CIV-E1050: Heat and Mass Transfer in Buildings

16.12.2016

Only key solutions, details can be found in lecture PPTs (slide number will be provided).Furthermore, you are welcome to visit my office before the course is closed).

Problem 1

1.1 Concept: Under what condition the thermal resistance concept can be used to calculate heat transfer rate? (skip)

1.2 A multiple-layer wall is exposed to 5℃ and 25℃ air with corresponding convective heat transfer coefficients 10W/(m^2K) and 5W/(m^2K), respectively, see Figure 1. Determine the overall heat transfer rate of the wall.

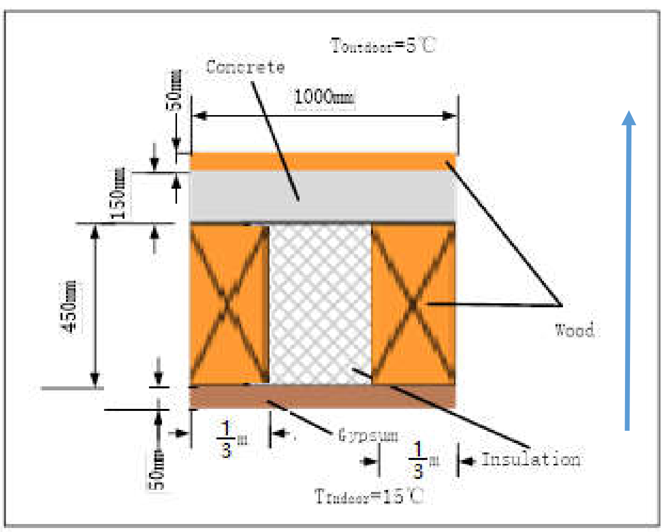

Figure 1. Multiple-layer wall structure

Data: Construction Material Properties.

Material	Wood	Insulation	Gypsum
Thermal Conductivity (k, W/mK)	0.056	0.036	0.16
Specific Heat (Cp, J/kgK)	2385	2200	1050
Density (ρ, kg/m³)	545	900	1600

The wall can be divided into 3 paths

$R_{h1} = \frac{1}{10} = 0.1 m^2K/w$, $R_1 = \frac{0.05}{0.056} = 0.89 m^2K/w$,…… $R_{h2} = \frac{1}{5} = 0.2 m^2K/w$

$R_{total} = 10.77 K/w$

$$q = \frac{25 - 5}{10.77} = 1.8 w/m^2$$

see lecture slide 4 for details.

Problem 2

2.1 Concept: What do you understand by the terms thermally developing and fully developed flow regions inside a pipe? Are there any differences of the convective heat transfer coefficients in these two regions and what are they if there are?

2.2 Wind is blowing parallel to the exterior wall with speed 15m/s and temperature 5°C. The dimension of the wall is: length L=10m height H=3m. The exterior and inner surface temperatures of the wall are 10°C and 18°C, respectively. Indoor air temperature is 30°C. Calculate the convective heat loss rate from the exterior surface and the convective heat gain rate from the inner surface.

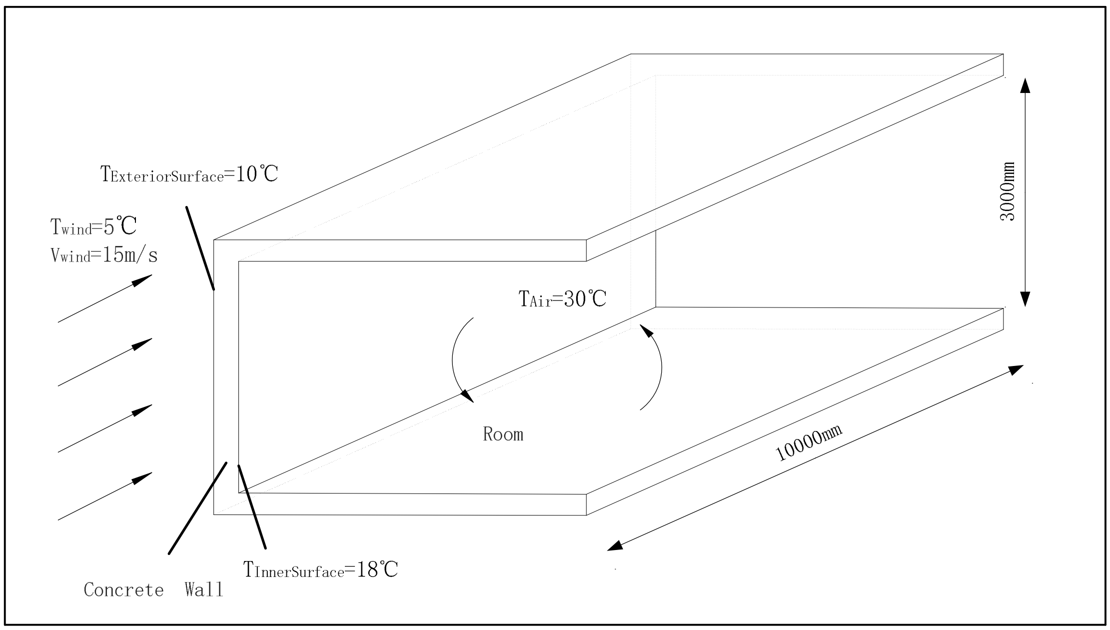

Figure 2. Schematic for the wall (left)

$T_{airboundarylayer} = \frac{5+10}{2} = 7.5$

Characteristic length is 10m

Force convection outside see lecture slide 6.

K, v, Pr = (based on 7.5C) (if this was missing to did it wrong, 25% of the points was reduced, similar for the exterior wall)

$Re_{wind} = \frac{10\times 15}{1.405\times 10^{-5}} = 1.068\times 10^{7} > 5\times 10^{5}$

Therefore, the flow is turbulent.

$Nu_{wind} = 0.037 Pr^{\frac{1}{3}} Re^{\frac{4}{5}} \rightarrow \mathrm{h}_{wind} \rightarrow \mathrm{Q}_{exterior}$

$T_{windboundarylayer} = \frac{18+30}{2} = 24$

Characteristic length of vertical wall is 3[m] $\rightarrow Q_{interior}$

Natural convection inside see lecture slide 6.

Problem 3

A knowledge of soil temperature under snow cover is important to field engineers. Assume the soil with initial temperature 10°C is covered by snow at –10°C. Calculate the soil temperatures at depth of 0.5 m after 30 days and 60 days assuming soil is a semi-infinite medium.

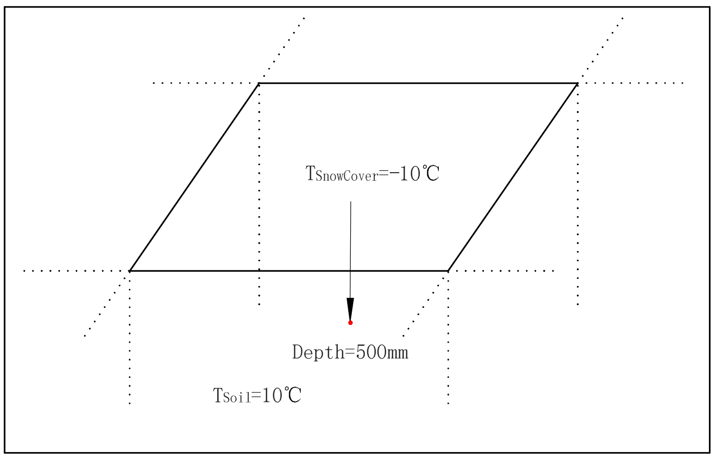

Figure 3. Semi-infinite medium of soil

Material Properties.

Material	Soil
Thermal Conductivity (k, W/mK)	0.4
Specific Heat (Cp, J/kgK)	250
Density (ρ, kg/m³)	1200

$\alpha = \frac{k}{\rho C_p} = \frac{0.4}{1200\times250} = 1.3\times10^{-6}$

$\frac{T(x,t)-T_i}{T_s-T_i} = erfc(\frac{x}{2\sqrt{\alpha t}})$

30 days later $T(0.5,30) = 10 - 20\times erfc(0.14) = 10 - 20\times0.88 = -7.6$

for details see lecture slide 5.

Problem 4

A skating hall is dome-shaped with temperature of roof 5 °C, audience area 15 °C and ice rink -5 °C, respectively. The emissivity of these surfaces is 0.9. Calculate the radiative heat transfer rate from the hemispherical roof to ice rink.

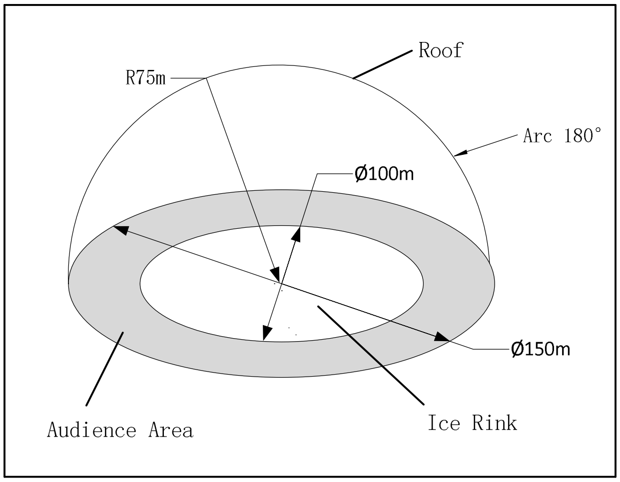

Figure 4. Schematic for the skating hall

$F_{R-A} + F_{R-I} + F_{R-R} = 1$

$F_{A-R} = 1$

$F_{I-R} = 1$

$F_{R-A} \times S_{Roof} = F_{A-R} \times S_{AudienceArea}$

$F_{R-A} = \frac{1\times 3.14\times(75^2-50^2)}{0.5\times 3.14\times 150^2} = 0.27$

$F_{R-I} = \frac{1\times 3.14\times 50^2}{0.5\times 3.14\times 150^2} = 0.22$

this is similar as lecture slide 7 page 26 ----some students forgot the surface resistance

Problem 5

5.1 Concept: Explain basic moisture transport mechanism for building porous materials, such as hygroscopic, capillary, and liquid flows. Explain the very different moisture contents in an interface between mortar joint and the adjacent brick at an equilibrium condition. Why is there no temperature difference at the interface?

5.2 A multiple-layer wall is exposed to indoor (temperature 20 °C, humidity 90%) and outdoor (temperature 0 °C, humidity 90 %) air as shown in Figure 5. Under steady-state condition, determine

a. If condensation can occur in the structure and where if it can.

b. By increasing the inner surface temperature, the condensation can be avoided. Determine the minimum inner surface temperature needed to avoid condensation.

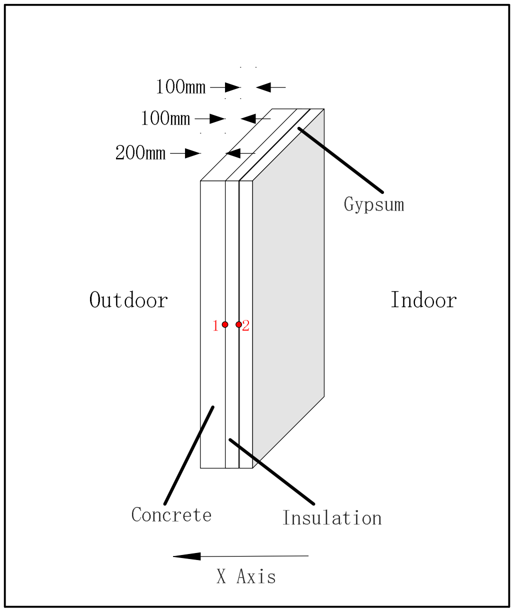

Figure 5. Wall structure

Data Construction Material Properties.

Material	Soil	Concrete	Wood	Insulation	Gypsum
Thermal Conductivity (*k*, W/mK)	0.4	1.63	0.056	0.036	0.16
Specific Heat (Cp, J/kgK)	250	970	2385	2200	1050
Density (ρ, kg/m^3)	1200	2300	545	900	1600
Permeability (ng / (smPa)])	30	4.7	0.094	0.26	1.08

This is exactly the same as lecture slide 9 -----(even simpler). Skip here.

The condensation will take place at point 1. To mitigate the condensation, the temperature at point 1 should be at least higher than 2 °C.

$$q_{new} = \frac{2-0}{\frac{0.2}{1.63}} = 16.3$$

$$T_{indoor} = 0 + 16.3\times\left(\frac{0.1}{0.16} + \frac{0.1}{0.036} + \frac{0.2}{1.63}\right) = 57°C$$

Problem 6

6.1 Consider a one-dimensional steady-state heat transfer in a wall section, constituted by a thermal insulation layer (conductivity 0.01W/mK, length 100mm) and by a structural layer (conductivity 0.01 W/mK and length 100mm) as shown in Figure 6. The left side temperature 20 °C and the right side loses heat by convection to the surrounding air at T_∞= 0°C and heat transfer coefficient h=5W/m^{2}K. Use 5 nodes and the finite difference formulation of heat transfer to determine the four nodal temperatures (node 1 to node 4).

6.2 A different thermal conductivity 0.1W/mK is assumed to the 100mm structural layer, show the resulting algebraic equation for the four nodal temperatures in matrix form.

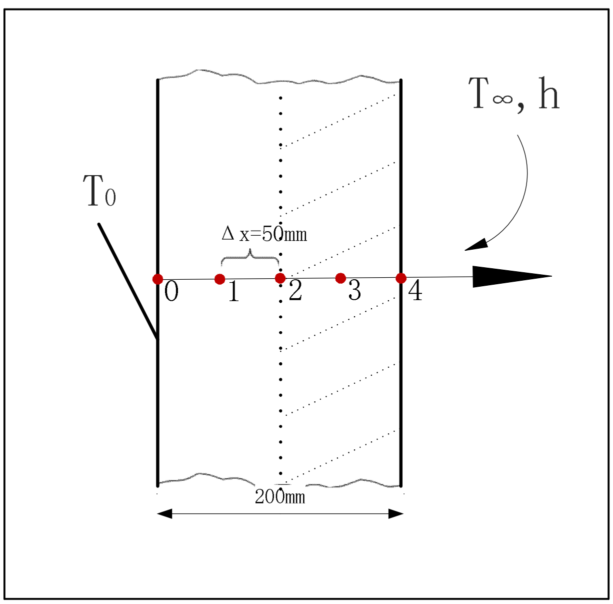

Figure 6. Wall with the nodes

$k\frac{d^2T}{dx^2} = 0$

This is exactly the same as examples in lecture slide 11, therefore I show brief solutions

Point 1: $T_1 = \frac{20+T_2}{2}$

Point 2: $T_2 = \frac{T_1+T_3}{2}$

Point 3: $T_3 = \frac{T_2+T_4}{2}$

Point 4: $k\times\frac{T_4-T_3}{0.05} = h\times(T_\infty - T_4)$

Then solve the system of equations

$$T_1 = 15.1$$

$$T_2 = 10.2$$

$$T_3 = 5.2$$

$$T_4 = 0.2$$

furthermore, see lecture slide….so only point 2 differs

Point 2: $k_{left}\times\frac{T_2-T_1}{0.05} = k_{right}\times\frac{T_3-T_2}{0.05}$

$$T_1 = 10.54$$

$$T_2 = 2.04$$

$$T_3 = 1.19$$

$$T_4 = 0.34$$