COMPOSITE WALL EXAMPLE: HEAT LOSS RATE FROM A HUMAN BODY

From the perspective of calculating heat transfer between a human body (surface area: $A = 1.8 \text{ m}^2$) and its surroundings (air/water, $T_\infty = 10^\circ\text{C}$), we focus on a layer of skin and fat (thickness $L_{sf} = 3 \text{ mm}$; thermal conductivity: $k_{sf} = 0.3 \text{ W/m-K}$), with its inner surface at a temperature slightly less than the core temperature ($T_i = 35^\circ\text{C}$).

To reduce the heat loss rate, the person wears special sporting gear (snow suit and wet suit) made from a nanostructured silica aerogel insulation with an extremely low thermal conductivity ($k_{ins} = 0.014 \text{ W/m-K}$). The emissivity $\varepsilon$ of the outer surface of the snow and wet suits is 0.95. The radiation heat transfer coefficient is $h_r = 5.9 \text{ W/m}^2\text{-K}$. The convection heat transfer coefficients in air and water are $h = 2 \text{ W/m}^2\text{-K}$ and 200 $\text{ W/m}^2\text{-K}$, respectively.

1. What thickness of aerogel insulation is needed to reduce the heat loss rate to 100 W (a typical metabolic heat generation rate) in air and water?
2. What are the resulting skin temperatures?

Assumptions:
1- Thermal processes involved:

Equivalent thermal circuit:

Total thermal resistance needed to achieve the desired heat loss rate:

Total thermal resistance between the inside of the skin/fat layer and the cold surroundings:

This equation can be solved for the insulation thickness:

Case 1: air surrounding
Assuming a radiation heat transfer coefficient \( h_r = 5.9 \text{ W/m}^2\cdot\text{K} \):
Case 2: water surrounding

2- These required thicknesses of insulation material can now be incorporated into the snow and wet suits.

The skin temperature can be calculated by considering conduction through the skin/fat layer:

Solving for $T_s$:

Comments: