)[(306\text{ K})^4 - T_{surr}^4) + 175\text{ W} = 0$$

Solving the equation above gives

$$T_{surr} = 266.2 \text{ K} = \mathbf{-7.0°C}$$

Therefore, the mechanic can work comfortably at temperatures as low as -7°C.