

1. A composite wall has 2 layers in perfect thermal contact. One is 20cm thick and of uniform thermal conductivity $k = 2.8 \text{ W/mK}$. The other is 10cm thick and has $k = 0.7 \text{ W/mK}$. Calculate the thermal resistance of the wall assuming one-dimensional conduction and, given that the rate of heat conduction through the wall is 9.2 kW/m^2 and that the temperature of the outer surface of the 10cm layer is 50°C , calculate the temperature at the interface and at the outer surface of the 20cm layer.

[Ans: 0.2143 K/W, 1365°C, 2021°C]

2. The cavity wall of a room has 2 layers of brick, each 11cm thick, separated by an 11cm air gap. The inner (room) surface of the inner layer is plastered to a thickness of 2cm.

Heat transfer is by convection only on all exposed surfaces and by conduction only through the solid layers.

(a) Calculate the heat lost per unit area of the wall and the temperature of each surface given that the room air temperature is 15°C and the ambient air temperature is -10°C .

(b) Calculate also the reduction in heat loss due to completely filling the air gap with urethane foam.

Data

Thermal conductivities:

Inner brick layer: 0.69 W/mK ; Outer brick layer: 1.32 W/mK ; Plaster: 0.48 W/mK ; Foam: 0.018 W/mK

Heat transfer coefficients:

Room air-to-plaster: $4.5 \text{ W/m}^2\text{K}$; Brick-to-air gap air: $4.5 \text{ W/m}^2\text{K}$; wall-to-ambient air: $10 \text{ W/m}^2\text{K}$

[Ans: 23.8 W/m² ; 3.72 W/m²]

3. A high-pressure steam pipe of diameter 28cm is lagged with 2 layers of insulation, the first being of thickness 5cm and thermal conductivity 0.086 W/mK . For the second (outer) layer, the corresponding values are 7cm and 0.06 W/mK . The pipe wall temperature is 500°C and the ambient air temperature is 25°C .

The heat loss from the outer surface of the lagging is by natural convection for which the heat transfer coefficient is given by:

$$h = 2.23 \left(\frac{T_{\text{surface}} - T_{\text{ambient}}}{D} \right)^{1/4} \text{ W/m}^2\text{K}$$

where D is the outside diameter of the lagging *in centimetres*.

Calculate T_{surface} and the heat loss/unit length of pipe (needs iterative/graphical solution).

Calculate also the overall heat transfer coefficient based on the exposed lagging surface area.

[Ans: 97.9°C, 288W/m, 0.371 W/m²K]

4. Recalculate the heat loss per unit area of wall for question 2 allowing for the additional heat loss due to radiation from the outer surface of the wall to the night sky for which the temperature is taken to be 20 degrees below the ambient air temperature. Take the case with an unfilled air gap.

Assume that the radiation heat loss per unit area of the wall outside surface is given by:

$$q_{\text{radiation}} = 0.93\sigma(T_{\text{surface}}^4 - T_{\text{sky}}^4)$$

where the Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$

[Ans.: 29.25 W/m²]

{ Hint: Note that radiation and convection transfer act in parallel at the outer surface. Their sum is equal to the conduction through the wall. Try plotting conduction and (radiation + convection) against external wall temperature on the same graph. The intersection of the curves gives the actual outside wall temperature.}

5. From Bejan, Ex 2.9.

The temperature of the human body drops from the core (or arterial blood) level $T_a = 36.5^\circ\text{C}$ to the skin level T_w across a subskin layer of thickness $\delta = 1 \text{ cm}$ and conductivity $k = 0.42 \text{ W/mK}$.

- Calculate the skin temperature when the body is swept by the flow of 20°C air with a heat transfer coefficient of $30 \text{ W/m}^2\text{K}$.
- Calculate the skin temperature when the external fluid is 10°C water and the skin-water heat transfer coefficient is $500 \text{ W/m}^2\text{K}$.
- How much greater is the rate of body heat loss to water than to air?
- Given the mass of the person is 70 kg , and that the specific heat capacity of 1.93 kJ/kgK , and assuming that the core heats up as one lumped mass, how long, in each of the above cases, before the core temperature drops the three stages of hypothermia – stage 1 at 35°C , when shivering starts, stage 2 at 33°C , when shivering is violent and uncontrollable and extremities turn blue, and stage 3 at 30°C , when vital organs begin to shut down. Assume internal heat generation is 100W and skin surface area is 1m^2 .



[answer: a) **29.6C** b) **12 C** c) **3.5** d) **3.6 min;8.5 min;15.8 min**]